Context Awareness for Wearable Computers

By

Huw William Bristow

A thesis submitted to
The University of Birmingham
for the degree of
DOCTOR OF PHILOSOPHY

School of Electronic, Electrical &
Computer Engineering
The University of Birmingham

Abstract

The research described in this thesis considers mobile technology with particular reference to the use of context sensing. It is argued that such technologies are useful to enhance user proficiency in everyday tasks. A wearable, context–aware computer system and a set of evaluation tasks are devised to investigate this premise.

A photograph diary study is carried out to elicit defining features of a broad range of everyday activities. These features are called Context Identifiers. From this a structured definition of context is suggested that bridges the gap between the current theoretical and technological definitions of context.

Based on a literature review of current mobile and wearable technology and on the findings of the photograph diary study, a novel wearable computer and supporting software is developed. The wearable computer can detect and interpret features of everyday context, including Location, Posture and Movement, and Objects.

During the design cycle of the wearable computer, experiments are conducted to evaluate three versions of the wearable computer. The usability of the computer is considered based on measures of efficiency, effectiveness and user satisfaction. Use of the system is shown to improve user task proficiency in the completion of simple tasks and the wearable computer is shown to capture context in a similar way to humans. Specifically when the first version of the system is used in an information retrieval task, the wearable computer is shown to significantly decrease task completion time when compared to using a standard internet enabled computer or users searching for information in their environment. In addition the task accuracy is increased. The second version of the system in which the number of everyday contextual features the system can detect is increased, again significantly decrease the task completion time when compared to the same system detecting less context features. The third version of the system which detects further more contextual features is shown to be highly usable based on a number of usability measures and is shown to capture context in a similar fashion to humans.

Acknowledgements

I would like to thank my supervisors, Dr. Chris Baber and Dr. Sandra Woolley for providing me with the opportunity, guidance and support necessary to complete this research.

Thank you for the financial support from European Union grant IST-2000-25076 'Lab of Tomorrow' and EPRSC grant GR/R33830 'Mobile Communications for Distributed Collaborative Problem Solving'.

Thank you to all of the many people who took part in the experiments carried out throughout this work. Without you this research would not exist.

To my colleagues in the Pervasive Computer and Educational Technology Group a big thank you for the technical help, guidance and participation in my experiments, especially to James Knight, my personal dictionary and sentence tester.

Finally thank you to my friends for their continued support throughout this long process of completing a PhD and to my family for their support through this research and all my life to get me to this point. My biggest thank you goes to Louise who has supported me in every possible way though this work and who without, I have no doubt, I would not have ever finished writing.

Table of Contents

Table of Figures

Table of Tables

Chapter 1 Introduction

The research described in this thesis considers mobile technology with particular reference to context sensing. It is argued that such technologies are useful to enhance user task proficiency in everyday tasks compared to conventional methods. In this introductory chapter the themes of interest are introduced and discussed. These include which technology could be used to present mobile information, definitions of context and, how well can it be sensed. An overview of the work and summaries of each chapter are included. The aims and objectives of the thesis and the novel contributions this research makes to the area of wearable context-aware computers are highlighted.

The research will investigate the definition of context, whether a wearable context aware system can be produced to present mobile contextual information, and if it can, how usable is it and how does it effect the task proficiency of users.

1.1 The research in context

Since the advent of the personal radio, people have had the opportunity to gain electronic information on the move. Mobile technology gives the most up to date information saving time, allowing work on the move and decisions to be made on the most recent information available. Laptop computers originating in the mid eighties enhanced the presentation method by allowing visual information to be displayed electronically when a user was mobile. In the late nineties, with the introduction and widespread use of mobile phones, users were finally able to have dynamic information that they could interact with while mobile. However this is just the beginning!

Development began with the radio broadcast where the interaction between transmitter and receiver is one-to-many and is controlled by the transmitter. As devices have become smaller and cheaper, they are available to all, allowing the relationship to become one-to-one or many-to-many or any permutation in between. Now there is a need to personalise each device, to make the device perform optimally for a particular user in a given situation. Humans are excellent at reacting to their context in a personal and appropriate manner. The challenge is to produce computers that can do the same. This thesis takes an initial step in addressing this challenge by looking at wearable computers as a possible device for presenting mobile information and context awareness to make the computer react in a useful appropriate manner.

1.2 Themes of exploration

This research has been carried out to develop a mobile, wearable computer, which can detect or sense a user's context and then react in an appropriate manner by presenting useful information. In this thesis a number of pertinent research themes or questions are considered:

- Is a wearable computer a viable means for mobile information presentation?
- What is context and how can it be defined?
- Does contextual mobile information presentation change user task proficiency?

This introduction shows where these ideas come from and how they may be investigated. In later chapters these are discussed in more detail, and conclusions are drawn.

Is a wearable computer a viable means for mobile information presentation?
Currently mobile information is presented on mobile phones, laptop computers or Personal Digital Assistants (PDAs). An advance from this could be a 'body-worn' computer, but would this be a more useful platform for displaying and interacting with mobile information? Attachment to the body could allow for use while on the move. This is not easy to do with a laptop computer. Superior processing power, and inputs and outputs over mobile phones and PDAs could allow for wearable computers to sense a user's environment and react in a supportive way.

Context in some form affects everything we do and is part of everyday activities. For example it may be axiomatic to say cold beer tastes best on a hot day, as such beer sales are highest in the summer (Progressive Grocer, 2002). A lesson teaches us most when taught in context, for example swimming is taught in a pool not in a classroom. Since context helps humans learn and react appropriately in many situations, is it possible that a computer that can sense a user's context and present relevant, context related information might improve task proficiency? Current mobile computers such as laptop computers and mobile phones detect little, if anything, about the user's context. Mobile phones have been used to give users location-based services. Given the extra processing power and inputs and outputs of wearable computers over mobiles, and the better usability on the move over laptop computers is a wearable computer a more effective solution? Therefore this research asks: is a wearable computer an effective platform for creating a context aware mobile information presenter?

What is context and how can it be defined?

Context is a fundamental aspect of everyday interactions with people and objects. In order to understand, model and recreate these interactions, there is a need to increase our understanding of the specific context. Conversely it is important to look at everyday activities when attempting to model a user's context. This is essential to the development of wearable computers designed to support performance in everyday tasks. We know that "humans are exquisitely attuned to their context" (Turner, 1998); however no research has so far investigated whether, and in fact how, the principles of context in human behaviour transfer to the virtual domain of context-aware computing. Before adding context awareness to a mobile computer, some problems need to be tackled. Including the limited understanding of what is actually meant by context and the limited research considering whether the use of wearable computers and contextual information can increase the task proficiency of users completing everyday tasks.

It is incredibly hard to find a consistent definition of context when used with wearable computing. Context is currently defined from two main viewpoints: a wide ranging all encompassing theoretical view and a very specific application-specific top-down technological view. The theoretical view applied by Dey et al (1999) and Abowd and Mynatt (2002) uses the typical dictionary or literary definitions for example that of The New Oxford Dictionary of English, (1998 A), as the basis of their definition.

These definitions are explored in more detail in section 2.5, Chapter 2. These definitions are effective in covering most, if not all aspects of context, however it is difficult to relate them to technically sensing and detecting context.

It is argued here that a more structured definition of context is needed to allow the connection of the theoretical definition and the technological sensing of the components of context. Often researchers tend to avoid defining context when using it with a specific application. Instead they state the features they will use for their specific application based on the technological sensors they will use. This is the bottom-up approach and is often used when adapting the theoretical definitions to technical systems. This involves looking at which sensors are available, adding them to a system, and then attempting to infer context. For example a system can detect the user's location therefore for this application the user's context is their location. Their definition is determined by the technology available rather than the definition determining technology development. They opt for this approach because for specific applications it works very well and simplifies the system. However by applying these principles to systems that are designed to work in a wide range of applications and situations, they may omit many components of context. Whilst location is one part of context, researchers cannot keep adding additional sensors detecting different components to their system, expecting to capture all aspects of context without first identifying what all aspects of context are.

It is argued therefore that a new approach is needed to identify all the components that form everyday context so that system designers can then select sensors appropriately. This thesis suggests a top-down approach, whereby activities are analysed for their characterising components. These components can then be considered for importance and the most appropriate added to a system. Other researchers, for example Kirsh (2001) looking at "The Context of Work" have applied a top-down approach. A top-down method first looks at what the user's activities are and then works backwards to how the designer can technically sense or detect them. Krish (2001) also notes that context includes many items that have not yet been technologically sensed and could indeed be very difficult to detect, highlighting that this is a non-trivial task.

> "Context is highly structured amalgam of informational, physical and conceptual resources that go beyond the simple facts of who or what is

> where and when to include the state of digital resources, people's concepts and mental state, task state, social relations and the local work culture, to name a few ingredients." Kirsh (2001).

Instead of purely looking at the context of work, situations or tasks at work, this research will attempt to look at the contexts of everyday life, everyday activities that happen in many locations and circumstances using a top-down approach. This will initially mean looking at what everyday activities individuals partake in, and then exploring how these can be defined and categorised and then finally sensed or detected by a computer system.

To date a literary review has failed to identify research connecting everyday activities to the detection or awareness of context. Research into everyday activities has mainly concentrated on learning-episodes in everyday activities and not the context of the general everyday activities. For example, Vavoula (2003) conducted a diary study looking at everyday learning episodes. Therefore this work will focus on a novel approach of defining and examining everyday activities.

For the literature review and the research carried out in this thesis the author of this thesis offers a definition of context as "a collection of detectable entities that characterise a situation and that make the given situation different for any other."

Does contextual mobile information presentation change user task proficiency?

Having defined context and added context awareness to a mobile computer, it would then be prudent to see if contextual information can increase task proficiency and is therefore useful. The study of Palmer et al (1975) suggested contextual information was useful in increasing the task proficiency of user's completing an object identification task. This task did not include wearable computers and did not include a set of everyday tasks. It is therefore not entirely obvious if these principles will automatically be applicable to wearable computers and contextual information presentation. The work discussed here aims to investigate whether context is useful in aiding users in a number of different activities, using a wearable computer as the delivery platform.

In addressing if a contextual wearable computer can increase user task proficiency we need to ask how usable is the system. This may help to explain how task proficiency is being affected and how best the system can be designed to maximise task proficiency. Poor design of a context-modelling computer could render it disruptive and frustrating to the user. Technologies are presented as devices to ‘augment’ everyday life, but often exhibit characteristics that are disruptive. Sharples (2003) uses the specific example of the classroom to discuss how “such devices raise both opportunities and challenges for classroom education”

This thesis investigates methods for introducing the benefits of contextual wearable computer with minimum disruption to the user. Specifically the effect of using minimal interaction input methods or using the user’s context to adjust the information presented is considered. This is deemed essential to enhance the usability and acceptance of the system. The usability of the developed wearable computer system will therefore be measured through fitting metrics. The International Standard Organisations recommended usability criteria: Efficiency, Effectiveness and Satisfaction (ISO, 1998).

This research aims to test whether the presentation of contextual information can increase task proficiency, when the information is presented on a wearable computer and the wearable computer is used to detect the users context. In addition it will ask how useable is the system and has the wearable computer or the presentation of the contextual information made the everyday tasks harder for users to complete.

1.2.1 Research Questions Summary

During this work three main research areas will be investigated. Firstly, what is the user’s context and how it can be defined to allow a computer to detect a wide range of contexts found in everyday activities? Secondly, whether a wearable computer is a viable option for displaying mobile information and can it be made to detect or sense a user’s context. And thirdly, to focus on how usable the resulting system is and how good is it at increasing users task proficiency.

To answer the first question a detailed study of everyday activities will be carried out. The activities will be analysed and grouped into features that describe the users' context while completing these activities. From this a definition of context will be suggested.

To focus on the second question the aim of this work is the development of a wearable computer that can sense through the use of sensors, some aspects of a users context. The context and resulting actions will be interpreted though the software developed during the research.

Finally experiments described in the thesis aim to demonstrate the viability of the system and the benefit to the user of providing context information to support task performance.

1.3 Aims and Objectives of the Thesis

The thesis aims to define context in terms of the features that make up user context in everyday activities. From this a context aware wearable computer system that can aid users in some everyday tasks and support task performance will be devised. The usability of the system and the validity of the context definition will be investigated.

To this end the specific objectives are to:

1. Examine the nature of context in everyday activities.
2. Develop and demonstrate new software that interprets the context detector states and infers aspects of a user's context.
3. Develop and demonstrate hardware for a wearable computer that includes some context detectors.
4. Ensure the system is highly usable.
5. Explore design features of the system and their impact on system and user performance.
6. Explore the application of a context aware system to everyday tasks.
7. Compare the system's performance of collecting contextual features with a human's understanding of context.

Table 1 presents a summary of the research aims in the thesis and the thesis chapters in which they are specifically addressed.

Table 1 - Summary table of research aims

Research Aims	Section of thesis
Examine the nature of context in everyday activities.	Chapter 3
Develop and demonstrate new software that interprets the context detector states and infers aspects of a user's context.	Chapter 4
Develop and demonstrate hardware for a wearable computer, that includes some context detectors.	Chapter 5
Ensure the system adopts principles of usability.	Appendix B, Chapter 6, Chapter 7 and Chapter 8
Explore the design features of the system and their impact on system and user performance.	Chapter 6, Chapter 7 and Chapter 8
Explore the application of a context aware system to everyday tasks.	Chapter 8
Compare the systems performance of collecting contextual features with a human's understanding of context.	Chapter 9

1.4 Overview of the thesis

The focus of the thesis lies with the development and demonstration of a wearable computer that detects and responds to the user context, and displaying relevant information to the user context. In order to develop this system a thorough exploration of everyday tasks will be made carried out to form a definition of context. From this definition, components of user context will be suggested. This information will be taken and used to suggest the most useful defining features of context; these will be described as Context Identifiers. Some of these will be incorporated into the initial design of the wearable computer system. As development progresses and following experimental application, additional detectors will be added to the system. The system viability and the affect on user performance will be examined though measures of the systems usability. This will be a continuous process taking the form of a design cycle. This is illustrated below in Figure 1.

It can be seen that the design process is initiated with a literature review. From this problems and ideas are formulated such as how best to define context, what detectors or sensors other systems have used and what technology is currently used to display mobile information. An initial experiment is carried out to define context or more specifically the components of context; in the diagram this is the Context Identifiers experiment. From here software and hardware are developed that would enable collecting of contextual information and subsequent presentation to the user. The hardware and software developed are then used in experiments to help answer the remaining research questions.

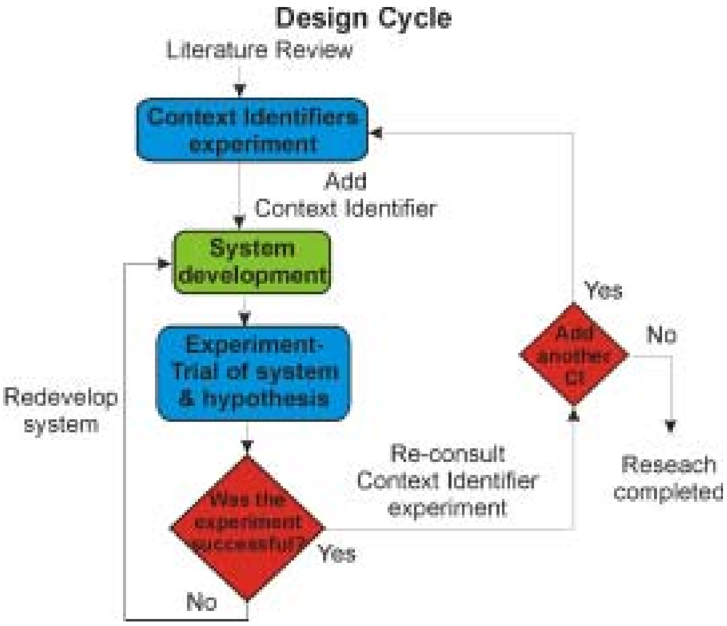


Figure 1 - Research design cycle

The background to the thesis is presented in Chapter 2. Here the relevant literature covering a selection of mobile information and context research is reviewed. The review starts by investigating mobile information devices and looks at the wearable computer as a possible means of presenting information to the user while mobile. Alternative interpretations and ideas of the definition of context are presented. Two approaches to the definition are highlighted and a new third approach, the top-down approach is suggested.

As part of a top-down approach, Chapter 3 investigates the devised method for eliciting the components of context. A photographic diary study of everyday activities is carried out. Themes of context, or Context Identifiers, are suggested as entities that could be sensed or detected by a wearable computer to measure some aspects of a user's context.

The building, design and wearable computer system development work is introduced in Chapter 4 and Chapter 5. This builds on the photograph diary study in Chapter 3 as a wearable, context aware computer system is developed. The system senses some of the elicited Context Identifiers from Chapter 3. The final system is a body-worn computer that detects a user's Location, Posture and Movement, any Objects that they interact with, and the Time.

The thesis has taken a usability-focused approach measuring the performance of the software and hardware developed in relation to the user. Usability measures are introduced in the literature review. In Appendix B an investigation is carried out to ascertain how usability testing methods can be transferred or applied to a wearable device.

The aim of the experimental work described in the thesis was to investigate not only the hypothesis relating to context aware systems but also reliability, success and validity of the hardware and software. Following a positive result, further development took place to include more Context Identifiers. The development of the system is achieved through an iterative cycle of development and evaluation.

The early chapters attempted to elicit features of context, subsequent chapters aim to test if context is useful. Chapter 6, Chapter 7 and Chapter 8 all attempt to answer this question. Getting users to complete everyday tasks using the system and comparing the usability of the system to conventional systems addresses this. The aim was to test if the contextual systems are disruptive to usability compared to conventional methods.

In Chapter 9 further photograph studies are carried out. The aim was to evaluate the original data collection in Chapter 3 and the functioning system in terms of a comparison with a human system.

Finally in Chapter 10 the conclusions of the thesis and interesting areas warranting further research, concerning the development and implementation of wearable context aware technology, are discussed.

1.5 Original Contributions

As discussed above the research themes or questions investigated in this thesis are:

- Is a wearable computer a viable means for mobile information presentation?
- What is context and how can it be defined?
- Does contextual mobile information presentation affect user task proficiency?

Exploration of these themes has resulted in the following original contributions:

- A novel method of analysing activities, including a photograph diary of everyday activities.
- Structured definition of the components that make up everyday context.
- A Top-down activity-based stance taken on the development of the context aware systems.
- Implementation of a wearable, context aware computer system.
- Adaptation of a usability-focussed approach to designing and building wearable computers.
- Development and practical demonstration of a complete novel wearable computer system.
- Context aware software that presents html based mobile contextual information.
- Novel method of automated collection of contextual data.
- Automated collection of context stamped photographs of users carrying out everyday activities.

- Novel method of examination of characteristics of human performance of everyday tasks.
- Demonstration and discussion of the effect a wearable computer can have on performance.
- Investigation of usability of the completed wearable computer system based on ISO 9421-11, (ISO, 1998).

The next chapter introduces and reviews a selection of relevant literature. It looks in more detail at the themes introduced here and other research that has been carried out in similar areas and what has already been found and concluded.

Chapter 2 Literature Review

Literature on the topic of mobile computing, wearable computers and context modelling is extensive. This chapter provides a critical review of some of the available literature and projects. It discusses current methods of defining context, mobile information, wearable computer design, and current projects using context, wearable computers and mobile information.

2.1 Introduction

Chapter 1 has introduced the main themes and aims of the research. In respect to these aims, the literature review will cover context modelling, mobile information, wearable computers and how these themes interact.

Mobile information is a current hot topic. A brief review of the current mobile presentation technologies was carried out to look at suitable technology for the research.

Wearable computers are selected as a possible mobile information presenter; therefore current wearable computer technology is reviewed. What are the ideals of a wearable computer? What are the current solutions and the current applications that they are put to? How does context fit into their operation?

A review of what context is, how people have attempted to define it is included. Three ways of definition are suggested; a typical theoretical definition, a definition based on current context sensing technology (a bottom-up approach) and the preferred activity based top-down approach.

Finally, one problem of new technology is user acceptance. How some new technologies have been adapted and what the current available metrics for measuring usability of these technologies have been reviewed.

2.2 Mobile information.

Mobile information is a hugely expanding area of commercial and academic research, simply because it is so easy to move around the world, be it by plane, train or automobile. People therefore are very often mobile and therefore need the information they have become used to in a stationary situation. The mobile phone industry is leading the way in commercially available systems that present some kind of information to a user while on the move. These types of systems started with companies sending text messages to users. In the initial systems e.g. O2 sending headline news once a day to a registered user (O2 alerts 2003), the context of the user was not sensed and the user would not necessarily be on the move, therefore they were not context aware in any other way than sending the information to the desired person. The next stage of commercially available systems was location aware systems that used the mobile phone cell system to identify a user in a given location and then provide information (at their request) about services in that location, e.g. the user might ask for all Italian restaurants within one mile of their current location. General Packet Radio Service (GPRS) was used and the data transfer method. The current stage of development is the introduction of Third Generation (3G) mobile telephone technology standard, which will allow much more media rich information to be presented to users on the move. “The services associated with 3G provide the ability to transfer both voice data (a telephone call) and non-voice data (such as downloading software, exchanging email, and instant messaging)”, (CampusProgram.com, 2004). IMT-2000 **(**International Mobile Telecommunications-2000**)** is the global standard for third generation (3G) wireless communications as defined by the International Telecommunication Union., (Wikipedia, 2004).

Wireless Application Protocol (WAP) was developed by the leading mobile phone handset manufactures in 1997 and published in the WAP Forum (WAP Forum Organisation). WAPs purpose was to allow html type information to be presented to mobile users using very low bandwidth appliances. Mobile phone users can now view WAP pages on their phones and location aware or not contextual information can be presented to mobile users. Some commercial examples of this are Nightguide or Loco

Guide (Vodafone UK ltd, 2003). It came at the beginning of mobile phone based information services and successfully proved that mobile information could be useful.

Another area of commercial development of mobile information has been GPS navigation systems in cars. Many companies have developed and sell such systems. The main aim is to display the location of the users car on a map of the area they are in and to direct the driver to a given location. In addition the system can provide information about the drivers current environment. For example listing of hotels, restaurants, banks etc within a given radius of the current location.

As the wireless communications sector continues to boom and more areas of buildings and cities are covered with wireless networks (3G phone networks or wireless networks (wi-fi)), then mobile information will become more widely available and used. It is now important to think about possible technology that will present the information to the user; one possibility is wearable computers (discussed in the section 2.3). It is also important to consider how to present the information in the correct way so that the user can make the best user of it, yet presented in a way that is resource efficient, thus cutting costs for both service providers and users. To achieve this, it is proposed that the technology (possibly wearable computers) is made contextually aware, involving the techniques described in section 2.6 and the techniques being researched later in this thesis.

In conclusion, mobility is no longer just about being moving, it is about moving between tasks, information spaces and changing contexts. From current forms of mobile information devices two questions seem important. What is the device that should present the information? How can the user interact and search the information provided to find the information they need to aid them in their tasks? Compared to stationary users, a richer technology is needed to present the information and a search or interaction system is needed that is effective when a user is mobile. Section 2.3 looks at one suggested richer technology the wearable computer. Sections 2.3 though section 2.4 look at the ideals of wearable computers, why they might be the right technology for mobile information presenters, and some current projects involving wearable computers. Section 2.5 investigates the ideal of using context or features of context to increase the interactivity of a device and allow a user to control the information in a way to get to the right information in the right place and time.

2.3 Current Wearable Computer Hardware

As with context, many researchers have stated their ideals for a wearable computer. Rhodes (1997) offered a list of defining characteristics for wearable computers at the First International Symposium on Wearable Computers. The list defines the following good principles for any wearable computer (Rhodes, 1997):

- “Portable while operational: The most distinguishing feature of a wearable is that it can be used while walking or otherwise moving around. This distinguishes wearables from both desktop and laptop computers.

- Hands-Free use: Military and industrial experiment application for wearables especially emphasize their hands-free aspect, and concentrate on speech input and head-up display or voice output. Other wearables might also use cording-keyboards, dials, and joysticks to minimise the tying up of a users hand.

- Sensors: In addition to the user-inputs, a wearable should have sensors for the physical environment. Such sensors include wireless communications, GPS, cameras or microphones.

- ‘Proactive’: A wearable should be able to convey information to its users even when not actively being used. For example, if your computer wants to let you know you have a new email and who it is from, it should be able to communicate this information to you immediately.

- Always on: By default a wearable is always on and working, sensing, and acting. This is opposed to the normal use of pen-based PDAs, which normally sit in one’s pocket and are woken up when a task needs to be done.”

Similarly Mann (1997) agrees with Rhodes defining features but adds, “…not monopolizing the user’s attention, observable and controllable by the users, attentive to the environment, useful as a communication tool, and personal". Later Mann (1998) says "A wearable computer is a computer that is subsumed into the personal space of the user, controlled by the user and has both operational and interactional constancy, i.e. is always on and always accessible". While Mann and Rhodes both have suggested proactivity, it is also important to make a wearable computer socially aware and not respond proactively in an inappropriate way (Schmidt et al 1999 B). Starner (2001) in his "The Challenges of Wearable Computing: Part 1" attempts to define "wearable computing through the effort to achieve a hypothetical, ideal wearable computer", something any wearable computer designer should be striving to do. Rhodes, Starner, Mann and many others all essentially agree on the basic principles of a wearable computer. These ideals therefore seem a good basis for the design characteristics of the wearable computer for this research.

Since an ideal wearable computer is just that, an ideal, it is necessary to come down from the ideal to the currently achievable. Therefore for the purposes of this research a practical wearable computer should:

1) Be able to be on a person i.e. be operational while being carried.
2) Have enough battery life capable of carrying out simulated 'real life' experiments.
3) Sense some key aspects of the user environment.
4) Provide enough processing power to sense some key aspects of the environment and to provide suitable information to the user.
5) Have an input-output mechanism suitable for use on the move.
6) Have Internet connectivity for receiving information or communicating to others.
7) Be proactive in aiding the user in a chosen task.

2.3.1 Commercially Available Wearable and Mobile Devices

There are very few truly wearable commercially available computer systems. Xybernaut: (Xybernaut, 2003) is one of very few companies that actually produce wearable computers. However their solutions are essentially laptop computers packaged differently and given head mounted displays (HMDs). In many of their solutions they have attempted to use altered conventional input systems, e.g. a miniaturised keyboard placed on the arm for typing.

Charmed Technology (Charmed, 2003), a MIT Media Lab spin-off is another company attempting to produce commercial wearable computers. Charmed have essentially gone down the Linux route (although have recently begun to support Windows), with the main interfaces being a Twiddler and Micro-optical HMD. While this is definitely a wearable computer it is relatively low powered and fairly expensive, around $6000.

The Panasonic toughbook (Panasonic, 2003) is designed not as a wearable computer but as a rugged mobile computer. The addition of a wireless touch screen is very useful for work in some fields where a fully wearable computer might be used in the future, for example, track side data collection, detailed archaeological data collection.

Standard laptop computers have been around since the early eighties. In 1981 Adam Osborne released the Osborne 1 (MB Solutions 2000 A). However it was not until 1985 when Toshiba introduced their T1100 that the first commercially successful laptop computer was on the market (MB Solutions 2000 B). While laptop computers are portable, they are in no way wearable. Importantly, they are not operational while mobile, contextually proactive, or always on. Some have hands-free capabilities and use some sensors but they are not the ideal solution for presenting mobile information.

PDAs are effectively cut-down laptop computers that are closer to being a wearable device. They have longer battery life, better mobile connectivity and are smaller, and so more portable. In their off state, they could be considered almost wearable, e.g. when in a user’s pocket. But to be used, they must be taken out of the pocket making them non-wearable. Their small screen restricts the amount of information that can be presented. All of these problems like laptop computers make them still far from an ideal platform for mobile information.

Mobile phones and Smart Phones (the combination of a PDA and a mobile phone) again have different properties that are useful for mobile information but still they are not the ideal devices. Mobile phones, from an audio point of view rather that text messaging, are hands free. O2's smart phone, the XDA can deliver location specific information (O2, 2003). Mobile systems have the advantage over stationary systems of being able to offer information on the move. However, laptops or Personal Digital Assistants PDAs are very difficult to use while the person is moving locally, that is relative to their local surroundings (as opposed to where the user is stationary within their local surrounding but moving globally, for example, in a train or car). Wearable computer systems should have the advantage that they can offer useful, comprehensible information when a user is moving locally. A mobile phone is a system that is partway between a mobile and a wearable computer system, Knight (2002 A) argues that a mobile phone is rarely a wearable device when in use and is generally a mobile device when in use, even with a hands-free kit the phone must be picked up to for a number to be dialled. However a mobile phone possesses some aspects that would be an advantage in a wearable computer. The voice aspects of a mobile phone are truly useable when a user is moving locally. The text aspects of a phone are difficult to use when moving locally; how many people have you seen almost walk into someone or something while trying to read a text message? Therefore it would seem sensible that audio systems work well when a user is moving locally and visual systems are more effective when the user is locally stationary. Smart Phones go even further and offer a user some basic contextual features like location aware information, of time based calendar information, along with personal profile information in the for of pre entered user options (for controlling menus or presentation of information). However both mobile phones and smart phones are not truly hands free and easily usable while mobile. They must be picked up for the screen to be viewed and for users to enter most information; it is worth noting that some functions for example making calls are available handsfree.

Starner (2002) discusses the problems of user attention while using mobile or wearable devices. He uses the example of a user attempting to read a map while driving. Two tasks (in this case visual tasks) of the same kind are difficult to tackle at the same time as the tasks compete for the users attention. Therefore some thought needs to be given to the way in which the wearable computer system allocates the user's attention, and augments the user's environment with information, while at the same time keeping the distraction from the user's primary task to a minimum. Psychological experiments (Allport 1972) showed that if the user's attention is split between dual tasks and the tasks use different senses, the users will perform better than where they are attempting to do the dual tasks using the same senses. Lund (2001) and Eysenck and Keane (1995) go on to note that our competence or task proficiency is affected by "task similarity, task difficulty and practice". Therefore to improve the task proficiency the wearable computer system needs to complement the user's primary task by displaying the information aimed to assist the user in a way that makes the task easier, or at least does not make it harder. The presentation method should be different than for the primary task. Finally the new task strategy (aided by the system) should be similar enough to the user's current task strategy to give them a starting point, which can be practised and will eventually improve the task proficiency. For example the Graffiti alphabet for palm PDAs for writing notes on PDAs is similar to writing but more appropriate for the PDA application. Brewster et al (2000 A and 2000 B) look at supplementing small PDA screens with sound for use on the move and to compensate for small screen sizes. They note "Mobile users need their eyes to look where they are going, so we aim to present as much information as possible in sound" (Brewster 2000 B). In a later example looking at presenting stock market graphs on mobile devices, "… visual attention is directed to moving around in the environment and not to the mobile device. One way around this problem is to use sound to present the data rather than graphics." (Brewster 2000 A)

A wearable computer with the properties described in section 2.3 seems to be a good platform for presenting contextual information to a user. They can be hands free with the addition of alternative input devices (voice instead of hands, context awareness to cut down the amount of direct interaction needed). They can be proactive by using contextual features to control to content delivery. They could be always on using Starner's human power (Starner 1996), or Kymissis's shoe power (Kymissis et al 1998). They can be operational while on the move through a combination of long power life, hands free use and by simply being wearable not portable.

2.4 Current contextual wearable applications and experiments

Dey et al (1999), Randell et al (2000) and others have demonstrated uses of wearable computers. However most of this work has faced problems with size, weight and technological restrictions. Lehikoinen et al (2001) have recently investigated using wearable computers to host digital maps. Augmented reality (where the real world is augmented with the digital) was used to overlay digital maps on to the real world. They have evaluated their system on a university campus. While this project does show that a high-powered wearable computer is in existence, it did not investigate how well the virtual environment and the real environment were being merged. Additionally it did not try to assess whether their system was indeed an improvement on a conventional map. Their system may have been augmenting or disrupting but this was not investigated.

These projects are just a few in a large area of research. Many others discussed in this section have produced supporting systems or infrastructure, if not wearable computers. The work in this section is split into sub sections dependant on its main focus. The next section, section 2.4.1, concentrates on sensor-based work. Section 2.4.2 looks at modelling methods and some applications, and section 2.4.3 looks at system architecture research.

2.4.1 Sensors

A Sensor is “a device which detects or measures a physical property and records, indicates, or otherwise responds to it” (The New Oxford Dictionary of English, 1998 B). Numerous sensors are currently being used to detect different aspects of context, these are then interfaced in the main to PDAs or wearable computers of some description. By far the most commonly used sensors are GPS, accelerometers and video cameras.

GPS is used as far back as 1997 Feiner et al (1997) in the Touring Machine. More recently Ashbrook and Starner (2002) have enhanced the use of GPS by using a hidden Markov model to predict the user’s possible location. While both of these projects have been very successful in using location, they have not integrated other sensors into their systems.

IR tags (Randell and Muller 2000) or active badges (using radio tags) (Dey et al 1999, Farringdon et al 1999) have also been used for sensing location. In addition they have been used to sense which other people are in a given location or are around a given person. Interestingly Dey et al also added a notion of time using the timetable of the conference to present different information at different times. This is one of very few pieces of research includes time into context, although time is regularly noted as a useful component of context (Dey et al 1999).

Accelerometers are currently probably the most increasingly used sensor. Decreases in price and easy availability have made accelerometers easy to use in large numbers. At the University of Lancaster, Van Laerhoven et al (2002) have used more than thirty accelerometers to build models of user's posture. While could be would suggested that this is over-complicated and over-resource intensive it is certainly it interesting work. Given the prerequisites of wearable computers (Rhodes, 1999), it is important to keep sensors to a minimum and as resource friendly as possible. Many other researchers have used fewer accelerometers to measure different aspects of user body positions (Kern et al 2002, Lee and Mase 2002, Cheok et al 2002, Park et al 2002, Ogawa et al 2001).

A consensus is that for outdoor location system GPS is the current standard, while for indoor location IR is preferred (although this is changing with the development of very good wi-fi system, for example Ekahua Finland, (2003)). GPS systems are now fairly accurate, cheap and the supporting infrastructure is already in place. Accelerometers would seem the preferred method for ascertaining the orientations and movements of users body parts when recording the data on a wearable devices in the real world. Like GPS, accelerometers are now cheap and widely available. It is therefore likely that these sensors will be used in the research described in this thesis. In general good sensors for wearable computer systems need to be small, light and easily compatible with large number of PC based and micro controller based computers.

2.4.2 Modelling methods used and applications.

Once choices about sensors are made, and data from sensors is beginning to be collected, the question of how to analyse the sensor data and then how to model the context should be considered. Many different methods have been tried. Neural networks are one method (Van Laerhoven et al 2002, Van Laerhoven 2001), creating hidden Markov models (HMMs) (Ashbrook and Starner 2002,) is another. While both of these methods have been shown to be successful they are both very complex and require lots of training data. Therefore a simple method may be better for building prototype systems that could demonstrate ways in which contextual wearable computers could be used. This could show concepts of wearable computing and context modelling, one of the aims of this research. Just-in-time, just-in-location information is one of the key advantages of contextual mobile computers over standard desktop computers. In this research, one of the objectives, is to show that context aware wearable computers can be made to show useful contextual information, that aids a user's task without using either of the of the complex methods used above.

2.4.3 Current architecture of contextual systems

This section discusses the architecture of context modelling systems. A large amount of current research in wearable computers is concentrating on the architecture of the systems, how to transfer the information around the system and how different components of the system connect together. Winograd (2001) and Hong et al (2001) both discuss the advantages and disadvantages of particular architectures. Most researchers have agreed that a system of widgets is needed to provide seamless integration of information, e.g. sensor information coming in to useful information displayed to the user. Several architectures have been proposed that employ a service infrastructure, where the main processing and storage of sensor and context libraries, protocols and software is stored on a central system and accessed via a network. This approach is preferred since it simplifies "the tasks of creating and maintaining context-aware systems" (Hong et al 2001). The Context Toolkit (Salber 1999) does not look directly at dealing with multiple sensors. Instead it endeavours to remove the sensors from the application designer, thus allowing useful applications to be designed without worrying about what sensors are being used and evaluating the raw sensor data. It accomplishes this by using ‘Context Widgets’ similar to GUI widgets. For example a location-widget will take information from whichever sensors sense location and process this information into a meaningful location for the user. This maybe a good approach to handling the diversity and number of sensors used in context sensing.

The Sulawesi (Newman (1998)) project at the University of Essex aims to “provide a ‘common’ integration platform which will be flexible enough to encompass a wide variety of input devices, separating the service (agent) development from the input mechanism”. This seems a very good idea in terms of the overall structure of a context aware system as it completely separates all the software/protocol handling the input sensors from the software (in this case a set a agents) that analyses the users context. The example shown in the Sulawesi literature is where the location service (the agent that handles the question of where the user is and passes it on the any part of the system that requires the users location) simple asks the sensor ‘where am I?’. The advantage is that it does not matter whether the sensor is a GPS, an IR location system, or a wi-fi based location system or some combination, the location service does not care. This is a good idea since it allows the system to be very versatile in changing the input sensors to suit different situations or availability of service. If a user walks around outside then GPS might be the best input-sensor, but when the user goes indoors then wi-fi might be better. The Sulawesi framework could handle this seamlessly.

A large problem with context modelling at present is the number of different sensors available. The more sensors and the more types, the more complex the architecture becomes. It has to cope with more protocols, inputs and outputs to talk the sensors and incorporate them into a system in the desired manner. Urnes et al (2001) in “Building Distributed Context-Aware Application” begins to address the problem of dynamically and automatically managing a multitude of location sensors. The ‘Jini Dynamic Discovery Protocol’ is used to interface with an arbitrary number of location sensors and deliver their information to a position service. Dynamic Discovery Protocols could be used generically to manage a wide variety of sensors. Along similar lines in concept, if not implementation, Pascoe et al (1999) has gone on to investigate further the supporting infrastructure that is needed before context-aware computing enters mainstream use. The supporting infrastructure is the link between multiple unknown sensors and the system that makes the solution context aware. This again addresses the problem of so many different kinds of sensors and different types of sensors to sense the same thing. His original idea of a Context Information Service (CIS) has been developed further in an attempt to standardise the classification of context from multiple unknown sensors.

Leonhardi et al (1999) address the idea of Virtual Information Towers (VITs), a type of information beacon. VITs are used to send the user location specific information. This system attempts to not only display information but also lets the user interact and change the information. A useful system for restricting the visibility of the VIT to the user is outlined, allowing the information presented to be very specific. Again this proposes solutions for the supporting infrastructure needed to makes contextual wearable computers a reality.

As noted before, the majority of research into context computing until now has focused on location, be it by GPS, active badges or vision recognition. A few other sensors have been used, for example microphones. However very little research has looked into the combination of many sensors to define a user's context. One paper that has attempted to incorporate many sensors is "Real-time Analysis of Data from Many Sensors with Neural Networks" (Van Laerhoven 2001). One way of combining that data from these sensors suggested here is Neural Networks. This is a good proven method to combine many simple small components to compute a large complex conclusion. This paper showed it is possible to learn simple activities and then to respond in a predetermined fashion. This paper also identified some important points about decision making once an activity has been identified and that making the wrong decision can be counter productive and render a wearable computer system unhelpful. However the method of neural networks is complicated and over-kill when using small numbers of sensors.

A system to sort and alter contextual content once the context has been found using possibly one of the sensor handling architecture discussed. Lum and Lau (2002) show a system that automatically alters the presentation of some content depending on context. In this case the context is the display device. For example they retrieve some content from a server. If the content were to be displayed in a small screen device they would remove the pictures.

It is concluded that a good architecture, therefore, is one that can easily handle all the required sensors and should ideally be able to handle changing sensors as a system grows or the technology changes. While the use of widgets or a sensor-independent-protocol would seem the best way to handle the sensors, an entire PhD of research could be spent researching and developing them. Therefore the system developed during this research will not implemented widgets. Lum and Lau's (2002) content adaptation ideas seem well thought out and well implemented. These ideas were applied in this research but spread the context to the wider context of the user (instead of display type), thus changing the content depending on the user's context.

2.5 Context

Turner (1998) noted that, in everyday life, you don't ride bicycles on trains. Not only is this obvious and self-evident, but it also demonstrates that the 'context' of a situation tells you what you can or cannot do and how best to act in any given situation. One can distinguish between the idea of context as a form of constraint (which defines appropriate actions) and context as a trigger (which cues actions) and context as a 'configuration of features' (which helps the actor to make links with other similar configurations). In terms of this latter notion, it has been well known for many years that context plays an important role in object identifying, learning and memory tasks. In recent years computing systems have begun to use context to aid the user. The first signs of this can been seen in software with the introduction of smart menus and user profiles. The Microsoft Menus are a good example, where the items on the menus that are used less often are removed from view, thus changing the context of the menus depending on the user's preferences. Another example is the Amazon site where the items that a user buys change the recommended items e.g. "Other people who bought this cd also bought …". This basic form of context awareness, akin to the idea of 'context as trigger', simply asks 'who is the person doing the task and what are their (probable) preferences.' In the late nineties mobile computing took off and the idea of context involving not only 'who you are', but also 'where you are' and 'what you are doing' began to evolve. In these developments, one can see systems that rely on 'context as constraints' beginning to evolve.

It is widely known that contextual information is very important in user task proficiency, in terms of the speed and accuracy at which a user can correctly complete a task, (Palmer et al 1975). In Palmer et al., users were asked to identify objects shown on picture cards. Users consistently identified the objects most correctly when a picture demonstrating the context of the object was shown before the object itself. Meyer and Schvaneveldt (1971) carried out an experiment to investigate semantic priming. Participants were asked to decide whether a string of letters was a word. They found that the response time was decreased if the string was primed with a preceding related word, a context word. In context aware computing the suggestion is that by priming information (instead of a string of characters) with contextual features or providing information that is right for the context, the performance in terms of speed of response to finding answers in the information should increase. Therefore, if context can be used to prime/aid a user in a task then their performance should improve.

2.6 Problems with defining context

At present there remains a frustrating lack of agreement as to what constitutes 'context': there are almost as many different definitions as researchers in the area. The phrase is clear to many, but difficult to operationalise. Literally, the term means "the circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood and assessed." (The New Oxford Dictionary of English, 1998 A), and this probably reflects the sense in which the term is applied to 'context-aware computing', i.e., everything that is (or could be) pertinent to a given person doing a given thing in a given place etc. The literature shows three broad perspectives to defining context.

Dey (2001) proposes that context could be regarded as, "… any information that can be used to characterise the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." This reflects the earlier definition of context literally meaning everything surrounding the text (or object of enquiry). This definition is somewhat tautologeous: context is defined as comprising of contextual features (assuming 'context' and 'situation' are synonymous). This implies that the word 'context', as it is used in the literature, can be ambiguous. It would seem from most of the context research thus far that one of the main problems is the lack of clarity of what context is: how to define the term and how best to make use of it. Context itself takes on many different meanings depending how it is measured or how it is used, depending on its context of use!

In an attempt to simplify matters, Abowd and Mynatt (2002) suggest that one can think of context in terms of 'who is using the system'; 'For what the system is being used'; 'Where the system is being used'; 'When the system is being used' and 'Why the system is being used'. In a similar vein, Baber et al. (1999) suggested the following classification scheme: event, environment, task, artefact, and person. Such approaches provide initial definitions of potential features of 'context' that could be detected, but do not indicate how these aspects relate to specific activities or how they interact with each other.

Once again, the number of people giving theoretical definitions of context is large and even though they agree in many ways, there is still no definitive definition.

The second perspective is to take a bottom-up approach, based on the availability of particular technologies that can sense or otherwise measure some aspects of 'context', for example, using Global Positioning Systems to define location, or accelerometers to define movement. Most context research is in this area. Typical projects look at very specific applications, where the aims of the task are clearly defined. This makes it straightforward to pick sensors that fit the given application. A consequence of this approach is that the 'context' of the application is defined and bounded by the designers' conception; a tourist guide might be designed to provide specific tourist information at a specific location. Whilst this may fill a 'context as location' conception, it does not deal with other factors, such as the tourist not wanting the information, being bored by the information or being distracted from their enjoyment of simply looking at a statue. In addition it does not give a full definition of context it just suggests that in this specific application the idea of context will include only the user and the location.

As context awareness is added to generic wearable computer systems that are expected to work in many situations, the applications the wearable computers are put to and thus the context sensors are less easily defined and current research may be missing some context features that could become useful in generic wearable computer systems. Therefore a third approach may be needed. The third approach is to take a top-down view of the problem, and it is this approach that is explored in this thesis. Very little research has looked at defining context from an activity point of view.

2.6.1 Creating a definition of context

Dey, Abowd, Schmidt et al (1999) use The Free On-Line Dictionary of Computing to define context as “that which surrounds, and gives meaning to something else”. Similarly Dey’s definition (Dey, 2001) from above “… any information that can be used to characterise the situation of an entity” defines context in a similar theoretical way. Kirsh (2001) goes on from this to suggest a more complex description, “Context is a highly structured amalgam of information, physical and conceptual resources that go beyond the simple facts of who or what is where and when to include the state of digital resources, people concepts and mental state, task state, social relations, and the local work culture, to name a few ingredients”. This is a good definition and encapsulates more of what context is and what additional features make up context than other definitions. Using the proposed top-down approach section 2.6.3, may find what more of these additional features are and how to fit into the overall notion of context combining both the theoretical and the technological definition from this and the next section, section 2.6.2.

Nardi (1996) discusses method for defining context with respect to learning behaviour. She compares Activity Theory, Situated Action Models and Distributed

Cognition concluding, “Activity theory seems the richest framework for studies of context in its comprehensiveness and engagement…”. Both Activity Theory and Distributed Cognition essentially start from the same point, the object or goal of the activity. “We are able to distinguish one activity from another only by virtue of their differing objects” (Leont’ev 1974, Kozulin 1986, Kuutti 1991). In theory this may be very effective, however trying to technologically sense and thus implement a system that senses the goal or aim of the activity is very difficult. While Activity Theory could be seen as a very comprehensive method of defining and investigating context it is very theoretical and turning theoretical definitions into working systems can often be very difficult. Situated Action Models use the reactions of a subject to their environment to define the activity (Nardi 1996). Again this may help in defining context but is again is difficult to implement. Sensing the environment is very much easier then sensing a reaction to it. Using the proposed top-down approach the advantages of both the theoretical methods and the technological methods can be harnessed.

2.6.2 Technology Defining Context

The literature focussing on context is generally related to context awareness, the ability of technology to respond appropriately to features of context that it has sensed. Location is currently the primary factor used for denoting context. It is highly likely that there are many other factors that make up context that have not been investigated. Schmidt et al. (1999 B) also points out that there is more to context than location. They propose “that ultra-mobile computing, characterized by devices that are operational and operated while on the move (e.g.PDAs, mobile phones, wearable computers), can significantly benefit from a wider notion of context”. They also provide a nice framework for context based on their interpretation of the dictionary definition of context, shown in Figure 2.

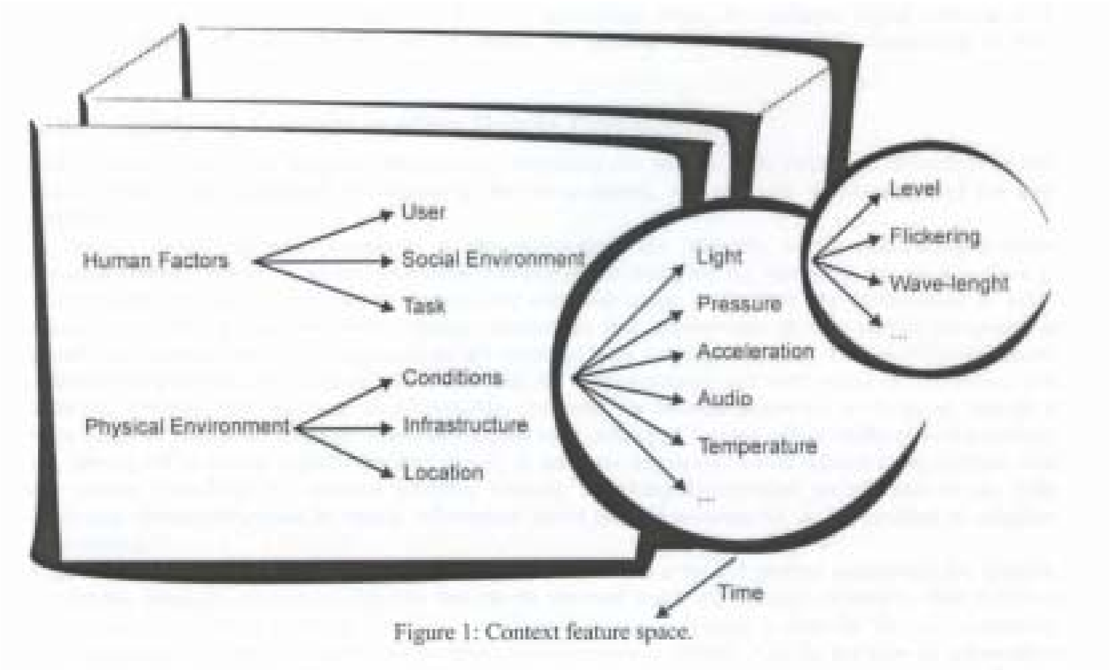


Figure 2 – Context Framework suggested by Schmidt et al (1999 B)

While this provides a good view of context it is not based on a systematic analysis of context, which could be backed up with empirical data. It would be interesting to see if a top down study of activities would produce that same context features and back the features up with data from the real world. This data could be useful to rate the features, in some manner, in terms of importance.

A definition of context-aware (Dey 2000) "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task". As can be seen from the above literature, context is not only about location but includes many other factors some of which can be measured or observed by technology and some that cannot.

Since 1999 there has been much more investigation of other factors such as movement. For example using accelerometers (Kern et al 2002, Lee and Mase 2002, Cheok et al 2002, Park et al 2002, Ogawa et al 2001). Schmidt et al (1999 B) list different ways to sense (and thus areas of sensing) that could be used for measuring context, a tabulated version of their discussion is shown in Table 2.

Table 2 - Schmidt el al's Sensor Technology

Sensor Technology	
What to sense	Technology/sensor
Optical/Vision	Photo-diode, colour sensor, IR and UV-sensor
Audio	Microphones
Motion	Mercury switches, angular sensors and accelerometers
Location	GPS, active badges
Bio-sensors	Pulse sensor, galvanic skin response measure, blood pressure sensor
Specialized sensors	Touch sensor, thermometer, barometer

However again these are found from looking at available technology and not components of context and therefore the measurements required. Schmidt et al like the others in the ‘technological defining’ category, sense with technological sensors, and then try to model context from what they have sensed. Whereas top-down supports a method for defining and then modelling context that first finds what makes up context, and then decides how to measure it, not the other way round.

2.6.3 The Top-Down approach

A top-down approach is suggested that is activity based, rather than being technology based or theoretically based, like the previous two sections. By carrying out an analysis of everyday activities, it may be possible to break down the activities into contextual components that can then be sensed using technology. It is believed that this approach will give a better idea of what context features need to be sensed than relying solely on what technology is available. It will also give evidence for the components that make up context.

Brown et al (2000) completed an activity-based diary-study of technology that people use at work (for example, digital cameras, PDAs, voice recorders) and attempt to find when and why they use this technology. The primary focus was to understand information capture in the workplace using these technologies. While this study is interesting and is activity based, it looked at a fairly specific set of activities in the workplace only and therefore does not capture the required activities to generalise for everyday activities e.g. at the workplace, at home and in the wider world. Also the study did not apply their findings to defining the users' contexts. The users in the study were asked to record any events where they were capturing information or would have liked to capture information if they had the means. For the purposes of this experiment this method captures the data required. In an experiment that aims to capture a whole host of everyday activities (not just ones when information capture is involved) this amount of freedom of capture is not appropriate. Thus a more structured procedure would be needed. The findings of this study were that information capture happens in a number of different contexts and reasons; this could then be used to tell them about possible applications for new information capture devices. However, the study essentially only looked at the context of one type of activity; information capture. If we are interested in a wider notion of context then it is necessary to look at many more groups of activities.

A second diary type study of 'domestic routines' is in Unremarkable Computing (Tolmie et al 2002). This study assesses the domestic routines of two ladies and how they knock on each other's doors at different stages of the day and week. They conclude that there are many things in everyday life that have routine character and importantly the routines are invisible to those involved in them. This is significant for their aim of developing 'invisible' ubiquitous technology. This study separates itself from Brown et al (2000) by looking are activities outside of the office environment. However it does still not apply its finding to the overall notion of context that this thesis aim to investigate.

Vavoula (2003) completed a study of everyday learning episodes and used a traditional written diary method to record participants learning. This is an interesting study as it looks at everyday life, however again it does not aim to apply the findings to assessing or defining everyday context.

Therefore a study looking at generic everyday activities that can be applied to finding a users context is needed. A top down approach is suggested, as it will be more specific than the theoretical definitions. It could enhance frameworks with Schmidt et al. (1999 B) specific data of activities and allow a weighting system to be produced to indicate importance, to designers, of context features. In addition it would not be based upon or biased by available technology.

2.7 Usability and User Acceptance

One key problem for any new technology is getting user acceptance. Products fail if the user's learning curve is too steep. They cannot learn to use the new technology before becoming frustrated by it, or if users simply do not like the product for whatever reason. Then a new device will never get widespread use, and thus will never be commercially successful.

Early systems disrupted a user's activity by the sheer size of the computer, making it difficult to move easily when doing the activity. Later systems that use input devices ill suited to mobile devices may again disrupt the user. So some thought therefore needs to be given to minimal-interaction input methods. Stein et al (1998) and Knight (2002 B) have been discussing the comfort scales of wearable computers and their input devices. An intuitive argument is that if something is uncomfortable then it will disrupt the user's activity. It is therefore important to look at input and wearable computer solutions that do not disrupt the user. Similarly it is important to present the information in an augmenting, non-disrupting manner.

One area of technology that has seen a huge user acceptance is the mobile phone. Palen et al (2001) looked in detail at a group of new mobile phone users during the first six weeks of usage. They investigated how the user learns to use the technology and interestingly how their social attitudes change as they become mobile phone users. Another study to discuss usability is Tang et al (2001) who have designed a device that aids user's communication with 'awareness information', social communication context features. They discuss in detail the usability issues when moving previously stationary and desktop-based solutions into the mobile domain. Different design issues are faced, "Industry experience with interface design for handhelds has highlighted that those interfaces must account for the more task-focused and urgent context of a mobile user" (Bergman 2000). Some thought during the design process must be given to these issues. Contextual systems need to be able to adapt to the presentation method of any device they are presented on.

General usability and usability of technology and the evaluation of have been extensively researched in recent years by Nielsen, (1993), Norman, (1988), Botman, (1996), Chapanis, (1991), Davis, (1993), Hix and Hartson (1993), Landay and Kaufmann, (1993) and Somervell et al, (2003)

ISO 9241-11 (ISO, 1998) suggests measuring usability on three levels Effectiveness, Efficiency and Satisfaction. Table 3 shows the suggestions of what to measure for each level.

Table 3 - ISO 9241-11 usability suggestions

Usability objective	Effectiveness measures	Efficiency measures	Satisfaction measures
Overall usability	Percentage of goals achieved; Percentage of users successfully completing task; Average accuracy of completing tasks	Time to complete a task; Tasks compared per unit of time; Monetary cost of performing the task	Rating scale for satisfaction. Usage rate over time; Frequency of complaints.

Each of these levels could be applied to the system during experiments to get an overall usability measure of the systems created. Effectiveness measures might include a number of questions answered correctly in an information retrieval task, or number of tasks completed from a list in a given time. Efficiency is probably the simplest where a simple time measure of time taken to do tasks would be useful. Satisfaction measures might include a SUMI evaluation (Kirakowski, 1996) for software satisfaction. Efficiency and satisfaction measures might include workload, the NASA TXL Test, (Hart and Staveland 1988) or comfort rating scales (Knight et al, 2002 C) for measuring a wearable computers comfort or satisfaction of wearing. Involving these measures should give a good overall picture of usability.

The NASA TLX can be used to measure efficiency aspects of usability. The NASA TLX has been used to evaluate a wide range of tasks, involving different technology (Bushey et al 1999, McKirdy 1999). It appears to be technology independent. The SUMI scale has been selected for its widespread use and large amount of validating; it has been used on well over two hundred pieces of software. The SUMI scale is used to rate the users' perception of satisfaction with the software. Another area of satisfaction for a wearable computer may be comfort. The Comfort Rating Scale (Knight et al., 2002 C) is a measure of comfort designed for wearable computers. The scale measure wearable computer comfort on six dimensions: emotion, attachment, harm, perceived change, movement and anxiety, to give a holistic interpretation of wearer comfort with an evaluation of its constituent parts.

2.7.1 Task time and task accuracy

Task time and task accuracy can used for the efficiency and effectiveness categories of usability. Time is simple to measure and can be used to compare how two systems perform. If tasks in a given experiment or experiment have discrete outcomes then task accuracy is easy to record and again can be used to compare how two systems perform.

2.7.2 The NASA TLX workload test

The NASA TLX is a multi-dimensional scaling system for the subjective assessment of human workload (Hart and Staveland, 1988). The scaling system involves participants answering six questions. Possible answers range from zero to twenty in agreement or disagreement with a given statement. Question one refers to the mental demand of the tasks, question two to the physical demands and question three to the temporal demands. Question four refers to the performance in terms of how successful the participant thinks they have been in achieving the goals set by the experimenter, question five to the amount of effort involved in completing the tasks and question six to the frustration level experienced during the tasks.

2.7.3 Comfort Rating Scales

For a wearable computer, one of the other components to make a system acceptable to a user is how comfortable it is to wear. When wearing a wearable device your level of comfort can be affected by a number of things, such as the size and weight of the device, how it affects movement, and pain either directly from, friction, collision, heat or indirectly from, muscle fatigue. In addition to physical factors, comfort may be affected by cognitive responses such as embarrassment or fear of the device. Therefore, just knowing that the wearer has a certain level of comfort when wearing a device does not help in determining what aspects of the devices are affecting the wearer's comfort. In an attempt to provide a tool that could be used quickly to generate a fairly detailed assessment of how wearing the device was affecting the comfort of the wearer, Knight and Baber (in review) developed the comfort rating scales. This scales measures wearable computer comfort on six dimensions: emotion, attachment, harm, perceived change, movement and anxiety, to give a holistic interpretation of wearer comfort with an evaluation of its constituent parts.

2.7.4 The SUMI test – Software Usability Measurement Inventory

"The Software Usability Measurement Inventory (SUMI) is the latest development in a series of studies into questionnaire methods of analysing user reactions" (Kirakowski, 1996). It is used to measure the usability of desktop software programs. Whilst not specifically suited to wearable or mobile devices, SUMI is well validated and at present no validated usability measure specifically for wearable or mobile devices exists.

The SUMI questionnaire consists of fifty questions each with a three-option answer: agree, can't decide and disagree. SUMI assesses users' reactions to software in three levels, in each case a mean value is quoted. Firstly a Global score is given. Then the software is analysed in five sections for, Efficiency, Affect, Helpfulness, Control and Learnability. Finally the software is analysed on an individual question basis. A mean score is calculated for each section.

Specifically the subscales look at:

“Efficiency: degree to which the user can achieve the goals of their interaction with the product in a direct and timely manner.
Affect: how much the product captures the user’s emotional responses.
Helpfulness: extent to which the product seems to assist the user.
Control: degree to which the user feels they, and not the product, is setting the pace.
Learnability: ease with which the user can get started and learn new features of the product.” (VanVeenendaal 1998)

“The mean for state-of-the-art commercials systems is set by SUMI at a score of 50 on Global and all other subscales” (Kirakowski, 1996).

These measures will be used in some or all of the experiments that follow using the hardware and software described later in the thesis. Appendix B discusses use of the SUMI scale in more detail.

While the aim of this research is not to produce a final commercial product, it is still important at an early stage of research to think how the users may use a system, and how not to make a given task harder than necessary (for example, harder than the task was before using the product) by introducing a new device. While researchers in the context field have produced numerous applications and experiments, very few have compared how their system compares with how people currently do the same or a similar task. One important part of this thesis is therefore to investigate how users use new technology compared to existing methods for completing given tasks.

2.8 Chapter Summary

This chapter has described and reviewed some of the current research in the fields of context and wearable computers, their applications and usability.

Context research has progressed from two main vantage points: A theoretical definition of context and a technology-based definition. The theoretical definition is based on interpretations of traditional literature-based definitions of context. The dictionary definition has been interpreted in many ways to suit particular projects and ideas. The technology-based definition is created by finding currently available sensors and then using them to sense some component of context for a very specific application. The theological and technological methods are good for defining context for specific applications but to build a generic wearable context aware computer, a wider model of what is involved in context is needed. An activity-based top-down strategy is suggested.

Mobile phone operators are mainly providing current mobile information. Commercial systems like mobile phones, XDAs, PDAs and laptop computers are being used to provide users with increasingly multimedia information while on the move. Mobile phones, XDAs, PDAs and laptop computers are not the ideal platform for delivering mobile content because, they are not always on, nor portable while operational, nor hand free, nor proactive or and they do not use sensors as additional inputs devices. Some are in limited ways contextual but they do not use the context to optimise the delivery of, or presentation of, the information to best suit it to the user or provider network.

A mobile information platform, possibly in the form of a wearable computer is needed to provide contextual mobile information delivery. The wearable computer should be complete with context sensing capabilities and the ideals of a wearable computer discussed in section 2.3.

To accomplish all the specifications of this near ideal wearable computer (section 2.3) it is important to keep a wearable computer system as simple as possible while still achieving the end goal of a high performance, useful wearable computer system. A trade-off needs to be found between the amount of functionality, the number of sensors, the types of input and output and the amount of power needed. To reduce that amount of direct interaction between the user and the computer i.e. making the computer more proactive it may be useful to increase the number of sensors that interact on the user's behalf. Increasing the number of sensors increases the complexity, thus possibly the processing power required and definitely the power consumption either to run the sensor or the extra power for extra processing. It is therefore important to choose the sensors carefully using the ones that will give most information, most often. In addition, increasing the amount of proactivity decreases the need for human-computer input-output devices and makes the task of making a wearable computer hands-free easier. However it is still important to give the user enough control, in a simple enough way, that they do not become disenchanted with the system and feel like they do not understand the proactivity and thus how to control the system in the way they want.

User acceptance is a crucial design issue for new technology. Badly designed technology may not be accepted by new audiences and thus become a commercial flop. Therefore design time and consideration should be given to producing a system that users like and is helpful, in terms of task performance and workload reduction for the user.

In subsequent chapters these ideas will be built on and developed, leading to a wearable computer system that is contextually aware. The next chapter describes a top-down activity based method for the definition of context and how context is made up. The photograph diary study analyses a large number of everyday activities to establish the components of context.

Chapter 3 Context Identifiers: The Components of Context

Following the literature review in the previous chapter the need for a new procedure for defining context has been identified. A top-down, activity based method for defining context and the components of context is suggested as beneficial. Therefore in this chapter a photograph diary study, as a top down method, has been employed to determine defining features or 'Context Identifiers' of everyday activities; aim one of the research. The elicited Context Identifiers are described and then ranked by importance. The resulting Context Identifiers are suggested as appropriate measures for determining a user's context in a context aware system.

3.1 Introduction - Elicitation of Context Identifiers

As noted in the previous chapter (section 2.6) current context modelling research is primarily split into two areas either a theoretical approach for example Dey (Dey 2001) or initiated from a technological point of view; 'here are the sensors, now what can we sense?' For example Schmidt et al (1999). If it is assumed that the ideal is a generic wearable computer that will work in everyday life, and not just in specific applications, then a new approach to defining and classifying context is needed. Taking solely the theoretical or solely the technological method for defining context could miss some of the important components necessary for a generic wearable computer.

It is argued that a more effective strategy would be first to find out what entities should be sensed to provide enough information to accurately model a person's context. In this chapter a top-down strategy, using a photograph diary technique is used to elicit suitable components. The photograph diary study aims to provide critical information about people's everyday activities and the items that need to be sensed, thereby determining the requirements of the technological sensors. By analysing photographs of everyday activities it will be possible to show what contextual components make each activity unique or which are contextually similar. Thus showing the components that need to be sensed.

The photograph diary study is a variation of a diary study. A diary study was chosen as an appropriate method for collecting contextual information because a method was required that quickly documented a large number of everyday activities. It was felt that asking participants to complete a written diary could prove difficult in deciding specifically what to record, in how much detail and at what times of day. Furthermore it might lead to participants recording information that they felt was interesting and relevant to the study rather than examples of all activities including mundane activities that we sought. Consequently, it was proposed that participants would record instances of their everyday activities at set times, and make these records using photographs. The photograph diary study aimed to explore everyday activities based on time of day rather than by activity types. It was hoped that a richer, more representative set of examples of activities would be collected. In addition taking photographs of situations instantly captures a great deal of information about a situation.

From the initial collection of the activity photographs to the elicitation of suitable Context Identifiers the study was to be conducted in five phases:

- Phase 1: Photograph collecting - a set of users collected photographs of everyday activities.
- Phase 2: Photograph sorting - a set of judges twice sorted the photographs into contextually similar groups and noted the Key Features that made each activity belong to that group.
- Phase 3: Theme sort (Post-It Sort) - the Key Features collected in phase two are written on Post-It and the sorted into groups by theme. Each theme is given a name classifying the Context Identifier.

- Phase 4: Weighting sort (Post-It Sort part 2) - the groups are weighted by the number of occurrences of a particular feature and by the total number of features in the group.
- Phase 5: Linkage Sort - the links between Context Identifiers is investigated.

The method involved in this experiment will now be discussed, given that it is a rolling developmental method where each phase's results are investigated before the next phase starts. The description of the method and results is written in the same way. Therefore there are not separate sections for method and results. Each phase is discussed in terms of method, results and discussion as one. The experiment is then concluded and the overall results put into context at the end of the chapter.

3.1.1 Aims

The study was designed to address the following aims:

- To find a diverse set of contextual features by participants photographing a wide range of activities.
- To identify the underlying themes of context by grouping activities.
- To weight the themes by finding how often they occur in the context of an activity.
- Finally it is aimed to find linking features between themes.

3.2 Experimental Approach

3.2.1 Photograph collecting – Phase 1

The photograph diary study involved seven participants taking photographs for tasks or activities that they performed every day.

Participants: Seven people took part in the study (3 male, 4 female: mean age 37.2 (±19) years). The sample size was limited in order to make the subsequent analysis less onerous. The selection of participants was intended to reflect as broad a population as possible. Their occupations were as a student, local government officer, teacher, social worker, gas engineer and two researchers.

Procedure: The week was split into eighty-four, hour and a-quarter sessions (each day started at 8am and finished at 11pm). Twelve sessions were randomly allocated to each of the seven users as shown in Table 4.

Table 4 - Time allocations for the photograph diary study (the numbers in the coloured boxes show the user number)

Time Slot Day	8:00-9:15	9:15-10:30	10:30-11:45	11:45-13:00	13:00-14:15	14:15-15:30	15:30-16:45	16:45-18:00	18:00-19:15	19:15-20:30	20:30-21:45	21:45-23:00
Monday	3	6	4	4	5	6	5	7	3	2	5	5
Tuesday	4	7	1	5	2	3	4	2	1	6	7	1
Wednesday	7	5	5	2	3	7	1	3	6	4	3	7
Thursday	2	1	2	3	7	2	7	6	5	5	4	6
Friday	1	4	3	7	6	1	2	5	4	3	2	3
Saturday	6	2	7	1	1	4	6	1	2	7	1	4
Sunday	5	3	6	6	4	5	3	4	7	1	6	2

The users were asked to take two photographs of one activity they did during each time period. Two photographs allowed the participants to capture two views of the activity increasing the amount of information gained. The participants were restricted to two photographs to reduce the cost, analysis time and the impact of taking the photographs on the activity. As the users took these photographs they were asked to note the time, exposure number and a one-line description of the activity. The objective was to get evidence of a wide range of typical everyday activities. The method was designed to minimise bias in the selection of activities people photographed during the time slots. It was felt that people might have concentrated on the more interesting aspects of their lives if they had been asked to simply photograph activities. It was therefore intended that by giving users time slots they would take photographs of the more mundane activities that may have been missed had they been give a completely free rein on what to photograph. It also gave the activities an even distribution over time. In addition the users were not told how to photograph their activity, only that the photographs should be self explanatory in describing the activity. Participants were granted some leeway in what to photograph, for example, they were allowed to exclude “personal” activities from the study, although some did not.

After the photographs had been taken, the users were asked to fill in a questionnaire. They were asked to rate their activities from 1 to 12 (1 being the most and 12 being the least) based on the following:

- Frequency (FR) - how frequently the activity occurred.

- Time consumption (TR) - how much time each instance of the activity took.

3.2.2 Photograph Sort One – Phase 2: Photograph Sorting

Once the activities had been recorded the sorting of the photographs followed a variation on the card sorting method by Sinclair (1995). This involved laying out all the photographs (the set of two photographs for each activities were attached to one piece of card to keep them together) in front of participants and then searching for features that would allow photographs to be grouped (Figure 3). This process was conducted by a panel of judges, who performed the card sort task twice. The reason for performing the task twice was to explore variations in sorting, which would emphasise different features in the photographs.

Participants: Seven judges completed the photo-sorting task. All the participants were engineering students (4 male, 3 female, mean age 25 (±3) years) and had not completed the photograph collection task.

Procedure: The photographs were mounted on pieces of card in their pairs to maintain association. Each judge was given identical verbal instructions to sort the photograph cards into similar groups. No definition of 'similar groups' was given; this was to be defined by the judge. On the back of each photograph was written the time they were taken, the frequency rating, the time rating, the one line description of the activity and the user number. The judges were instructed to only look at these details if they could not ascertain the activity from the photograph itself. The judges were then asked to give a heading to depict each of their sets and describe the Key Features that defined membership to the group. In addition the judges selected the key picture best illustrating the group.

Definition: Key Features – The defining features of a set of activities that make those activities belong to that set.

A manual sorting (as opposed to an automated) method was used since the number of judges was small and since the main benefit of automated sorts is speed (Rugg et al 1992). In addition since the cards were in fact pictures and not just words it would have been technically difficult to create an automated process. Whilst we could have written software that allowed images to be dragged and placed in folders, there did not seem any benefit to this over a manual method.

One week after completing the first sorting exercise the judges were asked to resort the cards, ensuring that their classification was different to that in their first sort. This was done to increase detail and variety of the Key Features elicited by the technique.

It was obvious from the first sort that judges primarily sorted in a similar manner, with location being the most popular Key Feature. It is, perhaps, interesting to note how ‘location’ serves as a ‘common-sense’ descriptor of context. Asking more people to sort the card from the random starting position (as in sort 1) would have produced more of the same Key Features. By getting the same people, who had familiarity with the photographs and the features to sort again, and more specifically in a different way produced a whole new set of features. Since the desired outcome of the exercise was to produce as many and as diverse range of features, the second sorting sessions went a long way to achieving this. A third sort was not carried out since by then end of the second sort most judges were struggling to find different groups of features. It was therefore thought that little information would have been gain from a third sort. Again the heading, features and card numbers were recorded for each group. Thus the original decision to make the judges complete two sorts was validated.

Figure 3 - Photograph Sorting

3.2.3 Theme Sort - Phase 3: Post-It Sort

In the third phase, a Post-It sort was performed. This had two purposes; firstly to identify groups of similar Key Features identified by the seven judges. These groups will be called Context Identifiers.

Definition: Context Identifiers – Components of context. Context Identifiers are headings for groups of similar Key Features.

Secondly, to assign an importance weighting to each of the Context Identifiers found (based on the number of occurrences of similar Key Features in each set). It is suggested in section 2.8 that to help achieve the ideals of a wearable computer that the number of sensors should be kept to a minimum while still providing enough information to model a user's context. Therefore it would seem sensible to select a sensor that will most often given useful information about the users context to the system. Producing a weighting based on the number of times similar Key Features occur, would allow a designer to select the most appropriate Context Identifier for their context-aware device. The Context Identifiers do not tell a designer anything about what types of sensors to use, just the types of entities to sense. It is important to note that the Context Identifier sorting and weighting process only looks at the context at the instant that the original photographs were taken. The historical context or possible prediction of context has not been included in this study.

Participants: In the theme sorting phases, the task was performed by the author rather than by participants. To verify the procedure an inter-rater reliability test study was carried out at a later stage.

Procedure: All of the elicited Key Features from both photograph sorts were recorded on small yellow Post-It notes. These Post-Its were then stuck to a large piece of paper and organised into groups of connected features (i.e., ones that contained similar key words or themes).

Results: This sorting produced a concise set of theme areas or Context Identifiers, these included Location, Posture and Movement, Object and others. In Location you would find terms such as home, work, office, indoors, outdoors. Location was then split into sub categories such as known-locations, indoors/outdoors, and novel-locations. The final groups of Post-Its can be seen below in Figure 4. The miscellaneous category includes terms that were too general to fit into any other category; generally they were terms that described an activity, for example, shopping, which is the activity rather than a component of the activity. Table 5 shows a summary of the Context Identifiers found but with no weighting given to each component.

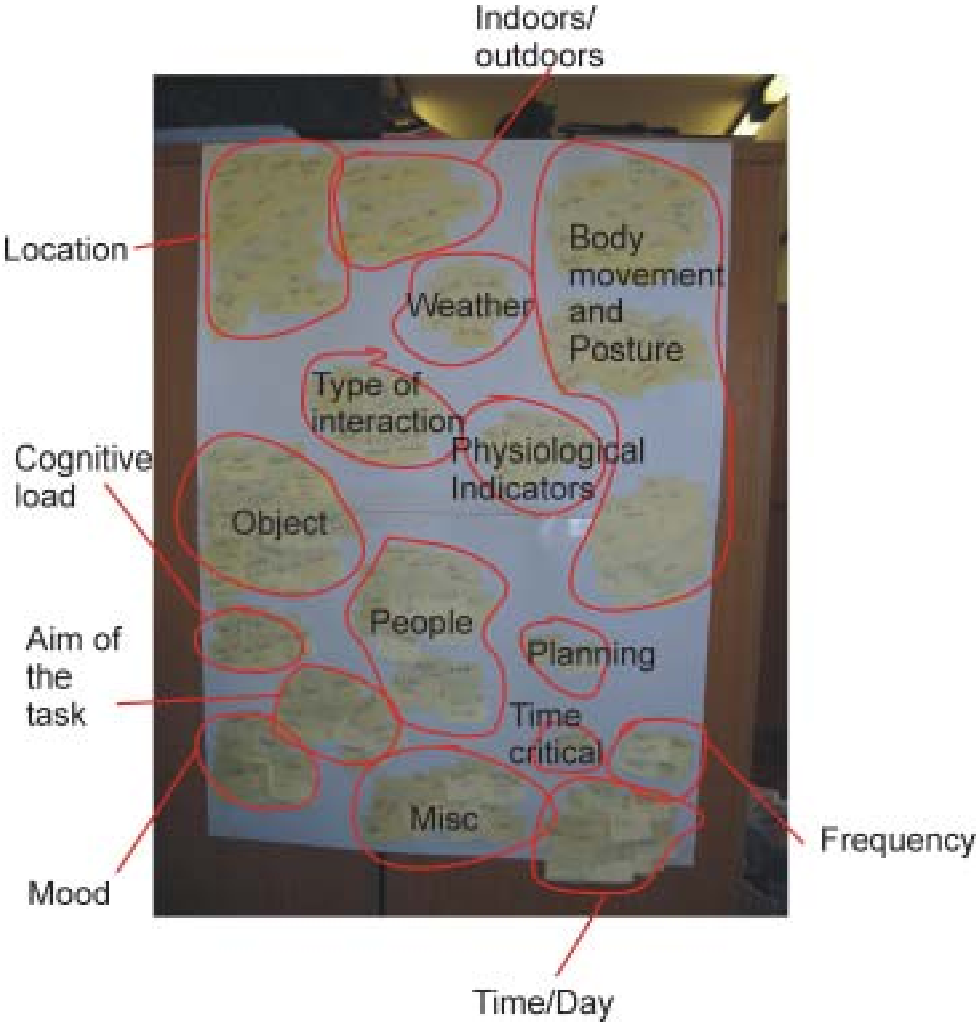


Figure 4 - Post-It Sort One

Table 5 - Initial Context Identifiers with no estimation of importance weighting

Context Identifier	**Possible States of the Context Identifier**
Aim of Task	*Is the task being done for enjoyment/work?*
Cognitive Load	*How mentally difficult is the task?*
Frequency	*How frequently is the task done?*
Indoors/Outdoors	*Is the person indoors?*
Location	*Is the location known?*
Mood	*Is the user relaxed/stressed?*
Object	*What object is being interacted with? E.g. is the user using a computer?*
People	*How many/which people are involved?*
Physiological Indicators	*Is the heart rate high?*
Planning?	*Is the task planned/spontaneous?*
Posture and movement	*Sitting, Standing, walking, moving?*
Time	*What time or day is it?*
Time Critical?	*Is the task length (time) constrained?*
Type of Interaction	*How did the interaction between people of object take place?*
Weather	*Good/bad weather?*

Since the author of this thesis carried out the Post-It sort an inter-rater reliability study was needed to validate the results. Three participants each repeated the Post-It sort with twenty percent (eighty) of the Key Features, selected at random. The key features were written on cards; each participant then pulled their eighty features from a hat and then sorted them into groups. In difference to the Post-It sort the participants were given the groups to sort into e.g. Location, Posture and movement etc. They were asked to place the terms into the group that they thought the term belonged to. To validate the results an eighty percent agreement rate was needed. In reality an agreement rate of 82.5% was achieved. The agreement rate was calculated by counting up the number of terms which the inter-rater reliability study participants put in the same groups as the author who carried out the Post-It sort. For example if both the author and the inter-rate participant put the term ’home’ in the Location group then one agreement point was counted. Thus on average 82.5% of the time the participants of the inter-rate and the author put the terms in the same group.

3.2.4 Weighting Sort – Phase 4: Post-It sort two

The second part of the Post-It sort aimed to give a weighting to each Context Identifier, to indicate which items are more important to sense. While the analysis could conceivably have been performed statistically, it was felt that a manual method would be more appropriate to this study. Any multivariate analysis requires some hypothesis as to how the items would be grouped and some metric to describe their relationships; both of these terms were to be derived from this process. The weighting was designed to look at two aspects of the Context Identifiers. Aspect one what percentage of the Key Features fitted into each Context Identifier. Aspect two, how concise the definition of the Key Features was or how many possible states a particular Context Identifier might have. The percentage indicates how often that feature makes up a component of context. The conciseness of the definition could indicate the number of states the Context Identifier could have, for example the Posture and Movement might just have two states ‘sitting’ and ‘standing’, where as objects might have hundreds of states because there are lots of different objects. Therefore a high percentage and a high conciseness would give an important Context Identifier.

Procedure: The analysis was done by counting up the number of terms that were repeated in each group, for example, ‘Home’ might appear twenty two times in the Location group. If only one occurrence of a term existed, then it stayed on the small yellow Post-It, if two to four occurrences existed the original Post-It was removed and was replaced by a small green Post-It with the term and the number of occurrences written on it. Similarly for five to nine occurrences a large green Post-It, ten to fourteen a small pink Post-It and finally fifteen to twenty two occurrences a large pink Post-It was used. This allowed Context Identifiers to be weighted in two ways, firstly by number of occurrences and secondly by area of each colour. Therefore the larger the area of pink the less possible states the Context Identifier has, thus easier it is to sense. The more occurrences the more likely the Context Identifier is to provide information about the users context.

Table 6 - Post-It classification

Number of occurrences	Post-It size and colour
1 occurrence	Stays as original yellow Post-It
2-4	Small Green
5-9	Large green
10-14	Small pink
15-22(the most number of occurrences)	Large pink

Results: Figure 5 shows the completed sorting process. The largest area of pink Post-Its was at the top left hand side of the picture marking Posture and Movement making it the most concisely defined Context Identifier, or the Context Identifier with least possible states. From Table 7 it can also be seen that Posture and Movement has the largest number of occurrences and therefore is the most important Context Identifier since it occurred most regularly in the Key Features identified in the Photograph Sort and is therefore most likely to regularly provide information about the user's context. From this Table 7 shows list of the ranked Context Identifiers, the top of the list being the most important. The 'percentage of total column' shows the percentage of the total Key Features that was made up by the given Context Identifier.

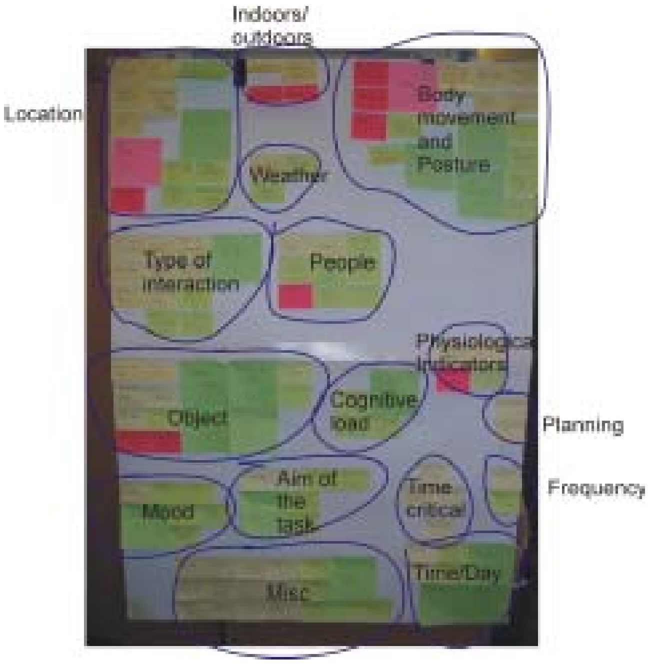


Figure 5 - Colour Post-It sort

Table 7 - Shows the completed weighted list of Context Identifiers

Context Identifier	**% of total**	**Possible States of the Context Identifier**
Posture and Movement	*24%*	*Is the person moving, walking, sitting, standing?*
Location	*15%*	*Is the location known?*
Object	*15%*	*What object is being interacted with?*
People	*8%*	*How many/which people are involved?*
Time	*7%*	*What time or day is it?*
Mood	*6%*	*Is the user relaxed/stressed?*
Indoors/Outdoors	*6%*	*Is the person indoors?*
Type of Interaction	*5%*	*How did the interaction between people of object take place?*
Aim of Task	*4%*	*Is the task being done for enjoyment/work?*
Physiological Indicators	*3%*	*Is the heart rate high?*
Cognitive Load	*3%*	*How mentally difficult is the task?*
Weather	*2%*	*Good/bad weather?*
Frequency	*1%*	*How frequently is the task done?*
Time Critical?	*1%*	*Is the task length (time) constrained?*
Planning?	*1%*	*Is the task planned/spontaneous?*

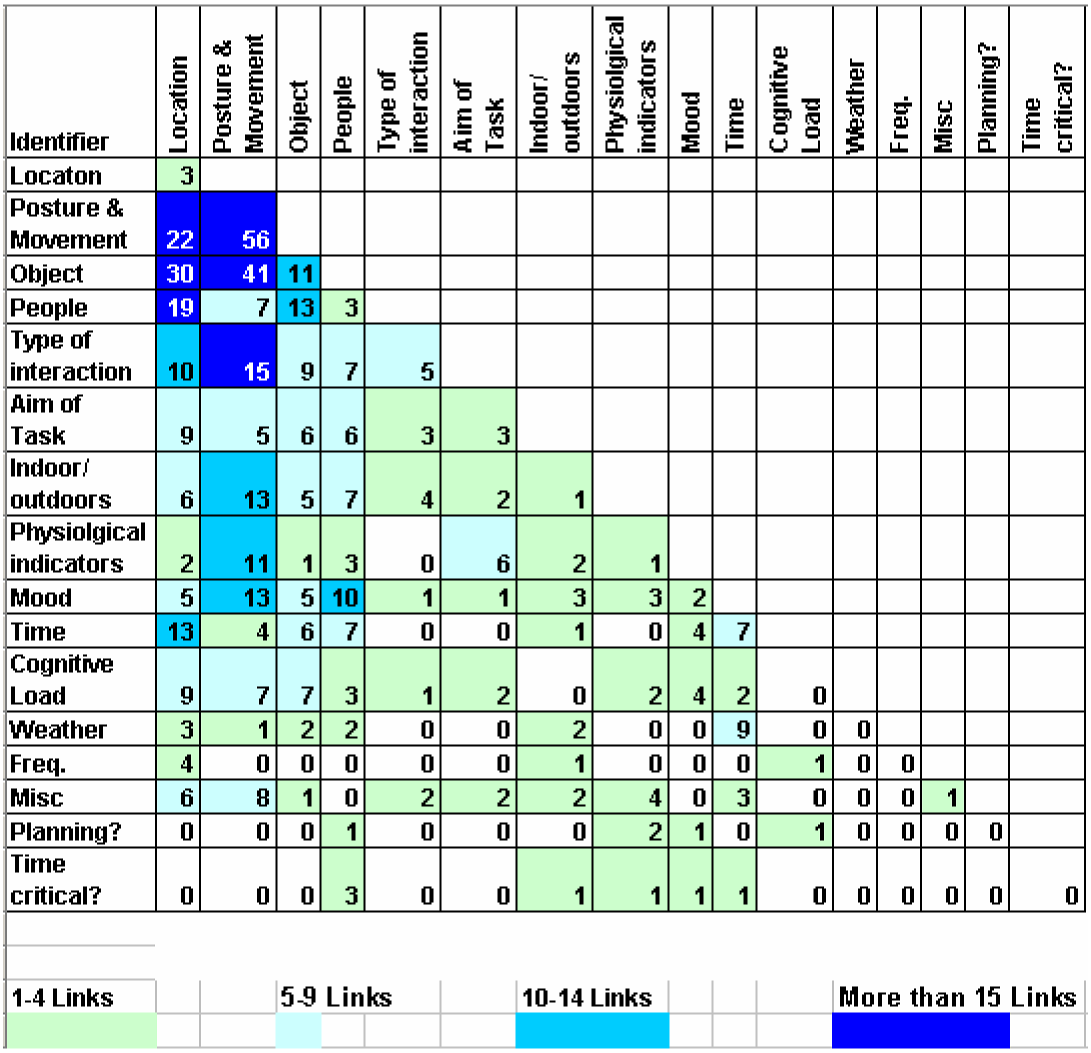
3.2.5 Linkage Investigation

Finally the linkage between Context Identifiers was investigated. From the links between Key Features and thus Context Identifiers it may be possible to infer one Identifier from another or use the connection between Identifiers, rather than the Identifier itself, in the modelling process.

For each activity (set of two photos) in the photograph sort, the Key Features were considered. Each Key Feature was translated into its Context Identifier (e.g. ‘Home’ translates to ‘Location’). Then a link was noted from each Context Identifier in that activity to the other Context Identifiers in the activity. The more links between two Context Identifiers, the higher their link weighting.

Procedure: Each time a connection occurred between two Context Identifiers in one activity, it was noted. For example from the original Photograph Sort one heading was ‘Working at a desk communicating by a device’, which had Key Features; 2 People, Sitting, communicating via a device, indoors, in an office, 2-way indirect dataflow, which correspond to Identifiers; People, Posture and movement, Type of Interaction, Object Indoors/Outdoors and Location. Therefore a connection between all of these Identifiers was noted.

Results: Figure 6 Show the number of links between each of the Context Identifiers.



Identifier	Location	Posture & Movement	Object	People	Type of interaction	Aim of Task	Indoor/ outdoors	Physiolgical indicators	Mood	Time	Cognitive Load	Weather	Freq.	Misc	Planning?	Time critical?
Locaton	3															
Posture & Movement	22	56														
Object	30	41	11													
People	19	7	13	3												
Type of interaction	10	15	9	7	5											
Aim of Task	9	5	6	6	3	3										
Indoor/ outdoors	6	13	5	7	4	2	1									
Physiolgical indicators	2	11	1	3	0	6	2	1								
Mood	5	13	5	10	1	1	3	3	2							
Time	13	4	6	7	0	0	1	0	4	7						
Cognitive Load	9	7	7	3	1	2	0	2	4	2	0					
Weather	3	1	2	2	0	0	2	0	0	9	0	0				
Freq.	4	0	0	0	0	0	1	0	0	0	1	0	0			
Misc	6	8	1	0	2	2	2	4	0	3	0	0	0	1		
Planning?	0	0	0	1	0	0	0	2	1	0	1	0	0	0	0	
Time critical?	0	0	0	3	0	0	1	1	1	1	0	0	0	0	0	0

1-4 Links 🟩
5-9 Links 🟦
10-14 Links 🟦
More than 15 Links 🟦

Figure 6 - Linkage Sort Results

As expected it was found that the most common Identifiers were connected most commonly, but there were also some other important connections. For example, given the strong connection between Posture and Movement, Location and Object, it is likely that if Posture and Movement, Location, or Object was sensed then the other may be able to be inferred. By examining the darker cells in this matrix, one could propose various routines for inferring the presence of one feature given the presence of others. This moves us towards a notion of integrating Context Identifiers to define specific context-states. Furthermore, some of the Context Identifiers might be held in user models rather than sensed.

3.3 Conclusions and Discussion

The photograph diary study has covered a large number of everyday activities. By randomly allocating time slots, many mundane activities were included that might have been missed. It is likely that people, given a free choice, would have tended to take photographs of what they considered to be interesting activities.

The results point to Context Identifiers that are likely to be significant. Table 8 shows the ranked list of Context Identifiers in order of importance (highest first) with a selection of current research that has addressed the particular Context Identifier. It is hypothesised that the highest weighted Context Identifiers are most important because they occur most often in the everyday activities analyses in this method, therefore they are likely to most often provide information about the users context. Posture and Movement is most important because it is a Key Feature in the make up of almost all of the activities analysed, whereas Weather was only a Key Feature in very few of the activities. As Posture and Movement was applied most frequently to characterise an activity, it was concluded that given a choice of the Context Identifiers it is also most often and most likely to provide useful information about the users context.

To put the Context Identifiers into context with current research a number of projects from the literature review are now described and Table 8 shows how they match up with the ranked list of Context Identifiers.

Ashbrook and Starner's (2002) location research has used GPS to log location data and then sophisticated Hidden Markov Models to predict a user's next location. Kern et al (2002) have used accelerometers to detect a user's Posture and movement and some Body Movement, in order to annotate recordings of presentations and discussions. Both papers report the development of specific applications. The integration of these and other projects with other Context Identifiers could, in the future, build up more generic context-aware devices. For example, consider the travelling individual in Ashbrook and Starner (2002). In addition to knowing the current and next locations, it would be interesting to know the Frequency of the current journey; if the journey is infrequent it might be appropriate to deliver detailed instructions to the driver, but such instructions need not be required for frequent journeys. Knowing the Weather could lead to changes in a schedule due to delayed journeys. Knowing that a task in the near future is Time Critical might change a schedule, to skip or reschedule the present task to keep the future task on time. Physiological Indicators and Mood might suggest stress; as a result again the schedule could be changed to a less stressful alternative or other stress reducing measures could be put into action. Knowing the Aim of the Task could provide support for efficient performance, for example, if the task is to ‘get to location B as quickly as possible’, then providing information about traffic conditions, road obstructions etc. could be useful. If the Aim of the Task does not include getting to the location quickly, then the information would be less useful. Linking together the correct Context Identifiers could in the future build a more sophisticated context models.

It is not being suggested in any way that the research already done is invalid, or that the wrong types of Context Identifiers have been selected. Each of the projects in Table 8 (and many others) have been designed for specific purposes and has selected the appropriate sensors and analysis techniques, however, as stated previously, as the specific purposes expand it is sensible to have an validated lookup for selecting Context Identifiers.

Table 8 - Ranked Context Identifiers and examples of current research

Context Identifier	Examples of Current Research
Posture and Movement	Ashbrook, D., Starner, T. (2002) use GPS to Predict users Global Movement. Van Laerhoven et al (2002) use accelerometers to detect Body Movement.
Posture and movement	Kern et al (2002) use accelerometers to ascertain Posture and movement.
Location	Ashbrook, D., Starner, T. (2002) use GPS to find known Locations.
Object	Kirsh, D., (2001) looks at the Objects found on a desk that make up the Context of Work
People	The Conference Assistant (Dey et al, 1999) notes which other people are in the same location as the user.
Time	
Mood	Picard (1997) in Affective Computing looks at various Physiological Indicators and mood

Indoors/Outdoors	
Type of Interaction	
Aim of Task	
Physiological Indicators	Picard (1997) in Affective Computing looks at various Physiological Indicators and mood
Cognitive Load	
Weather	
Frequency	
Time Critical?	
Planned?	

Given the bottom up method used by the majority of research, it is unsurprising that some of the Context Identifiers have not yet been researched in detail. These are left blank in Table 8. For example, if a project is designed for a specific application then the ‘Aim of Task’ is already known therefore. There is no need to sense it. As the systems become more generic, this may become more important.

If the results of this study are compared to the ‘working model for context’ suggested by Schmidt et al (1999 B) then it differences and similarities can be seen in Table 9.

Table 9 - Comparison of Schmidt et al (1999 B) and the photograph diary study

This study	**Schmidt et al (1999 B)**	
Physiological Indicators, Cognitive Load, Mood, Posture and Movement	Human Factors	User
Type of interaction, People,		Social Environment
Aim of task, Planning?, Time Critical		Task
Weather,	Physical environment	conditions
Object		Infrastructure
Location, Indoors/outdoors		Location

From this it can be seen that all the features found by a systematic analysis of everyday activities fit into the context feature space considered by Schmidt et al (1999

B). The photograph diary study, however, goes further by giving physical evidence for these features and how they related to activities. The study produced empirical data further backing up the results. A rating schema is suggested based upon the empirical data giving designers an idea of how important each features are and how they may link together. This would allow the design of similar more efficient context aware systems.

It is important to note that the photograph diary study only looks at a snapshot of overall context i.e. it looks at the present context, but does not include historical and predicted context, which will undoubtedly be useful and important. Using a photograph is very good at capturing a large amount of data about an activity in an instant. However it is a potential shortcoming of the method that some components of context will have been missed. Both historical and future context play an important role in defining overall context. How a person may react (and thus what aid a system may be able to give them) in an activity/situation may depend on the previous activity or depend on the activities coming up in the near future. For example, if someone arrived late for a meeting then they may be more stressed during the meeting, or a person facing surgery later in a week may find themselves approaching activities earlier in the week in a different way. While the photograph capturing in this method will miss historical and future context, the method still provides a comprehensive analysis of the present context. It also is important to note here that while photographs capture many things they will undoubted miss some features that would have to be addressed in a different way. These might include audio features and peoples thoughts and emotions, although some emotion may be gained though body language and facial expressions.

Having established suitable information or Context Identifiers, the next step is to devise ways of sensing or measuring each of these. Some have already been addressed e.g. Location using GPS or Posture and movement using accelerometers, and are again shown in Table 8. Others are more complex, requiring both physical sensors and user profiles. In addition the future systems may need to include more Context Identifiers (for example Location, Posture and movement, Object and Time or a combination of any of the others) allowing them to build a more complete model of the context. As more Context Identifiers are included in each system the links between individual Context Identifiers become more important to the overall design of the system.

3.4 Chapter Summary

This chapter has described a study of everyday activities that attempted and succeeded in finding context features (Context Identifiers) on a wide range of everyday activities. Aim one of the thesis was to examine the nature of context in everyday activities this has now been completed.

The study began by collecting photographs of 84 everyday activities ranging in time from 8 in the morning until 11 at night and in content from going to the loo to shopping in the high street. These activities were then sorted twice into contextually similar groups. The Key Features of these groups are collected and sorted into similar groups, giving a list of features that make up context – Context Identifiers. The Context Identifiers were then weighted to give an importance factor to aid designers in choosing a suitable context feature to sense.

The weighted list of Context Identifiers should now be used to create a generic contextual wearable computer system. The system should be capable of using some of the Context Identifiers in the list to ascertain a users basic present context.

In the next two chapters the development of a contextual wearable computer system, which later leads to experiments using the system, is described. Firstly the software written to interpret the sensor data and show contextual information is described. The software has a number of versions as more Context Identifiers and thus sensors are added to the system. Secondly the development of a wearable computer to run the context interpreting software and be used in experiments is described. Both the software and hardware development has posed some interesting challenges.

Chapter 4 Software Architecture and Context Adaptation

Aim two of the thesis was to develop and demonstrate new software that interprets the context detector (sensors that measure parts of contect) inputs and infers aspects of a user's context. Software Architecture and Context Adaptation describes the development of three different versions of this software. Each version includes more functionality and more ability to sense context than the last. At each stage in the design process the photograph diary study, described in Chapter 3, is consulted to choose the Context Identifier that is to be added to the software version. Design decisions are described in detail and screen shots of the software versions are shown. The first version only included Location as the context sense. The final version included, Location, Posture and Movement, Object and Time as context components.

4.1 Introduction

During the literature review a top-down strategy for defining the components of context was suggested (section 2.6.3). Using this strategy the photograph diary study (Chapter 3) attempted to find the components of context by carrying out an extensive study of everyday activities. Eighty-four activities were recorded and analysed. From this a list of weighted Context Identifiers (in order of importance) was suggested, Table 10 revisits this list. The weight of Context Identifiers was calculated from the number of Key Features in an activity belonging to each Context Identifier. Thus the higher up the list the more often the Context Identifier will tell something about the context of the user.

Table 10 - Shows the complete weighted list of Context Identifiers

Context Identifier
Posture and Movement
Location
Object
People
Time
Mood
Indoors/Outdoors
Type of Interaction
Aim of Task
Physiological Indicators
Cognitive Load
Weather
Frequency
Time Critical?
Planning?

Using these Context Identifiers, as a design basis a contextual wearable computer system will be developed. In this chapter the development of the context software that will give the wearable computer context awareness is described. In the next chapter (section 2.3) this is incorporated into a wearable computer producing a context aware system, that is applied experimentally in the remainder of the thesis.

The software developed during this research has evolved as a result of the experiments performed using each version of software and the Context Identifiers derived from the photograph diary study. Figure 1, in Chapter 1, shows the design cycle used though the development of the software system, hardware system and the later experiments.

Each iteration of the development builds on the last version, the photograph diary study and the experiments carried out with each version. Each version is described in detail in this chapter. The experiments that were involved in the development process are described in later chapters (Chapter 6, Chapter 7 and Chapter 8).

At each stage of software development, the list of Context Identifiers found by the photograph diary study has been revisited and used to select the next Context

Identifier to be added to the system. Each time, the next most important or next higher rated Context Identifier has been added.

Each version has the aim that when added to a wearable computer system it should model some components of context and then presents information to the user to aid in a task.

The software has gone though three iterations of the design cycle illustrated in Figure 1, Chapter 1. As with a lot of current research, the first iteration (Section 4.2) concentrated on Location as the primary context indicator. Given that this is high on the list of Context Identifiers (Table 10) and as noted in the literature review is already often used as a notion of context, this is a good place to start. The first version of the software, Version L, simply detects the Location and displays different information to the user depending on their location.

The second iteration Version LBp (Section 4.3), adds the most important Context Identifier, Posture and Movement. The software, building on Version L now displays different information to the user depending on their Location and Posture and Movement. Specifically the information changes in content depending on Location and in detail (or amount of content) depending on Posture and Movement to support the users given task.

The third iteration Version LBpOT (Section 4.4) adds the third most important Context Identifier, Object; this refers to the object that the user is interacting with. This version adds functionality, by allowing the user to choose information (from a contextually weighted list) for themselves. If they feel the information automatically shown is inappropriate or if the system has got the context sensing wrong then the user may wish to have more control of the content. Time is also added as a Context Identifier, in the form of a to-do list and calendar. This is done to add a small amount of future context, in terms of forthcoming activities. This is explained in greater detail in Chapter 8.

Table 11 - Summary of versions, Context Identifiers sensed and additional functionality

Version	Context Identifiers Sensed	Other functionality added
Version L	Location	
Version LBp	Location and Posture and Movement	Integrated Internet browser
Version LBpOT	Location, Posture and Movement, Object and time	Content choice (allowing users more choice over the content they receive)

4.2 Version L -Location

4.2.1 Version L -Location Outline

The photograph diary study determined important Context Identifiers displayed in Table 10. Near the top of this table and therefore identified as one of the most important Context Identifier is Location. The starting point of the software is therefore a system that ascertains the user’s location. While Location is not the number one Context Identifier it makes sense to start with Location for a couple of reasons. Firstly, as noted in the literature review (Chapter 2) many other research projects have already used location of a based for context, therefore there is a lot of information to aid the design and use of the system and other systems to compare the results of the research to. Secondly while Posture and Movement is the primary Context Identifier it does not practically make sense to use it on its own, or when not in combination with other Context Identifiers. It would not be obvious which information to present when sitting, standing or walking, since with no other information very little can be told about the context and thus any guess at which information to present would be a bad guess.

4.2.2 Version L -Location Software Description

A number of different positioning systems exist and have been used in context aware computing. Infra Red (IR) or radio positioning (Dey et al, 1999), image matching techniques (Aoki et al, 1999) and GPS (Feiner et al, 1997) have all been used to pin point the user’s location, to varying degrees of accuracy. This system was initially designed for use around campus and mainly outside; GPS was therefore considered the most appropriate method for finding the users location. The GPS infrastructure is already available in the form of twenty-four satellites, thus no IR or radio beacons need to be put in place. The accuracy of GPS (less than 6 meters) is perfectly adequate when attempting to find the user’s location in or around something the size of a large building.

A Garmin GPS (Garmin International Inc, 2004) was used and the software, as shown in Figure 7, strips longitude and latitude coordinates from the GPS data stream. In addition to extracting coordinates, the software also performs error checking and invokes different routines depending on the absence or weakness of signals from the GPS. The coordinates are used to query a Microsoft Access database of previously identified locations in order to call up a URL. The URL is then passed to Internet Explorer and the user is shown a page that is associated with their current Location.

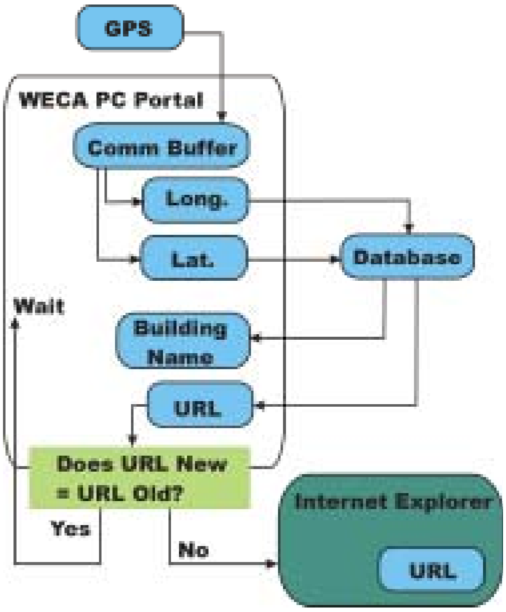


Figure 7 - Software architecture

The database was created manually and contains the longitude and latitude ranges needed for each building, along with the building's name and assigned URL. Ten buildings around campus were logged giving ten database entries. A database is useful for this since it is easy to update with more buildings or changes in URL's. It is also easy to run a query on a database. Microsoft Access was chosen since it is straightforward to create simple databases and supports SQL, the standard database query language.

The longitude and latitude ranges for the building were built up from four points logged at each corner of the buildings. Logging involves recording twenty values for the position at each corner and then taking the average. An average is taken to reduce effects of GPS drift. For the user to be in or around a building then the following requirements must be met:

- Users latitude must be less than latitude top (for the building. Top being most northerly)
- Users latitude must be greater than latitude bottom (for the building. Bottom being most southerly)
- Users longitude must be less than longitude top (for the building. Top being most easterly)
- Users longitude must be greater than longitude bottom (for the building. Bottom being most westerly)

These points are illustrated in Figure 8 for a scenario where the user in not near a building with coordinates contained in the database.

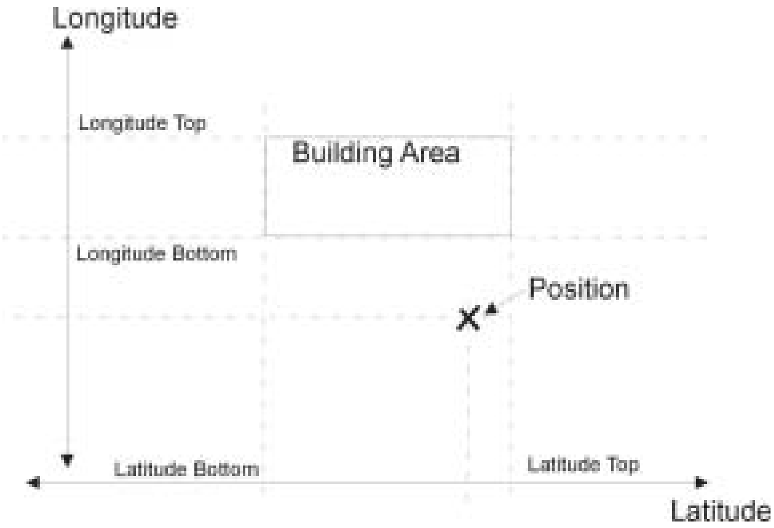


Figure 8 - Justification of SQL query. Looking at the building from above.

A query as simple as this does not take account of the fact that buildings do not run exactly along lines of latitude and longitude or that a lot of buildings are not square or rectangular. However this is not really important for this application, since the user will probably want to know about the building just before they get to it, not the second they walk through the door. Thus the query is valid for this application. An active zone is created around a building which runs along lines of latitude and longitude; this is the zone for which the query is valid.

If the user's GPS signal is lost or corrupted then the user is shown a map of the campus. Unfortunately this happens when the user walked into a building. At this early stage in the software development no consideration was given to how to know when a user has entered a building and what to display. Therefore in the application of this software in the Location experiment (Chapter 6) the users were never asked to enter building but just to get near them.

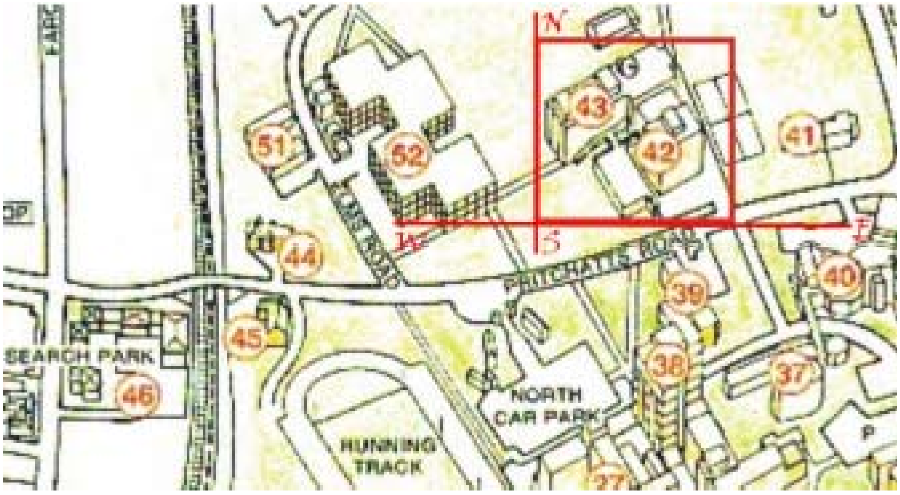
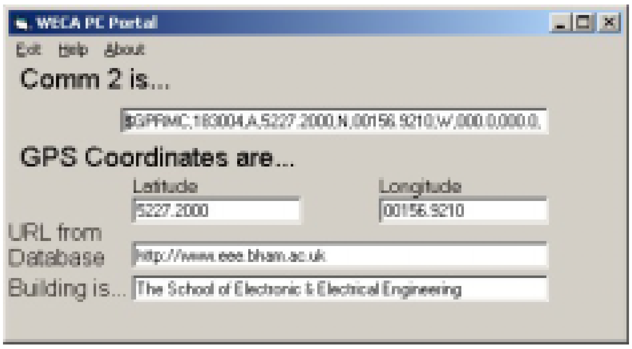


Figure 9 - Active zone around a building

Version L, therefore, can identify the user's location anywhere on campus. It can then tell the user if they are near a building that has been logged (entered in the database) and has some information associated with it. If they are not, then the user is told that they are near an unknown location and a map of the campus is displayed. Figure 10 shows a screen shot from Version L.



Comm 2 is...

$GPRMC,183004,A,5227.2000,N,00156.9210,W,000.0,000.0,

GPS Coordinates are...

Latitude: 5227.2000

Longitude: 00156.9210

URL from Database: http://www.eee.bham.ac.uk

Building is... The School of Electronic & Electrical Engineering

Figure 10 - A screen shot from Version L

The users during the experiment would never see this screen, as stated before the URL from the database is passed to Internet Explorer and if users were standing near electronic engineering then they would see a screen like Figure 11.

Figure 11 - Screen shot of Internet Explorer

4.2.2.1 Summary

The user's location is found using GPS, a URL associated with the location is retrieved from a database and sent to Internet Explorer where the web page associated with the user's location is displayed. This software is used in the Location experiment (Chapter 6).

4.3 Version LBp – Location and Posture and movement

4.3.1 Version LBp – Location and Posture and movement Outline

The photograph diary method concluded by determining the important Context Identifiers displayed in Table 10. Near the top of this table the first Context Identifier is Location and at the top is Posture and movement. After successful experiments with Version L of the software (described in Chapter 6), this next development, version LBp, adds the most important Context Identifier Posture and Movement to the system. Version LBp captures and analyses data from the GPS and the accelerometer. The information presented to the user is selected first by Location (determined by GPS) and then by Posture and Movement (determined by an accelerometer).

4.3.2 Version LBp – Location and Posture and movement Software Description

The functionality of identifying the Location was carried over from version L. Data from the accelerometer is used to tell whether the user is sitting, standing or walking. A two-axis accelerometer was used with an X and Y-axis. When the accelerometer is attached to the leg, the X-axis runs parallel to the leg and the Y-axis at right angles to it. The software takes a root-mean-square reading over 2 seconds (200 values) to get a value of the acceleration, then uses this value to assess whether the user is moving or not. Three body postures were chosen. They are the three most commonly occurring body positions recorded in the Photograph Diary Study. Other body positions obviously exist and could have been added to the system however for the purposes of the concept demonstrating experiments only three easily replicated, comfortable body positions were needed.

When the user is walking there is a higher acceleration in both directions, particularly the X-axis. Thus when the average X value is greater than 1.6g (g being the standard acceleration due to gravity ($9.80665 ms^{-2}$)) the user must be walking. The value for each of the thresholds (in this case 1.6g) was determined experimentally.

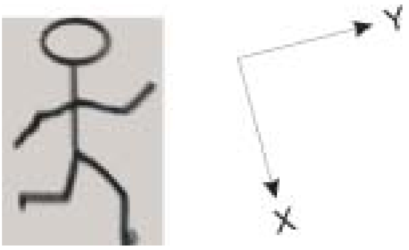


Figure 12 - User walking

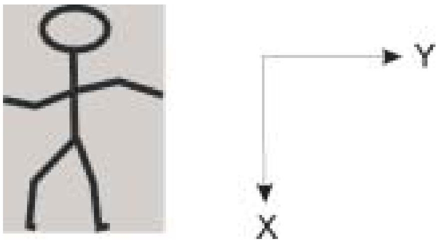


Figure 13 - User standing

When the user is in the standing position, gravity acts on the X-axis, making the acceleration 1g or greater. In addition since the user is stationary the Y acceleration is small. When the average X value is greater than or equal to 1 and when the average Y value is small (less than 0.5g) the user must be standing.

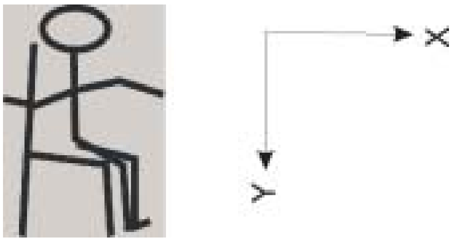


Figure 14 - User sitting

When the user is in the sitting position, gravity acts on the Y-axis, making the acceleration 1g or greater. In addition since the user is stationary the X acceleration is small. When the average Y value is greater than or equal to 1 and when the average X value is small (less than 0.5g) the user must be sitting.

Posture and movement	X value	Y value
Walking	X >1.6	
Standing	1.6 > X > 1	Y < 0.5
Sitting	X < 0.5	Y > 1

Figure 15 - Summary of X and Y values for determining the Posture and Movement

Once the user's Posture and Movement has been determined, the database is queried with both the GPS coordinates and Posture and Movement and retrieves a URL associated with the combined context. The architecture is show in Figure 16 below. The database for this version is slightly more complex; since there are ten possible building and three possible Posture and Movements, therefore a total of thirty different pieces of information of URLs to be stored as entries in the database, e.g. (Library, walking, URL A), (Library, sitting, URL B) or (Electronic engineering, standing, URL C). Adding more Context Identifiers will almost exponentially increase the number of possible entries in the database; therefore a more complex database structure will be needed. In future software versions, where increasing numbers of Context Identifiers are to be added, this problem will have to be addressed.

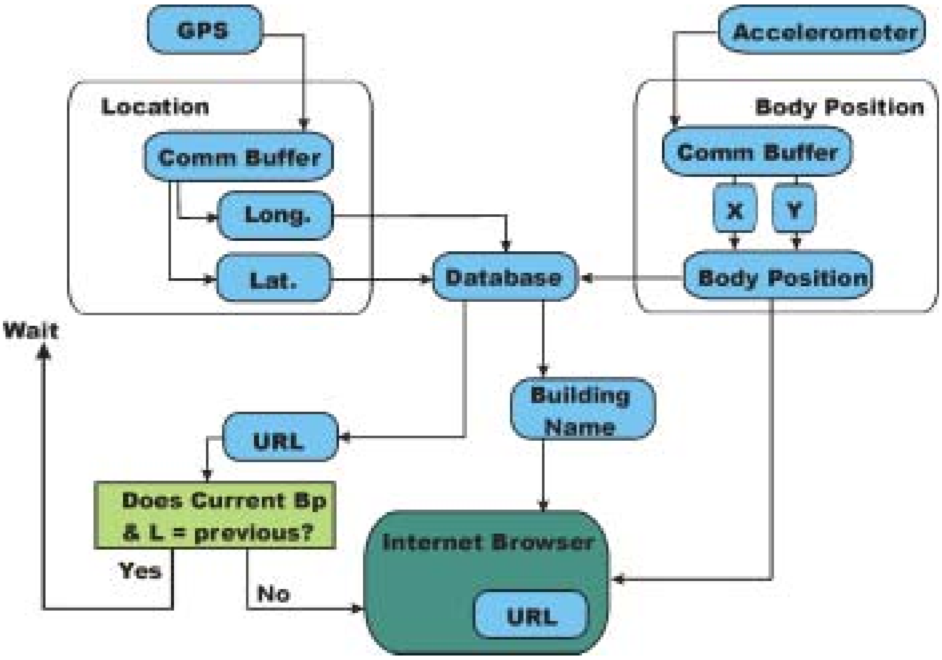


Figure 16 - Version LBp Architecture

In Version L the URL was passed to Internet Explorer however Version LBp has a custom Internet browser built in so the URL is sent to this. The browser can be seen in Figure 17. The user is told the Location and Posture and Movement via the headset; they are also shown at the top of the browser. The headset is a Plantronics (Plantronics Ltd, 2004) USB audio headset, with headphones and a microphone. An integrated Internet browser was chosen because it gives the programmer more control over what the user can and can't do, removal of options menus etc, and gives the programmer control over what the user can see. This was particularly important in showing the user their Posture and Movement and Location.

Address: http://www.eee.bham.ac.uk

Welcome to Electronic, Electrical and Computer Engineering

Figure 17 - Screen Shot of version LBp Software

4.3.2.1 Context adaptation discussion

In Version L the straightforward strategy was to change the information presented depending on the user's location; a 'tour guide approach' where users get 'you are here' information. As more Context Identifiers are added to a system it could become less obvious how to change the information being presented depending on the context. For version LBp some thought was needed on how to change the information both as the user got to new Locations and as they changed their Posture and Movement.

Considering the important usability issues identified in the literature review (Chapter 2) this wearable computer system is designed to alter the level of information depending on the user's Posture and Movement (local movement). If the user is walking, a blank screen is shown. The user does not need to look at the screen making it easier to walk. When the user approaches a building of interest, an audio command tells the user they are walking near the building. They are also told to stand still or sit down if they want more detailed information. This dual task situation, walking is a highly visual task, therefore the system needs to present information to the user in a way that will not take too much attention away from the primary task of walking, but at the same time present the information required. Audio presentation seems an appropriate choice for using a different sense to receive the information needed.

When the user sits down, the web page is shown in full. However if the user stands still, they are shown a cut-down version of the web page. At present the web page is pre-edited manually; however this could be automated. Thus the information displayed to the user is adapted for their current context. As a user walks they interact with many entities in limited detail, therefore any additional information presented needs to be simple and non-distracting. When a user stands still they can cope with more detailed information; they can devote more attention to the task rather than looking where they are going. Again if the user sits down they can devote still more attention to the information being presented to them and cope with a higher level of information.

4.3.2.2 Summary

Version LBp of the software senses the Location using GPS, and Posture and Movement using an accelerometer. A database containing URLs associated with each combination of location and Posture and Movement is queried and a URL returned. The URL is then loaded in the Internet browser. The system is designed to aid the user while not taking all their attention away from their current task (walking). If the user is walking, they get an audio message telling them their Posture and Movement and Location. If a user is standing, they get audio messages and some limited-detail visual information. If the user is sitting, then they get an audio message and some high detail visual information about their location.

4.4 Version LBpOT – Location, Posture and movement, Object and Time

4.4.1 Version LBpOT – Location, Posture and movement, Object and Time Outline

The photograph diary method concluded by finding the important Context Identifiers displayed in Table 10. Near the top of this table the first Context Identifier is Location, the second is Posture and Movement and the third was Object. After successful experiments with Version LBp of the software (described in Chapter 7), identification of the Context Identifier Object: the object that the user is interacting with was added to the system. Now the top three Context Identifiers that account for sixty percent of the Key Features have been included. In addition an element of history and Time was added by a To-Do and Task-List.

Similarly to version LBp, the system alters the information presented to the user as their context features change. The users are also given a choice of content, presented in the form of a weighted list. The content is weighted based on the number of context features present in its description. The description contains details about the Location, Posture and Movement, Object and Time that the information is designed to suit. In addition this version captures context changes using a camera that takes a picture every time any one of the Context Identifier states changes.

4.4.2 Version LBpOT – Location, Posture and movement, Object and Time Software Description

The previous versions of the software have given the user very little control over the system and over the information they could view. They could only interact with the web pages presented to them and had no choice as to other information that might have also fitted their context. Version LBpOT aimed to give the user more control over the information presented to them in addition to adding Object and Time. The architecture similar to the previous versions is shown in Figure 18.

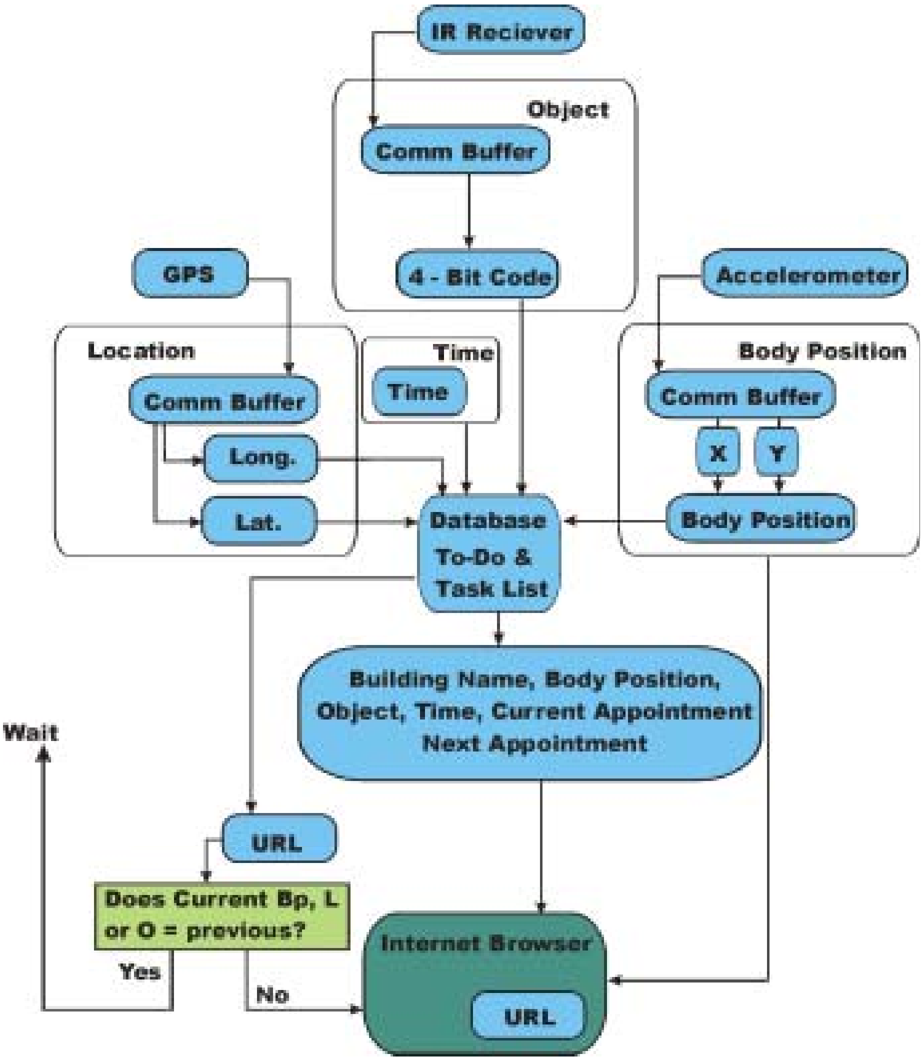


Figure 18 - Complete wearable computer system architecture

4.4.2.1 Location, Posture and Movement and Time

Location and Posture and Movement are measured in exactly the same way as in version LBp of the software (section 4.3). Time is simply the time of day, taken from the system clock of the wearable computer.

4.4.2.2 Object

If it is assumed that within the next ten years most objects will have a digital tag of some kind, e.g. a radio or IR tag, then it is not inconceivable that it would be relatively easy to interpret what object a person is interacting with. While support for this argument could not be found in the literature, given the media hype over wireless communications this does not seem an unreasonable assumption. For the purposes of this prototype system, a number of everyday objects (e.g. a book, a coffee cup, a diary etc) have been tagged with an IR tag that simply transmits a 4-bit code. A receiver on the wearable computer receives this code and the software queries the database to find which object has that code. A total of eight objects have been stored in the database. Each object was given an action, which could be mail or display. Mail sends or receives some information for a specified person or object and displays some information on the display of the system. 'Display' simply displays some information. Also each object could have a URL associated with it (but did not have to). Each location in the database had a URL associated with it: this is known as the default URL. Each location also had a mailing list. The display action displays information that is selected by the content choice described in Content Choice below. The 'mail action' emails a message to the mailing list for that location giving the users activity and location, the default URL is then used to display information.

After adding the other Context Identifiers, Object and Time, to make the system perform better some features were added. These features were chosen from feedback from users in the earlier experiments.

4.4.2.3 Content Choice

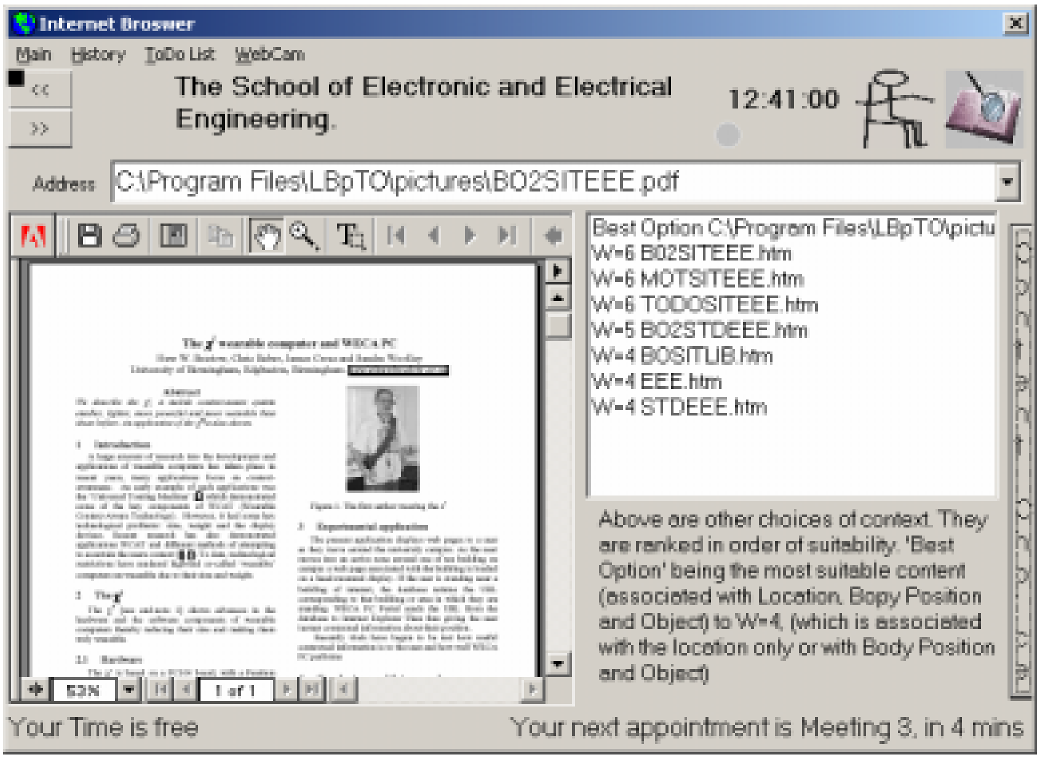
From observing how users had used the system in previous experiments and feedback made after the experiments it was obvious that users would like more choice over the information presented. Sometimes they felt that the information was not appropriate or that the system had not calculated their context correctly and they wanted to have the choice. For example, the user might have been sitting but the system thought they were standing. The information presented to them was selected for when they were standing not sitting but they had no way of getting to any information that was designed for when they were sitting.

A large amount of information was created to fit with different contexts. For example 'sitting' in the 'library' with a 'book' might display some detailed information about the book and would be stored in a file called BOSITLIB.htm (Object code Posture and Movement code Location code.htm). When the software has collected the information about the user's context (their Location, Posture and Movement and Object and the object's action) it searches though the possible information looking for the most appropriate information. The most appropriate is the one that has all the Context Identifiers in the file name e.g. for someone standing at Electronic Engineering with their diary (TODO) the system would look for TODOSTDEEE.htm. As the system searches though all the possible content, it gives each piece a weighting. The weights are calculated from the number of Context Identifiers in the file name. Location has a higher weight (4) than Posture and Movement (3), which has a higher weight than Object (1), relating to their positions in the Context Identifiers list. Therefore the most appropriate information will have a weighting of 8. If content with weight 8 is found then it is displayed. If a piece of content with weight 8 is not found, then the default location URL is used. It was decided that the system should weigh information with correct Location and Posture and Movement and no Object, higher than information with correct Location, Posture and Movement and the wrong Object. If the system finds content that fits the Location, Posture and Movement but the wrong Object (i.e. associated with an object the user is not interacting with) the Object weighting changes (to –1). This gives content with the correct Location and Posture and Movement, but no Object a higher weighting than content with the right Location and Posture and Movement, but the wrong Object. Content with weightings lower than 4 are not shown in the content choice. Table 12 below shows an example of how the weighting system sorts the content. If the Object has some content specifically associated with it then this is given precedence over the weighted content. Access is given to the content with lower weights by the 'content choice' shown in Figure 19 below. The user can then click on the relevant content to display it.

Table 12 - An example of the weighting system

Example: The user is sitting in electronic engineering with a book	Information weighting	Correct Context Identifiers present in content	Incorrect Context Identifier present in content
BOSITEEE.htm Book, Sitting, Elec Eng	8	Location (4), Posture and Movement (3), Object (1)	
SITEEE.htm Sitting, Elec Eng	7	Location (4), Posture and Movement (3)	
TODOSITEEE.htm Sitting, Elec Eng, Diary	6	Location (4), Posture and Movement (3)	Object (–1)
BOSTDEEE.htm	5	Location (4), Object (1)	Posture and movement
STDEEE.htm	4	Location (4)	Posture and movement
COFSTDEEE.htm	3	Location (4)	Object (–1), Posture and Movement
SITLIB.htm	3	Posture and movement (3)	Location
BOSITLIB.htm	2	Posture and movement (3)	Location, Object (–1)
BOSTDLIB.htm	1	Object (1)	Location, Posture and Movement

Figure 19 shows what how the users would see the content choice list. On the right-hand side of the screen the content choice list is shown with the best option, the content with a weighting of 8. Thus if the users wishes to view other content that is also related to their context, they can do so through this list. This list can be shown and hidden by clicking the content-choice button.



The School of Electronic and Electrical Engineering.

12:41:00

Address: C:\Program Files\LBpTO\pictures\BO2SITEEE.pdf

Best Option C:\Program Files\LBpTO\pictu
W=6 BO2SITEEE.htm
W=6 MOTSITEEE.htm
W=6 TODOSITEEE.htm
W=5 BO2STDEEE.htm
W=4 BOSITLIB.htm
W=4 EEE.htm
W=4 STDEEE.htm

Above are other choices of context. They are ranked in order of suitability. 'Best Option' being the most suitable content (associated with Location, Bopy Position and Object) to W=4, (which is associated with the location only or with Body Position and Object)

Your Time is free

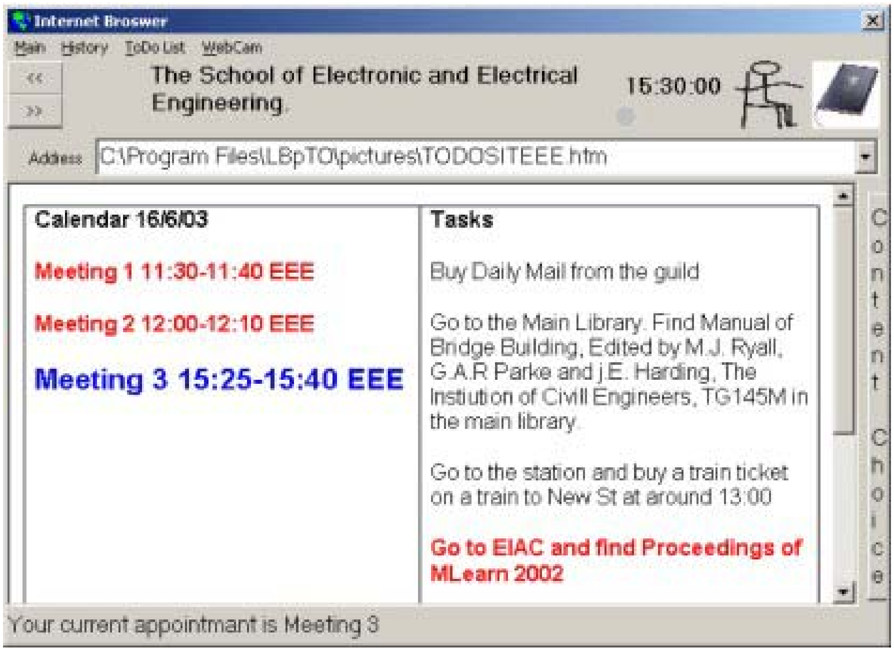
Your next appointment is Meeting 3, in 4 mins

Figure 19 - Version LBpOT showing the content choice, allowing user to view other content associated with their context. The value after the 'W=' allows users to see how well the system thinks the content relates to their context. The closer the value is to eight the better to match or association.

4.4.2.4 To-Do and Calendar

The to-do list and calendar were added for a number of reasons. Firstly, when the user's current activity is one on the list (either a task or and appointment) then the time makes part of the current context (number five on the Context Identifiers list Table 10). Secondly, when the activities are in the future or past then they make part of the users future or past context, parts of the user's overall context. As noted in the photograph diary study (section 3.3) one of the potential short comings of the method is that it only included present context. Given that current activity is part of current context, it would make sense that future and previous activities make up part of overall context. Therefore the to-do list and calendar goes some way to improve the extent of the user's context that can be incorporated into the system. Thirdly by adding the to-do list and calendar the experiment using this version (Chapter 8) of the system can easily be linked back to the photograph collecting (section 3.2.1) by filling the to-do list and calendar with activities covered in the photograph collecting.

The implementation of the to-do list and calendar are as follows. The message bar across the bottom of the software tells the user about their current and next appointment. The next appointment is displayed when it is 15 or less minutes to the start of the appointment. The to-do list and calendar can be displayed either by clicking the to-do list button or by interacting with the diary. That is done by placing their diary with the IR tag in front of the IR receiver. When the user interacts with their diary, a web page is dynamically created and displayed as an online diary. The user's current appointment is highlighted in blue and any other appointments or tasks that are to take place in the user's current location are highlighted in red. An example is shown below in Figure 20 below.



The School of Electronic and Electrical Engineering.

15:30:00

C:\Program Files\LBpTO\pictures\TODOSITEEE.htm

Calendar 16/6/03

Meeting 1 11:30-11:40 EEE

Meeting 2 12:00-12:10 EEE

Meeting 3 15:25-15:40 EEE

Tasks

Buy Daily Mail from the guild

Go to the Main Library. Find Manual of Bridge Building, Edited by M.J. Ryall, G.A.R Parke and j.E. Harding, The Instiution of Civil Engineers, TG145M in the main library.

Go to the station and buy a train ticket on a train to New St at around 13:00

Go to EIAC and find Proceedings of MLearn 2002

Your current appointmant is Meeting 3

Figure 20 - The dynamically created To-Do list

4.4.2.5 User Scenarios

The software's functionality will now be described using a number of scenarios.

User walking

When the user is walking, only audio information is presented. There are a number of possible circumstances when announcements could be made.

1) They are walking near a known location.

2) They are walking and move from a known location to an unknown location.
3) Their next appointment is in 15 minutes.
4) They are not in the right location for their current appointment.
5) Their current appointment has some content associated with it, which they should select from the content choice.

The content choice allows the user to see other information while they are walking if they wish. However it is unlikely that the user will actually be able to read, interact with the information and walk at the same time.

User Standing

When the user is standing ideally a cut down, limited detail web page is displayed that is associated with the user's Location, Posture and Movement and Object. However, in a number of cases content like this will not be shown.

1) If content does not exist, then the default content for the Location will be shown.
2) If the Object has a specific piece of content associated with it this overrides the automatic content choice.
3) If the Object action is mail, then an email is sent and the default page is displayed.

User Sitting

When the user is sitting the most detailed content is shown to them. Again this is content that matches the Location, Posture and Movement and Object of the user. Like the standing scenario this content may not be displayed in the same circumstances as above.

4.4.2.6 Capturing and validating context using the wearable computer

Since the original photograph diary study was about taking snap shots of everyday activities, it was thought that it would be interesting to see if the design loop could be completed. The aim was that the complete wearable computer system would take automatic snapshots of a user's everyday activities, with a mind to comparing the pictures taken during an experiment to the original photographs of the same activities taken for the photograph diary study (section 3.2.1). In the photograph diary study the participants were asked to take photographs that were "self explanatory in describing the activity". The activities photographed were then classified by sorting and resorting them by their components (Context Identifiers). The aim of the final version of the software was to take photographs from the Context Identifiers (i.e. take a picture depending on the sensor data). If the photographs taken automatically could be compared favourably to those taken in the original photograph study (i.e. if the automatic pictures and the original pictures of the same activity had the same essence in the picture) then the system can be seen to be collecting the Context Identifiers appropriately. This is explained in more detail in Chapter 8.

To accomplish this, a USB camera was added to the system. The software recorded a picture every time any one of the context features changed. It was thought that this would give an interesting snapshot story of the time a user was wearing the system. Each picture was stamped with the context features at the time the picture was taken. An example of the types of pictures the system took can be seen in Appendix D and E. These pictures are taken from the full system experiment (Chapter 8).

4.4.2.7 Summary

Version LBpOT of the software has added a lot more functionality in addition to the two addition Context Identifiers, Object and Time. In this version, ideal content presented to the user has to match all four Context Identifiers. Users can also choose other content from a list if they are not happy with the information automatically presented. This gives the user more control and increases the usability of the system. The list is weighted in terms of the number of Context Identifiers in the content name/description that match correctly the Context Identifier states of the user at the time. Therefore if all four match, this piece of content is considered most likely to be appropriate for the given context. When the user interacts with objects, actions are performed, either information is presented, an email is sent or both. Thus the system now has the capability to aid users in tasks that require context specific information and match the content by four levels of context.

4.5 Chapter Summary

This chapter has described the development of three versions of the contextual software. The software has been designed to be used in experiments described in later chapters (Chapter 6, Chapter 7 and Chapter 8). Each version of the software builds and improves on the previous versions, experiments carried out with previous versions and the photograph diary study (Chapter 3). Aim two of the thesis was to, develop and demonstrate new software that interprets the context detector states and infers aspects of a user's context this has now been completed.

The first version, version L, simply presents Location specific information to a user wearing a wearable computer. The location is measured using a GPS and a database contains the known locations and information location associated with it. The second version LBpOT, finds the user's Location and Posture and Movement using GPS and accelerometers. It then displays location specific information and alters the detail of the information depending on the user's Posture and Movement. The third version adds sensors that sense the Time and Object. In addition the users are given more control, to increase usability, over the information presented to them using the content choice. Location, Posture and Movement, Time and Object dependent information is displayed to the user. The content choice gives the users a weighted list of content, weighted on the number of the users Context Identifiers match those associated with each piece of content.

This chapter has outlined the development of the software used in this research. The progressive addition of Context Identifiers has been explained and justified. The development chain is illustrated in Figure 21 below.

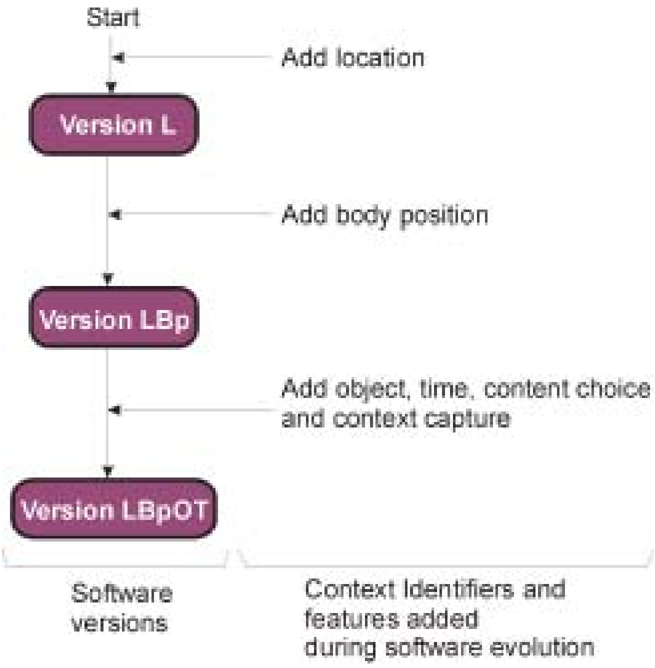


Figure 21 - The software development chain

Later chapters will describe the applications of these software versions experimentally.

The next chapter (Chapter 5) deals with the wearable computer on which each of these software versions will run on. There are many technical challenges in building a wearable computer that has the ideals suggested in the literature review (section 2.3).

Chapter 5 Building a Wearable Computer

> There are many technical challenges involved in building a functional wearable computer. Aim three of the thesis was to develop and demonstrate hardware for a wearable computer that includes some context detectors. This chapter describes the building of the wearable computer that is used in the subsequent experiments. Design issues have been discussed and the completed systems described in detail. This wearable computer combines high processing power with large numbers of inputs and outputs to give the user good control and handle many sensors to sense and combine many components of context.

5.1 Introduction

In this chapter a wearable computer is described that has been designed and constructed by the author.

Building the wearable computer has been a considerable technical challenge. In the case of a desktop computer the majority of the input and output devices required are readily available, cheap, and have had many years to evolve into a form which allows them to be easily interchanged and interfaced. As discussed in the literature review (Chapter 2) the ideals of a wearable computer have been identified by a number of authors. The wearable computer community is not currently able to achieve all of the specified ideals. Therefore for the purposes of this research these have been adapted to make the ideals for this wearable computer achievable and to focus more on some aspects of the wearable computer system that are being researched. For example, while power and hands-free use are undoubtedly ideals for a wearable computer, they are not the main focus for this research and therefore have less priority than the ability for the system to handle lots of sensors. Table 13 shows a summary of these adapted ideals.

Table 13 - Ideals of a wearable computer for this research

1) Be wearable, i.e. be operational while carried.
2) Have battery life capable of carrying out simulated 'real life' experiments.
3) Sense some key aspects of the user environment.
4) Provide enough processing power to sense some key aspects of the environment and to provide suitable information to the user.
5) Have an input output mechanism suitable for use on the move.
6) Have internet connectivity for receiving information or communicating to others.
7) Be proactive in aiding the user in a given task.

From these ideals the following requirements can be elicited:

- For the wearable to be "operational while being carried" a carrying system is required, input devices that can be used on the move are required, and the system must be small and light enough to be carried easily. (Section 5.2.7)
- For the wearable computer to "have battery life capable of carrying out simulated 'real life' experiments", power consumption must be kept to a minimum and an efficient power supply and battery designed. The battery life should be at least two to three hours since this is the likely maximum time for that an experiment. (Section 5.2.2)
- For the wearable computer to "sense some key aspects of the user environment", a number of sensors should be added to the system. The choice of sensors has already been discussed in the previous two chapters (Chapter 2 and Chapter 3) (Sections 5.2.8 and 5.2.9)
- For the wearable computer to "provide enough processing power to sense some key aspects of the environment and to provide suitable information to the user" a high-end processor is needed, with many input and output options that are capable of running at low enough power to accomplish aim 2. (Sections 5.2.1)
- For the wearable computer to "have an input/output mechanism suitable for use on the move". The wearable computer needs to have input/output devices that are small, preferably hands free, allowing the user to be fully mobile. To be fully mobile, the user should be able to move all their limbs freely. The sensors

should be small and light enough to accomplish aim 1. (Sections 5.2.3 and 5.2.4)

- For the wearable computer to “have internet connectivity for receiving information or communicating to others” it needs either a mobile phone based connection, be it GSM, GPRS or 3G, or a wi-fi connection covering the area of use.
- For the wearable computer to “be proactive in aiding the user in a given task” some software should control the inputs from the user and, more importantly, from the sensors that are sensing the environment and make the computer react in some way. Suitable software has been previously described in Chapter 4.

This chapter discusses each component of the wearable computer and then describes two completed versions that have been used in later experiments, the χ^3 and the χ^{3+}. These are the two systems used in the experiments in later chapters (Chapter 6, Chapter 7 and Chapter 8). Although the two systems have different specification, and the second is an iteration of the first they mainly share the same components. Figure 22 shows how these components fit into the wearable computer. The designs address the ideals and requirements outlined and fulfil the objective of producing a novel context aware wearable computer.

A number of commercial wearable devices were discussed in Chapter 2. A wearable computer could have been bought, however custom building a wearable computer had a number of advantages. Firstly at the time of development the cost of the developed system is under half of a similar commercial wearable computers. Secondly more flexibility in design was given by constructing a custom system. Thirdly The University of Birmingham already had considerable expertise in the development of wearable computers.

Figure 22 - Components of the final wearable computer

The following sections (section 5.2.1 though 5.2.9) discuss the design choices of the wearable computer. The two iterations, the χ^3 and the χ^{3+} are then described in section 5.3.

5.2 Wearable Computer Components

Figure 22 above shows the components of the final wearable computer system. The earlier version had some but not all of the components described. The following sections (section 5.2.1 through 5.2.9) discuss the design choices in the design of the wearable computer. The two iterations the χ^3 and the χ^{3+} are then described in section

5.3. Figure 23 below shows how the components connect together in terms of dataflow between them.

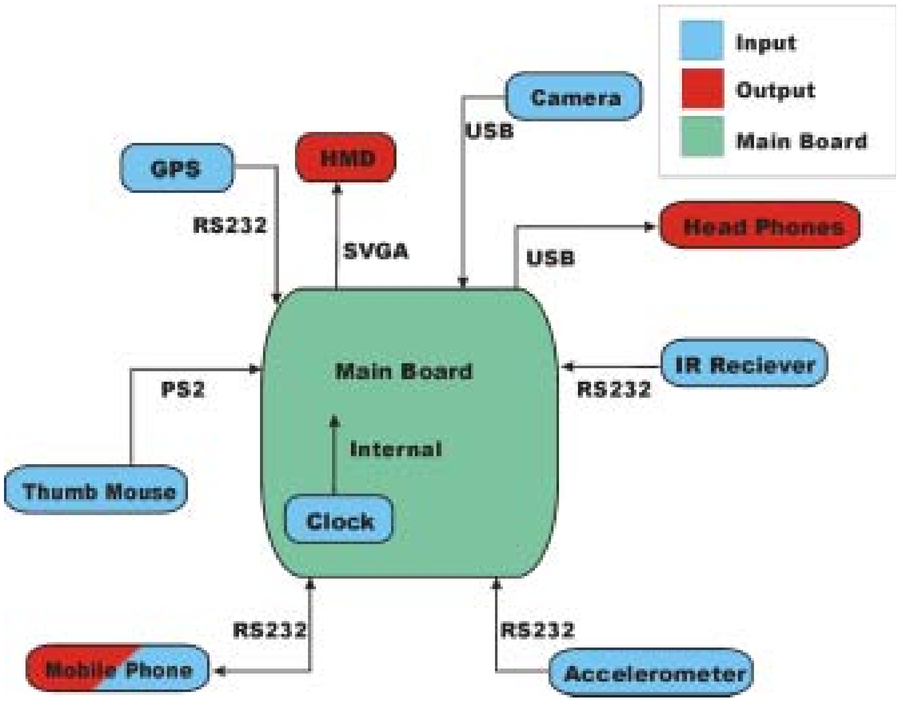


Figure 23 - Dataflow diagram showing how the components connect together

Each section of Figure 22 and Figure 23 is now described in detail, linking the design ideals expressed in the introduction with the system diagrams.

5.2.1 Main Board

The main board chosen for use for this research was a PC104. It was chosen for its high processing power and integration of many interfaces and modules onto one board. Its previous use at The University of Birmingham was important giving a base of technical advice and familiarity. A picture of the PC104 can be seen in Figure 24. The PC104 family has processors running from 60 MHz 486's to high-end Pentium 3 boards. Integrated on the main boards are on board LAN, two comm. controllers for handling RS232 inputs, USB and a number of other interfaces. This makes the PC104 range very powerful and versatile.

Figure 24 - The PC104 main board in the χ^{3+} *case*

5.2.2 Power

Power is always one of the main limiting factors with any mobile device (Starner 2001). Building a power supply that is small enough to fit a wearable case, and powerful enough to deliver the 6-8 amps (A) required to drive the latest PC104 is very difficult. James Cross (Cross et al 2000 A) produced the design of the power supply at The University of Birmingham and has used it successfully in his versions of the χ^3 (www.wear-it.net).

The power supply has evolved from an original design, which was designed to deliver 5A, for the 166 and 233MHz PC104 boards, to an 8A version required for the 400 and 700 MHz boards. The 5A supply was slightly smaller and more compact than its larger, more powerful successor. The new PC104s running at 400 or 700 MHz require 6A and when additional devices such as USB sound devices or a CD-ROM (for software installation) are added, 8A may be required. It has been found during the design process that, for bench development, it is best to use a conventional desktop ATX power supply, because it is powerful enough and more stable than its mobile alternative.

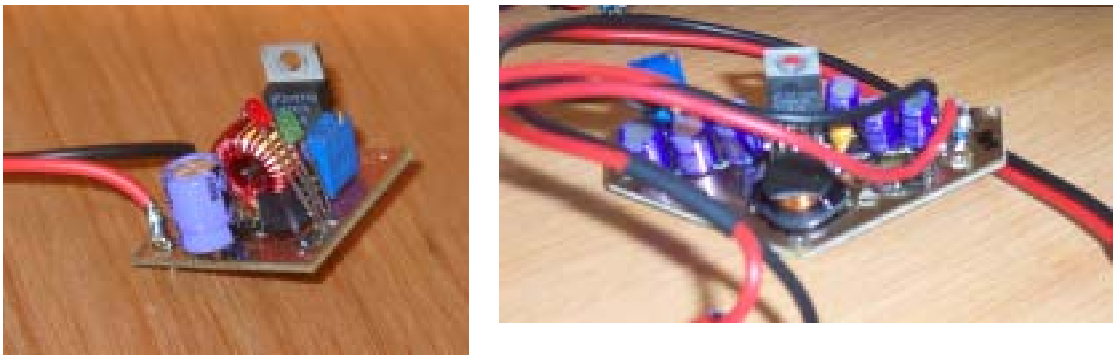


Figure 25 - The 5A and 8A power supplies

At present, when the wearable computer is mobile it is runs on lithium-ion batteries. In the future, alternative power sources (e.g. Starner 1996, Kymissis et al 1998) may become viable, but for now, rechargeable batteries are the primary source of power for all mobile devices.

5.2.3 Sound input and output

In order to allow the device to be hands-free and to give the user options of I/O, a head audio headset was required. Two options were considered for producing sound from a PC104. First a PC104 add-on soundboard is available, however the soundboard is the same size as the main board, therefore almost doubling the total size of the device. This option was therefore not chosen. The second option is a USB sound device. This is a sound card in a small module on the lead between the USB port and the headset. It was chosen as the sound input/output device is smaller and gives better sound.

The chipset used on the 166 and 233MHz boards was not compatible with the USB sound device and therefore the early versions of the wearable computer had no sound input/output. This problem was solved when the boards were superseded by the 700Mhz version and the chipset was improved to support USB sound devices.

With the addition of the USB sound device, the wearable computer could now output voice commands or music and give an alternative output to a screen. The microphone and voice-recognition software could potentially allow the user to control the wearable computer using their voice, but this has not yet been implemented.

5.2.3.1 Sound Input

Starner (2002) discusses a number of problems with using speech recognition technology as an input method for a wearable computer. Many very specific applications have been suggested for speech input. The CompCap was used in the early nineties for hands-free use for phone engineers or office dictation systems. IBM Via Voice and Dragon Dictate are examples of dictation and PC control systems. However if speech is to be used as an input method for general wearable computers, then

> "we must overcome several challenges to using speech recognition in more general contexts, and interface designers must be wary of applying the technology to situations where speech is inappropriate" (Starner 2002).

It is not hard to imagine a situation with a carriage full of business users sitting on a train all talking to their wearable computers; the volume of noise would be unbearable and no doubt the performance of the speech recognition systems would become so poor, due to background noise, as to render them useless.

It would seem that the key to user interaction with a wearable computer is to minimise the amount of direct input from the user by using appropriate contextual features to proactively control the system on behalf of the user.

While the early versions of the wearable computer (the χ^3) planned to give the capability of surfing web pages with the users voice, it was not added to the system for a number of reasons. In the early versions the USB sound system did not function, therefore there was no method of speech input. In the later versions, the microphone was functional and through the use of software from Conversay (Conversay, 2002), which allows users to surf html pages using their voice, voice recognition could have been added to the system. However, it was felt that this would have added extra complexity to the system that the users could not cope with during the short time they had to learn to use the system during the experiments. In addition, for the purposes of the experiments, there would be no advantage gained by using a voice recognition system. It was difficult enough to get participants to dress up like cyborgs and walk around the university campus, without asking them to be seen talking to themselves as well!

5.2.4 Control Devices

The chosen input method for the wearable computer is a thumb mouse. It is relatively easy to use, and similar to using a familiar mouse or tack ball. It does not need a surface like a mouse and so can be used on the move. The thumb mouse is small and light, making it well suited to the wearable computer environment.

5.2.5 Operating System Choice

Most wearable computer research (Piekarski and Thomas 2001, Dey et al 1999, Starner 1997) worldwide has chosen to use LINUX as their operating system, claiming it is faster and more suitable for wearable computers. However we argue that Windows has greater user acceptability, compatibility and functionality and therefore it is a better choice. When using many different input devices such as USB sound or GPSs, the number of compatible devices and, more importantly, their drivers for Windows, is a great advantage.

Opposition to Windows may have come from its processor-hungry reputation (in comparison to other operating systems and in terms of processing power and disk space it requires a higher minimum requirement (Microsoft, 2004), (Redhat, 2004)), however the high-end processors (700Mhz) are easily capable of powering Windows. Power consumption (in terms of Watts) may also have been a problem, but Windows XP and Win2K both contain some very good power saving features. This can be seen by the fact that the $\chi^{3,}$ a Windows machine can run for more than eight hours on one set of batteries.

5.2.6 General Problems

Many general problems have occurred during the building of the wearable computer. The largest and most frustrating has been the continual failure of the operating system to cope with corrupted files. Operating system files have regularly been corrupted because the standard hard drives are not suited to mobile life. During the set up of the PC the “Blue screen of death” has been a regular occurrence and has only been rectified by a complete re-install of Windows. These problems have been frustrating and time consuming. In future versions, as with PDAs, it may be more appropriate to use solid-state (for example, compact flash memory) memory; however this is at present expensive and not available in large enough memory sizes to be suitable for this project.

Early PC104 boards were not supplied with input/output (I/O) boards, thus a board that had connectors for mouse, keyboard, and monitor had to be custom made. The later higher performance boards came with an I/O board which was very helpful for bench development. However it would not fit in the case, so again custom connectors had to be developed.

Personal computer connector standards have been mainly derived from the desktop computer. When these systems are miniaturised, as in the case of wearable computers, many problems occur with the connectors. Often the standard miniature connectors do not exist. In this case custom connectors must be produced which is time consuming and costly. For example, one awkward problem was found when attempting to attach a CD-ROM to the wearable computer. It is essential to have a CD-ROM to install operating systems, drivers and applications. The PC104 IDE bus uses a standard laptop computer 2.5” bus, needed for attaching a standard laptop computer hard drive. Laptop computer CD-ROM drives do not use the standard IDE connector and instead use a KX15-50KLDL or equivalent connector, followed by a custom build adapter to connect this to the motherboard of a given laptop computer. It seems very difficult to find an adapter to convert from KX15-50KLDL to 2.5” IDE. A second approach was to connect a desktop CD-ROM. This was achieved using a 3.5” IDE cable and then converting from 3.5” to 2.5” with an IDE converter, which are widely available.

Once these problems had been overcome a solid, stable test and development bed was constructed. It became easier to continue the development.

5.2.7 Carrying System

A number of carrying systems have been investigated. Two main systems have prevailed each of these has been used in at least one of the experiments and its comfort assessed using the Comfort Rating Scales (Knight et al, 2002 C). The first system modelled in Figure 31 is an across-the-shoulder design. This was reasonably successful for the simplest early system. Unfortunately as more components and sensors were added to the system, it no longer performed as required. During the experiments, due to the positioning of the components on the bag, it tended to twist around the users body, thus making it uncomfortable and moving the main computer unit (seen in the figure next to the user right hand) into a position restricting the user’s arm movement, damaged the connections to the mouse, GPS and battery. Therefore a better system was needed. The second system (Figure 32 and Figure 33) using a ‘Camel Back’ backpack was devised. This system allowed for many more devices to be added e.g. the USB sound device and the accelerometer and object sensor modules, and was less restricting to the user’s movement.

5.2.8 Accelerometer Development

The accelerometer is needed to identify the user’s Posture and Movement; are they sitting, standing or walking? An accelerometer was chosen because it is small, easy to power and interface to, readily available, relatively cheap and very effective as a tilt sensor. A number of methods have been considered for analysing the data from accelerometers. You could choose to have different numbers of accelerometers. Van Laerhoven et al (2002), have put accelerometers all over the body and have used neural networks to analyse the data to determine the Posture and Movement. From their data they can identify numerous Posture and Movements, e.g. arm positions, head movements etc. This amount of detail would not be beneficial to this system at this stage; therefore a simpler solution was sought. The solution chosen is to use one accelerometer attached to the body just above the knee. The philosophy behind the Posture and Movement calculation is described in more detail in section 4.3.2. Here we will just look at the hardware involved.

The raw data from the accelerometer (an ADXL210E) is passed to PIC16F84 in the module on the leg. This is in turn sent to a module on the main system, that converts the signal into a RS232 data stream and passed the data to the Communications port of the wearable computer, where the software (section 4.3) performs the decision process and finds the users Posture and Movement. Figure 26 shows the accelerometer attached to the leg just above the knee where it can measure the tilt of the upper leg to determine when the user is sitting or standing and the impact force of the leg when the user is walking. Figure 27 show the electronics that process the raw data from the accelerometer, package it and transfer it using RS232.

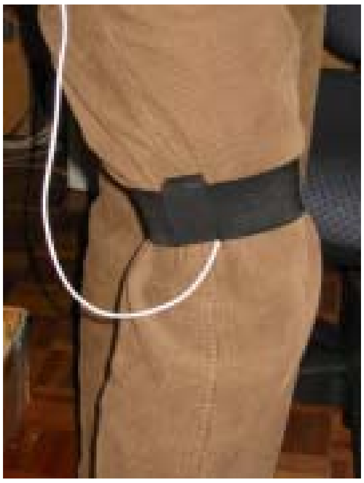


Figure 26 – Leg Accelerometer Module

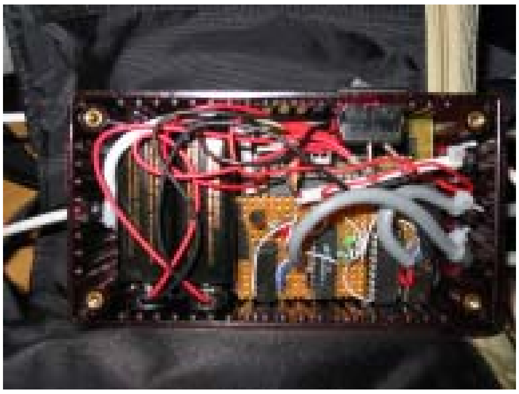


Figure 27 - Main accelerometer processing module

5.2.9 Object Sensor

For the final version of the wearable computer, the χ^{3+}, used in the Complete Wearable Computer System experiment (Chapter 8) it was necessary for a number of objects to be tagged so that the wearable could tell when the user was interacting with them. Interaction is assumed when the object is placed in front of the user where the object sensor can see the object. Many solutions for tagging objects, people, animals and locations have been devised (Dey et al 1999, Biotrack, UK) most are based around IR or radio tags. The implemented solution was chosen for its simplicity and cheapness.

The solution involves each object having an IR tag attached to them (Figure 28). This tag continuously transmits a 4-bit IR code (thus you can tag up to 16 objects). An IR receiver is then placed on the front of the user as seen in Figure 29. The received signal is then packaged by a PIC16F84 and sent to the wearable computer's COMM port. Here, similarly to the accelerometer data, the software processes the information and in this case decides what the object is based on the given IR code that has been sent. While they are fairly reliable, IR transmission can have some problems when used in high levels of sunlight. Although this could have posed problems for a mobile device that is designed to be used outdoors, the problems are minor and only occur on very sunny days. These problems can also be overcome by shading the area around the infra-red receiver.

Figure 28 - Cup tagged with an IR tag

Figure 29 - IR receiver placed near the shoulder on the strap of the wearable computer

5.3 Completed system used in experiments

5.3.1 The $\chi 3$

The χ^3 is a wearable computer developed by the University of Birmingham. The χ^3 uses a PC104 embedded PC board. It has SVGA out, two COMM ports and on-board LAN. The main unit is a 166Mhz Pentium class chipset. A MicroOptical head-mounted display is used (with its own power source and data converter), with the addition of a SVGA to NTSC converter allowing the screen to be made larger for reading text from web pages. A Garmin Global Positioning System (GPS) is used for tracking the users location.

The wearable computer runs Windows 98. This offers the capability to run commercially available software and to share files between different computers. However, Windows is branded as ‘power hungry’ from two perspectives. Firstly Windows requires more processing power than other operating systems. Secondly and as a result of high processing power Windows based computer require more Watts to power them. It has been found, through work carried out by James Cross (Cross, J. 2000 B) that it is possible to modify BIOS settings in such a way as to significantly reduce power requirements and so extend battery life. As a result the χ^3 can typically expect some 6-8 hours of battery life (and have managed to run for 10 hours on full load in laboratory settings). While these times are, perhaps, too short for commercial applications (it would be annoying to keep running out of power towards the end of the working day), they do suggest that it is possible to control power management in Windows to give an acceptable battery life for the completion of concept demonstrating experiments.

Figure 30 - The $\chi 3$

Figure 30 shows the χ^3. It measures only 170 mm by 40mm by 100mm. Even with the addition of the head mounted display and battery the system is still comfortable, light and easy to wear.

Development one of the carrying system from the front, worn during the Location experimental, Chapter 6

Development one of the carrying system from the back

An alternative belt mounted carrying system

Development two of the carrying system

Figure 31 - The author wearing the χ^3 and developments of the carrying system

5.3.2 The $\chi 3+$

The χ^{3+} is an upgraded version of the χ^3. The main board is still a PC104, however it is now a speedy 700Mhz 256Mb RAM. In addition the USB sound card and headset that was not operational with original χ^3 is now functional, due to a more powerful power supply and different chip set. Unfortunately the increases in speed and the addition of the USB sound come at a price. The battery life has now dropped to around two and a half hours when in full operation. This is still long enough to run concept-demonstrating experiments. A Personal Display Systems Cy-Visor has replaced the Micro-Optical head-mounted display; this much improved the display giving a true 600 by 800 resolution making text clearer and easily readable. However this display was not translucent and therefore did make seeing where one was working more difficult. As with the χ^3 a Garmin GPS was used. For the second level of context a two-axis leg accelerometer was added. The operating system was upgraded from Windows 98 to Windows 2000.

5.3.2.1 Completed Systems

Figure 32 - Two users using the χ^{3+} *during the Posture and movement Experiment (Chapter 7)*

Between the Posture and Movement experiment (Chapter 7) and the Complete Wearable Computer System experiment (Chapter 8), a camera was added for collecting images every time any aspect of the user’s context changed.

Figure 33 - A user using the final version of the χ^{3+} *during the Complete Wearable Computer System experiment, Chapter 8*

5.3.3 A feature comparison of the χ^3 and χ^{3+}

Table 14 - Comparison of feature of the χ^3 and χ^{3+}

Feature	χ^3	χ^{3+}
Main board	PC104	PC104
Processing power	166 MHz	700 MHz
RAM	32Mb	256Mb
Context sensors	GPS	GPS, Accelerometer, IR object tagging.
Carrying system	Across shoulder system	'Camel Back' system
Head mounted display	Micro-Optical, single eye, 200 by 300 resolution, translucent	Cy-Visor, dual eye, 800 by 600 resolution, opaque
Sound		USB headphones and microphone
Power supply	5A	8A
Operating system	Windows© 98	Windows© 2000
Control device	Thumb mouse	Thumb mouse
Internet connectivity		GSM Nokia 6210 Mobile phone, 9.2kbps data rate

5.4 Chapter Summary

This chapter has seen the development of a wearable computer system. The design of the wearable computer has attempted to address the issues and ideals highlighted by the literature review (section 2.3). Aim three of the research was to, develop and demonstrate hardware for a wearable computer that includes some context detectors this has now been addressed.

A unique carrying system has been devised that allows the user to use the computer while on the move, making the system wearable.

A major problem of power has been addressed by altering power saving settings, custom designing a power supply (power supply designed by James Cross, (J Cross 2000 B)), and having a large enough battery. This means that the system can be mobile and operational long enough to carry out some concept-demonstrating experiments.

A number of sensors have been added: GPS, acceleration, object and time sensors to sense some aspects of the users environment. These are essential to meet the objective of producing a context aware system. How successful these sensors proved will be investigated experimentally in later chapters.

A PC104 board, hosting a 700 MHz Pentium chipset gives a high-power processor capable of running the operating system of choice and the software designed in the previous chapter (Chapter 4). In addition the PC104 has the required input-output capabilities to control the user interface and sensors. While the extra speed is helpful in increasing the processing capability of the system and the speed of response to user actions, the main advantage of the faster board was the change in chip set allowing the introduction of the USB sound device.

Portable input and output devices have been added to the system to make it truly usable while mobile. A thumb mouse, HMD, USB sound device provide the input output mechanism allowing the user to use the system on the move. Speech is a potential input method but was considered inappropriate. While speech may be appropriate in some situations, while driving alone for example, it would not work in a number of cases, for example, in a busy train carriage.

The chosen system for connecting the wearable computer to the Internet is a GSM mobile phone, giving a data rate of 9.6kbps. Although slow, mobile networks have large coverage and will work almost anywhere, compared to a wi-fi network, which as yet does not even cover the university campus.

The software described in the previous chapter in conjunction with the sensors (GPS, acceleration, object and time) allows the system to be proactive in displaying contextual information to the user.

The author of the thesis constructed the wearable computer. This included building the power supply from the design by James Cross, (J Cross 2000 B), designing and building the custom carrying system, designing and building the object and posture and movement sensors and constructing the main pc.

Finally the components and development of the χ^3 and χ^{3+} have been described, showing the two systems that have been used in the experiments. The χ^{3+} is a later evolution of the χ^3 with sound, camera, new carrying system and more inputs and outputs added.

A context aware wearable computer system has been created. The literature and a photographic study of activities have been used to guide the creation of the wearable computer system. Some components of a user's environment, specifically Location, Posture and Movement and Object, can now be sensed and through the software designed, can control information presented to a user. The performance of the system will be investigated experimentally in the forthcoming chapters.

In the Appendix B usability is discussed and a number of measures introduced and investigated. An experiment is reviewed that investigates the validity of the SUMI scale for wearable computers. These measures are then applied to the following three experiments.

The next three chapters describe three studies carried out using the χ^3 and χ^{3+}. In the first two studies a formative evaluation of usability is carried out using some but not all of the suggested usability metrics. The third investigates usability employing all of the metrics suggested giving an overall picture of usability. Given that the development of the χ^3 uses rapid application design, the initial phase deals mostly with the technological development of the system where the efficiency and effectiveness are crucial to the performance of the system. Therefore measures such as time and task accuracy are used. As the technological aspects of the system become more developed and reliable then the focus shifts to making the system more usable and satisfying to the users. Therefore extra measures of usability that look at satisfaction can be added to give a more complete overview of usability.

Location, the next chapter deals with an experiment using the χ^3 and version L of the software. A comparison is made between using the wearable context aware solution and two everyday methods of searching for information. Performance in each condition is compared and conclusions drawn to influence future/further design of the hardware and software.

Chapter 6 Location

Location has been found by the photograph diary study (Chapter 3) to be the second most important Key Feature of context. In addition a large amount of research already uses Location as a Context Identifier. Based upon this evidence a system has been designed that makes use of data relating to a user's location to influence the information presented to them. In this chapter an experiment is described that has been carried out to find if a location-based contextual system can improve the performance of a user completing an information retrieval task. The location-based contextual system was found to perform faster and more accurately than the control conditions. By carrying out user trials using the system, aim five; to explore the design features of the system and their impact on system and user performance will be addressed

6.1 Introduction

After designing Version L of the software and the χ^3, the Location experiment described in this chapter was carried out. Figure 34 shows the design cycle. The current stage, the Location experiment is highlighted.

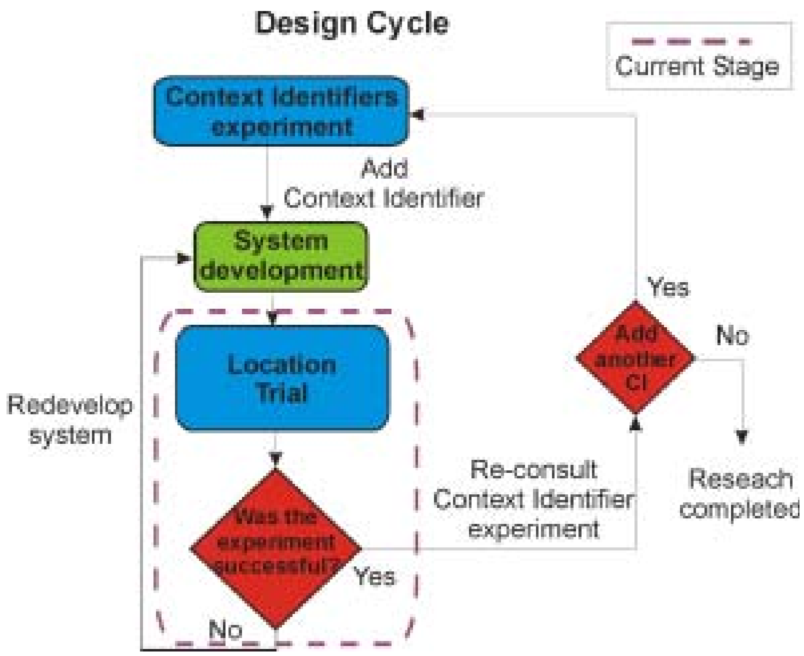


Figure 34- Design cycle, highlighting the Location experiment Stage

The system described in this chapter and used in the subsequent experiment consists of Version L of the software described in section 4.2 and the χ^3 described in section 5.3.1. The system identifies the user's location using a GPS and presents different information depending on the user's location on campus in order to support an information retrieval task performance. The users are positively primed with contextual information relating to your location. Eight buildings on campus have been logged in the database (described in section 4.2.2) with a URL associated with each building. As a user walks into the vicinity of a logged building the web page, which is stored on the hard drive, is displayed. For example the web page associated with the location-'library' would be the library home page, URL: http://www.is.bham.ac.uk. Figure 35 shows a general outline of how the system works in the experiment.

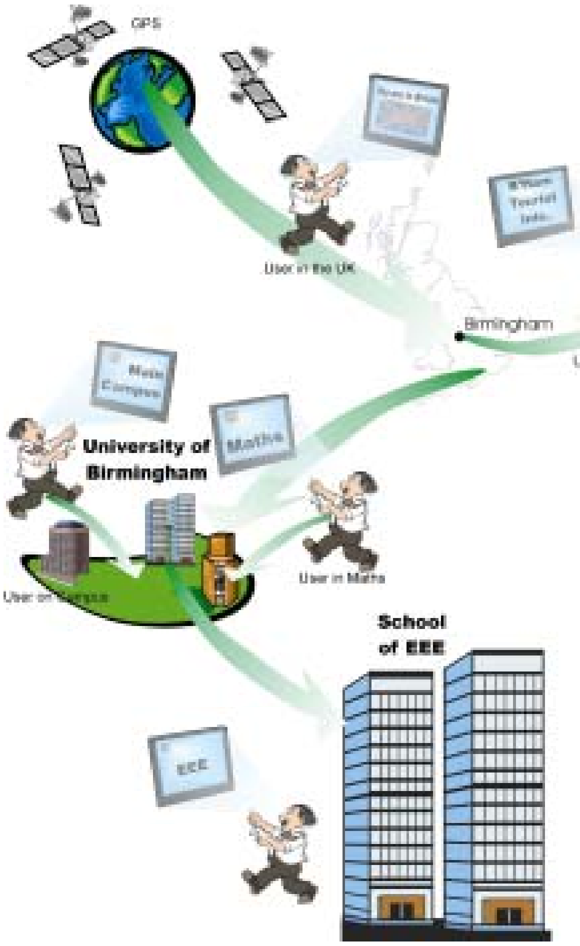


Figure 35 - General overview of the system used in the Location experiment

The aim of the experiment was to determine whether a location-based context-aware wearable computer would be a useful aid in information retrieval tasks. Since the computer is wearable and connected to the Internet, it offers the advantages of use in the environment, as well as Internet connectivity. It was assumed that such a device would allow users to extract information from both the Internet and from the world around them (their environment). Consequently the experiment was constructed so that people would search for information in one of three independent conditions:

- Condition one Wearable: Using the context aware wearable computer when walking around.
- Condition two Internet: Using the Internet only in an office.
- Condition three World: Using information available in the environment when walking around.

It is important to note that all questions are answerable in all conditions, from all information sources. Thus participants in condition one have the choice of information source.

The comparison between the three conditions, was intended to test:

- Whether wearing a context aware device led to superior performance, in terms of time and accuracy, compared to simply using information readily available in the environment.
- Whether mobile access to the web led to superior performance compared to simply accessing the web on a static terminal.

Time and accuracy are chosen as the measures of performance because the usability chapter, section 2.7.1, ISO 9241-11 (ISO, 1998), suggests them as measures of effectiveness and efficiency, which in turn make up overall usability. If a new piece of technology has high usability then it is likely to be accepted and used.

It is expected that the wearable computer will assist the participants to choose the information source that allows them to answer the question correctly most efficiently. As a result they will show improved task performance times. Collecting information to answer the questions quickly will mean that participants do not give up looking for the answer, as they might in other conditions, resulting in a more accurate performance and more questions answered correctly.

Potential drawbacks of the wearable computer may result in condition two Internet, and condition three World, producing superior performance in some aspects. Wearing the computer might impede mobility, resulting in the world condition (condition three) having significantly faster mean time between questions than the wearable condition (condition one). Here the mean time between questions is the time taken walking between buildings for the mobile conditions, and the mean time rested between questions for the Internet condition. The Internet should allow quick information retrieval, and so should support faster times to find information, particularly when one considers that the Internet condition would employ the traditional mouse and keyboard and a 17” monitor familiar to all participants. It is believed that giving the user the choice of information will outweigh the disadvantages of the wearable computer system and still lead to superior performance.

6.1.1 Hypotheses

In summary, it was hypothesised that the experiment would show that:

1) Using the wearable computer will increase the speed at which the user completes the task.
2) Using the wearable computer will increase the accuracy with which the user completes the task.
3) The wearable computer may be uncomfortable and may slow the movement of participants around campus.

6.2 Method

6.2.1 Participants

Twenty-seven undergraduate electronic engineering students participated in the experiment (23 male and 4 female) with a mean age of 19 years, (range: 18 to 22).

6.2.2 Metrics

- Performance assessment was based on time (efficiency) and accuracy (effectiveness).
- The time taken to answer each question (in minutes) measured as the time taken from the user arriving at the location that the question relates to, to the time when the user has answered the question.
- The total task time, the answers and the information source were all recorded by the observer.

- The comfort of the user will be assessed using the Comfort Rating Scale (Knight et al., 2002 C)

6.2.3 Procedure

The participants were randomly allocated to one of three conditions, with nine in each. In each condition the participants were presented with a different information source to complete the experimental task. The task involved answering questions about buildings on the University of Birmingham campus.

Condition one: Wearable

In the wearable condition the user wore the χ^3 with Version L (section 4.2) of the software installed. This provided them with access to both environmental data as well the Internet. As the participants approached a target building, a single web page was displayed. In each case this page contained the answer to at least one of the questions asked about that building.

Condition two: Internet

In the Internet condition the user only had access to virtual data via the Internet. The participants were asked to sit at an Internet terminal in the School of Electronic and Electrical Engineering and only use the University of Birmingham web sites to find the answers.

Condition three: World only

In the world condition the participants were asked to walk around campus with a paper map, visiting the relevant building to answer the questions. They only had access to environmental data.

A set of questions about buildings around the university campus was devised (See Appendix B). The questionnaire comprised two questions about each of four target buildings, eight questions in total. The participants were issued with the set of questions on paper and any queries regarding task instructions were addressed. Each group was then told that they had twenty minutes to complete the task (although they were not stopped if they went over this time).

All participants were given a brief explanation of the task and were then provided with written instructions and an answer sheet. The participants in the wearable condition were given a brief overview of the wearable computer system and a two-minute demonstration of how to use it. Training was limited, as it was aimed to see how people would cope with the novelty of the wearable computer.

A participant observer was asked to record the answers to the questions and the time that it took them to answer each question.

- In the Wearable condition, this was measured from the time when they arrived at the building, which is when both the environmental and virtual information became available to them, (it was assumed that the system reacted instantaneously to the participants getting to the buildings and presented the virtual information, in most cases a fair assumption) to the time they found the answer.
- In the Internet condition, measured from the time they arrived at the web page for the building, which is when the virtual information became available to them, to the time the found the answer.
- In the World condition, measured from the time when they arrived at a building, which is when the environmental information became available to them, to the time they found the answer.

Observers were also asked to record the total task time, whether they answered the questions making use of virtual or environmental information and any problems they encountered. At the end of the experiment, the answers were scored and the participants and observers debriefed.

When the participants in the wearable condition had completed the experiment and returned to the starting point they were asked to fill in a Comfort Rating Scale (CRS) (Knight et al. (2002 C) rating the comfort of the wearable computer over the time they had worn it during the experiment.

The CRS could be used in later system development to find areas of the wearable computer that needed improvement in terms of the participants’ emotion, physical attachment, harm to the user, perceived change, impeded movement or the participants’ anxiety when using the wearable computer.

6.2.4 Metrics

In the literature review, ISO 9241-11, (ISO, 1998) was noted as a guide to measures of usability. This experiment addresses two measures that make up usability, effectiveness and efficiency. One suggested component of efficiency was time, and of effectiveness was accuracy, therefore these are used as two performance metrics. The time taken to answer each question and the total time completing the task were recorded in minutes, reported by the observer. The time between each question was also considered. For the ‘outdoor’ conditions, (the wearable condition and the world condition) this was the time taken from completing a task at one building to arriving at the next building, and in condition two: internet, this was the time to move to the relevant web-page. Accuracy scores were based upon the percentage of questions answered correctly.

6.3 Results

The results are considered in terms of the effect of condition on performance time, and the participants’ ability to answer the questions.

In addition the CRS (Comfort Rating Scale) results are shown.

6.3.1 Effect of condition on time

Figure 36 shows the mean time spent answering the questions, time between questions and complete task time for each condition.

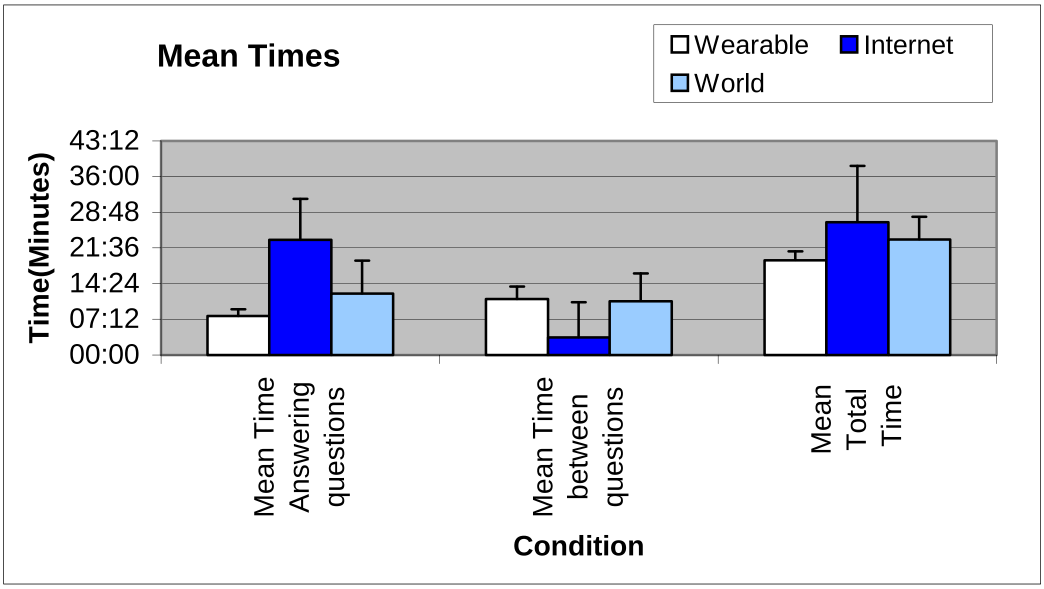


Figure 36 - Chart shows means times from experiment

A Kruskal-Wallis test was carried out to compare the mean times between the three conditions.

For the time spent answering questions the results show a main effect of condition [$\chi^2 = 11.779$; df = 2; $p<0.005$]. Looking at the mean times it is apparent that the wearable condition (condition one) performed significantly faster in answering the questions than the other conditions.

An effect of condition on 'Time between Questions' was also revealed [$\chi^2 = 6.11$; df = 2; $p<0.05$]. Again by looking at the means in Figure 36 it can be seen that the time between questions is much greater for condition one: Wearable, and condition three: World (walking around), than for the condition two: Internet.

The difference between the conditions in terms of total task completion time was not shown to be significant although the participants in condition one can be seen to have completed the task in the shortest amount of time (see Figure 36).

6.3.2 Effect of condition on accuracy of response

Figure 37 compares the mean performance on question answering in terms of percentage of questions answered correctly.

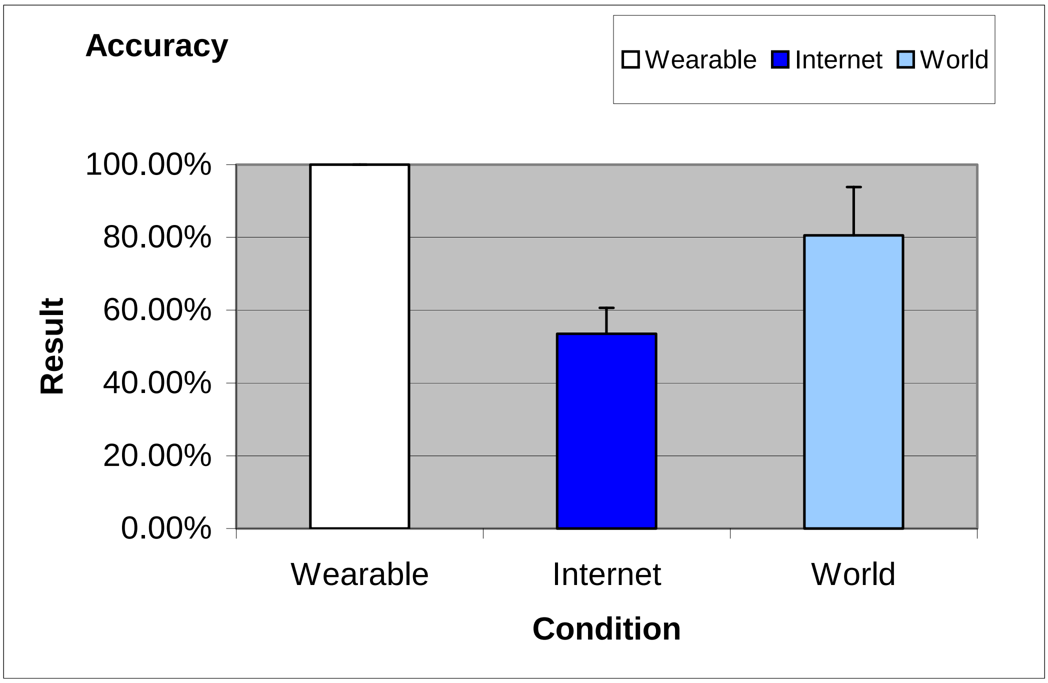


Figure 37- Chart shows the accuracy results for each condition

A Kruskal-Wallis test indicated a main effect of condition on performance, as the conditions do not perform equally well. [$\chi^2 = 14.853$; df = 2; $p < 0.001$]. Inspection of Figure 37 suggests that while the condition two: Internet, and condition three: World, performed at similar levels, the wearable condition exhibited superior performance.

Having determined an effect of condition on time and accuracy, an analysis of the information sources used by the participants has been carried out in an attempt to explain this difference

6.3.3 Use of information sources

It is interesting to consider the information sources that the participants used to answer the questions and answered the questions correctly. In conditions two and three the participants had no choice in the information source. However in the wearable condition where they had a choice of environmental or Internet information there is an interesting trend in the source they chose for any given question. Figure 38 shows for each question the number times the question was correctly answered in each condition. For the wearable condition, the number of correctly answered questions is split into the number of correctly answered questions using each source (either environmental or virtual). For these graphs the information source has only been noted if the user found the correct answer to the question. If the answer was not correct the information source was set to 'Answer not found' and not displayed.

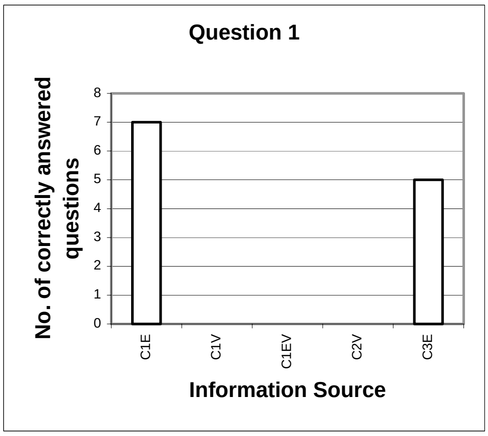
Key for Figure 38:

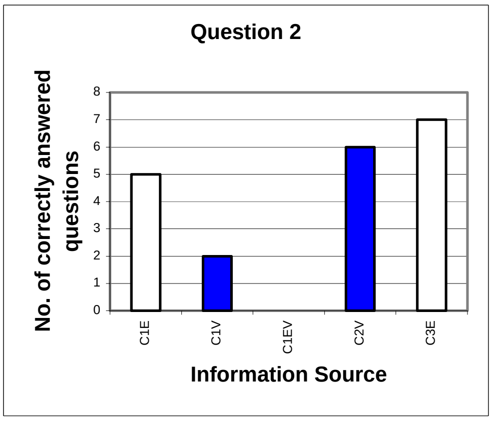
Condition **Info. Source**	**1**	**2**	**3**
Environmental	C1E		C3E
Virtual	C1V	C2V	
Environmental & Virtual	C1EV		

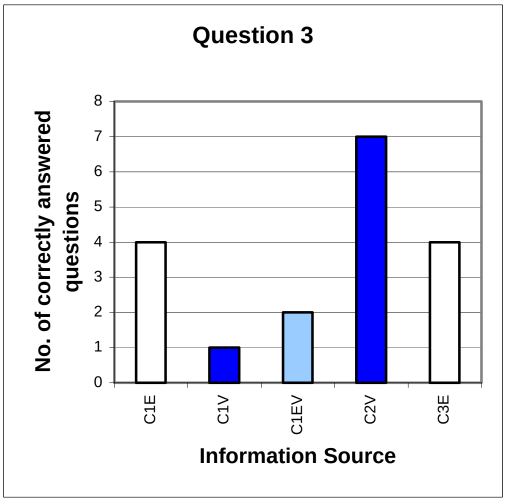
☐ Environmental source

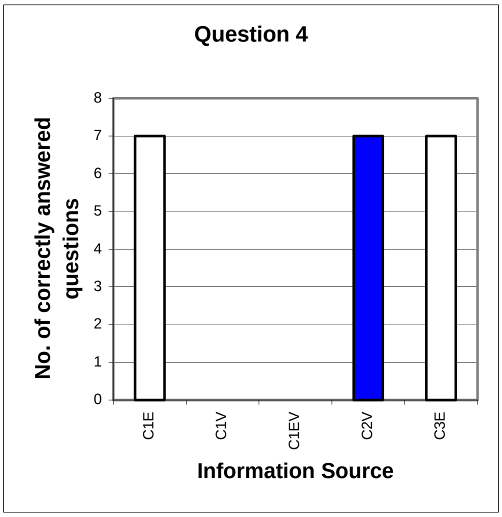
■ Virtual Source

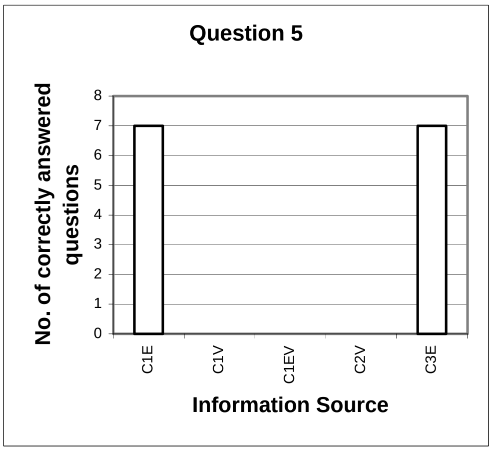
▨ Mixture of Environmental and Virtual Sources

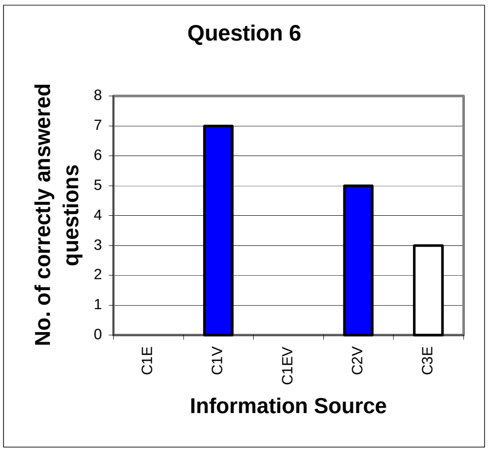

Question 1
No. of correctly answered questions
0
1
2
3
4
5
6
7
8
C1E
C1V
C1EV
C2V
C3E
Information Source


Question 2
No. of correctly answered questions
0
1
2
3
4
5
6
7
8
C1E
C1V
C1EV
C2V
C3E
Information Source


Question 3
No. of correctly answered questions
0
1
2
3
4
5
6
7
8
C1E
C1V
C1EV
C2V
C3E
Information Source


Question 4
No. of correctly answered questions
0
1
2
3
4
5
6
7
8
C1E
C1V
C1EV
C2V
C3E
Information Source


Question 5
No. of correctly answered questions
0
1
2
3
4
5
6
7
8
C1E
C1V
C1EV
C2V
C3E
Information Source


Question 6
No. of correctly answered questions
0
1
2
3
4
5
6
7
8
C1E
C1V
C1EV
C2V
C3E
Information Source

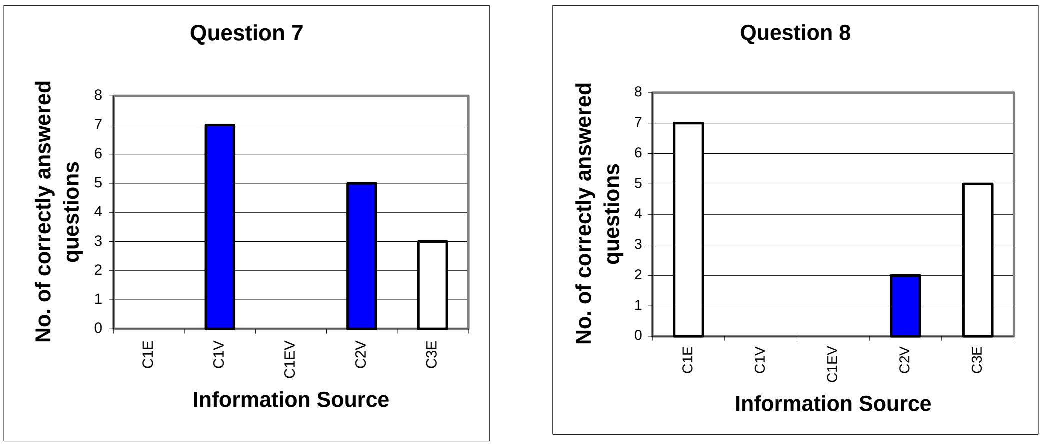


Figure 38 – Simplified bar graphs showing the information source used by each condition for each question, excluding wrong or no answer counts

6.3.4 Comfort results

Figure 39 shows the CRS results. The results from this experiment are compared against others carried out by Knight et al (in press). The χ^3 compares favourably to the other devices tested.

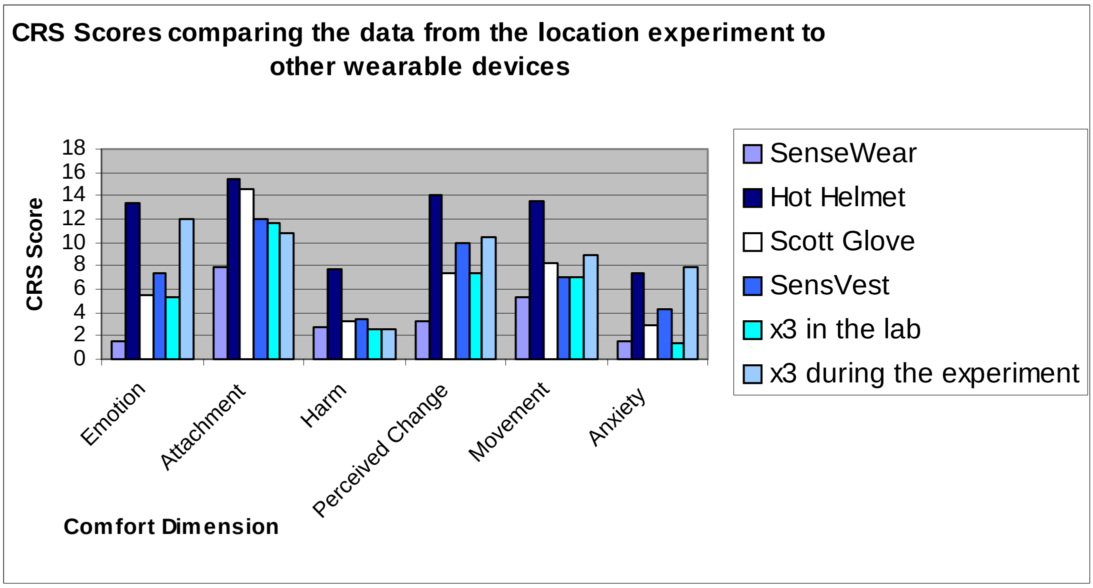


Figure 39 - The CRS results for the participants in condition.

From the graph it can be seen that participants did not feel the χ^3 harmed them. They felt embarrassed when wearing it, they felt some awareness of how the device was attached to them, some perception of a change to their activity, slightly anxious and that it impeded mobility slightly.

6.4 Discussion and Conclusions

6.4.1 Effect of condition

Performance has been considered across the three conditions in terms of time and accuracy. The wearable condition was most successful in terms of minimising time taken to answer questions, complete the task and in attaining the highest scores. The Internet condition performed worst. It is suggested that the wearable condition out performed the other two conditions because it enabled participants to choose the source of information they used to answer the questions and presented the correct information to them at the correct time and location.

- In this experiment participants in the wearable condition significantly out performed the participants in the other conditions in both time and accuracy.
- It was hypothesised that the wearable condition performed better than the Internet and world condition because the user had the choice of environmental and virtual information in the right place at the right time. This allows participants to identify the correct answer quickly. Thus saving time and identifying the. This hypothesis was supported by the experiment results.
- In terms of the overall research this experiment shows that location based context aware systems can improve the performance, in terms of minimising time taken and increasing the accuracy of the results of the users in the given tasks thus far.

6.4.1.1 Time

In terms of task completion time, it has been shown that the wearable condition took least total time to complete the task and to answer each question. This can be explained by the participants being presented with contextual information. The provision of information specific to the participants' Location reduced the amount of time spent searching the web for, ‘just-in-time’, and ‘just-in-location’ information. The wearable condition, in comparison to the world condition where the environment information is obviously location based, the environmental information is supplemented by the virtual information, allowing the user to answer the questions faster when the virtual source was a more suitable information source for answering the question.

The mean time taken between questions (or physically the time taken walking between buildings) was greater for the wearable and walking around conditions, where walking was necessary, than for the Internet condition where the participants has only to sit at a computer. What is interesting (and against the expectations) is that these times are comparable for the Wearable and World condition. This was taken to imply that the wearable computer did not significantly impede performance. This is further supported by the results of the CRS, where the movement measurement is quite low. The responses suggest that the participants were not physically restricted by the weight or size of the system, suggesting it complies with a necessary requirement for a wearable computer system.

6.4.1.2 Accuracy

In terms of answering questions, the mean number answered correctly was greater for the Wearable and World condition than the Internet condition.

Secondly, it is proposed that the participants’ ability to answer each question was dependent on the source of data available to the user. In other words there is a relationship between the source of the information, whether it is environmental or virtual, and the accuracy and speed of response for each of the specific questions. Certain questions were more easily answered based on the source of the information available. This is indicated by the results, as it is clear that the participants in the Internet and World conditions answered different questions correctly. It is further supported by the link to the choice of information source selected by the Wearable condition; the participants in the Wearable condition consistently chose the most appropriate source, that being the one that had proved successful by either the Internet or World condition.

Participants in the World condition (condition three) scored higher than expected because they made use of ‘other’ information sources in the real world. For example, one of the questions related to degree programmes: participants in this condition all went into the relevant undergraduate office to ask the secretary.

6.4.2 Use of information sources

The graphs in Figure 38 suggest that there is a direct relationship between the source of information (whether it is environmental or virtual) and the accuracy and speed of response for each of the specific questions. Certain questions were answered therefore more easily based on the source of the information available to them, although all questions were answerable in all conditions, Wearable, Internet, and World. This is shown by the participants in the Internet, and World conditions consistently answering different questions correctly. It is further supported by the results of the participants in the wearable condition. When the participants in the Internet and World conditions failed to answer a question effectively (i.e. several of the participants did not find the answer correctly using the given source) this was reflected by the choice of information source by the participants in the Wearable condition for that specific question. They successfully rejected any source that had failed and hence maintained greater accuracy and speed of response.

This pattern is demonstrated in all but one of the graphs in Figure 38. It can be seen that the highest number of participants from either the Internet or the World conditions is matched by the same colour for the number of participants in the wearable condition, i.e. the two highest columns have the same colour. The same information source has been used to answer the questions correctly.

This is clearly illustrated by the graphs, Question 7- Figure 38. In the Internet condition the number of participants who answered the question and noted the source successfully used the Virtual source (the only one available to them). There were five participants who fit this situation, shown by the blue or black (if you are viewing in back and white) bar.

In the World condition, all of participants who answered the question and noted the source successfully used the Environment source (the only one available to them). There were three participants who fit this situation, shown by the white bar.

As expected the highest number of participants using one source (either Virtual or Environment as they had a choice) in the wearable condition used the Virtual source (the highest of the other two conditions). One possible explanation might be that participants were able to identify the source that would most adequately provide the necessary information to answer the questions. Based on time as a good measure of perceived ease, it can be seen that on average the participants in the Wearable condition accurately chose the fastest / most appropriate method by which to get the information. Providing the right information source in the right location has been demonstrated as beneficial to the user.

6.4.3 Comfort results

The comfort results suggest that the wearable could be designed to be more comfortable for the user; impeding their movement less and making them feel less embarrassed about wearing the wearable computer. The results show that the χ^3 was rated more comfortable when worn in the lab. This is probably due to the users not moving as much with the system in the lab, and the lack of other people that could have increased their embarrassment (covered in the emotion dimension). The results also suggest that the comfort of the χ^3, in both the lab and in the field, during this experiment are similarly comfortable to the other devices rated in Knight et al's (in press) study.

6.4.4 Benefits of experimental design

In this experiment, performance times were considered at a number of levels. It is important to note that if the experiment had only looked at total time to complete the task, no useful results would be found. This is often the case in comparative evaluation of products and technologies; differences lie in the process rather than the outcome of task performance. The fact that times were considered for each individual component of the task has been useful in ascertaining the full implications of using the χ^3.

6.4.5 Specific problems

Some participants found a problem with the GPS, particularly when near a specific building. This can be accounted for by two factors. Firstly if a user is standing near the edge of the active area (the area in which Version L will react and load the relevant web page) around each building, the GPS has a certain drift factor, this can then virtually move a user in and out of the active area, thus loading and unloading the web page, and so causing confusion. Secondly, if the area the around the building has a number of high buildings, as the participants walked though small gaps between the building, the GPS view of satellites may have been affected by the buildings thus confusing the system.

Participants also complained about the Head Mounted Display, feeling that the resolution and size of the display made it almost impossible to read text from a page without zooming and scrolling around the screen for the relevant piece of text. It was not very easy to operate and many participants found it frustrating. This problem can only really be solved by a new display. Displays are now available that produce 800 by 600 resolution which would be a great improvement and are used in later experiments. Despite this problem, their performance was not felt to be unduly impaired.

6.5 Chapter Summary

This chapter has described an experiment aimed at testing if a location-based contextual system is useful for information retrieval tasks. The system described has been compared to two existing systems, a user using Internet-ready computer and a user walking around their environment. For information retrieval the location-based contextual system has been shown to perform favourably in terms of reduced task time and in increased accuracy of results.

A wearable computer system, including custom built software and hardware, has been developed and tested in the experiment and has been shown to work as a wearable device and not impede the participants' mobility. The system could in the future be improved by adding a more accurate GPS system and a higher specification HMD that displays text at a greater resolution allowing easier readability.

It is concluded that using the wearable computer not only reduced the mean question-answering time but also enabled the participants to answer all of the questions correctly. Those using this system performed more effectively and efficiently than the two control conditions, Internet, and World.

It has been shown that a location-based contextual system is useful for information retrieval tasks.

Adding more levels of context, and finding more information about the participants' context by adding more sensors to the system, may improve performance further in similar tasks. Using information from the photograph diary study to help chose the next relevant sensor, more sensors will now be added to the system. The next chapter describes an experiment to assess the performance of a new more contextually aware system and ascertain whether it will improve performance further.

Chapter 7 Posture and Movement

The previous chapter indicated that location-based contextual systems are effective in improving a user's performance (in terms of accuracy and speed) of information retrieval tasks. To improve the system performance further it is suggested that more context awareness is given by enabling the system to sense more components of context. After revisiting the photograph diary study in Chapter 3**,** a contextual system has been developed to incorporate sensing of a user's Posture and Movement and Location. Subsequent experiments have been carried out to test if the new system can further improve the performance of the user for a different information retrieval task.

7.1 Introduction

The experiments described in this section follow on from the promising results of the previous Location experiment. Between the Location experiment and this experiment, Version LBp of the software, as described in section 4.3, was created and the hardware progressed to the χ^{3+}. Figure 40 shows the stage of the design cycle.

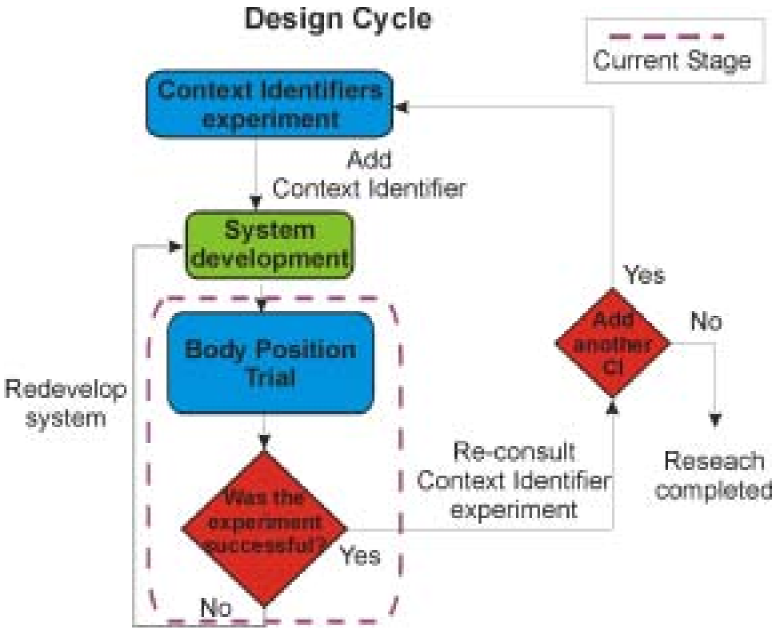


Figure 40 - Design cycle, highlighting the Posture and Movement experiment

After choosing another Context Identifier, Posture and Movement, the system has been redeveloped. The Location experiment (Chapter 6) indicated that the users performance improved in terms of accuracy and speed by employing a location-based contextual system. Given that limited context awareness has improved a user's performance, it is probable that more context awareness would improve the performance further. It was therefore decided the next step would be to add more context awareness to the system. From the photograph diary study (Table 7) Posture and Movement is the most important Context Identifier, therefore the new system incorporates the user's Posture and Movement. Section 4.3 describes the development of the version LBp software that is used in this system. This software was installed on the χ^{3+} (described in section 5.3.2). Figure 41 gives an outline of how the system is designed to work, showing that the information displayed is based on the Location, and then changes detail based on the user's Posture and Movement. The user's location is tracked using a GPS; as the user gets to selected buildings, different web pages are shown. If the user is walking, then an audio announcement is given telling the user which building they are walking near (the screen is blank so that the user does not need to look at it.) If the user stands still, a limited detail web page is displayed, giving brief details of information about the user's current building, and an audio announcement is also made. Finally if the user decides to sit down, the full web page for the building is shown, giving the user the maximum detail of information.

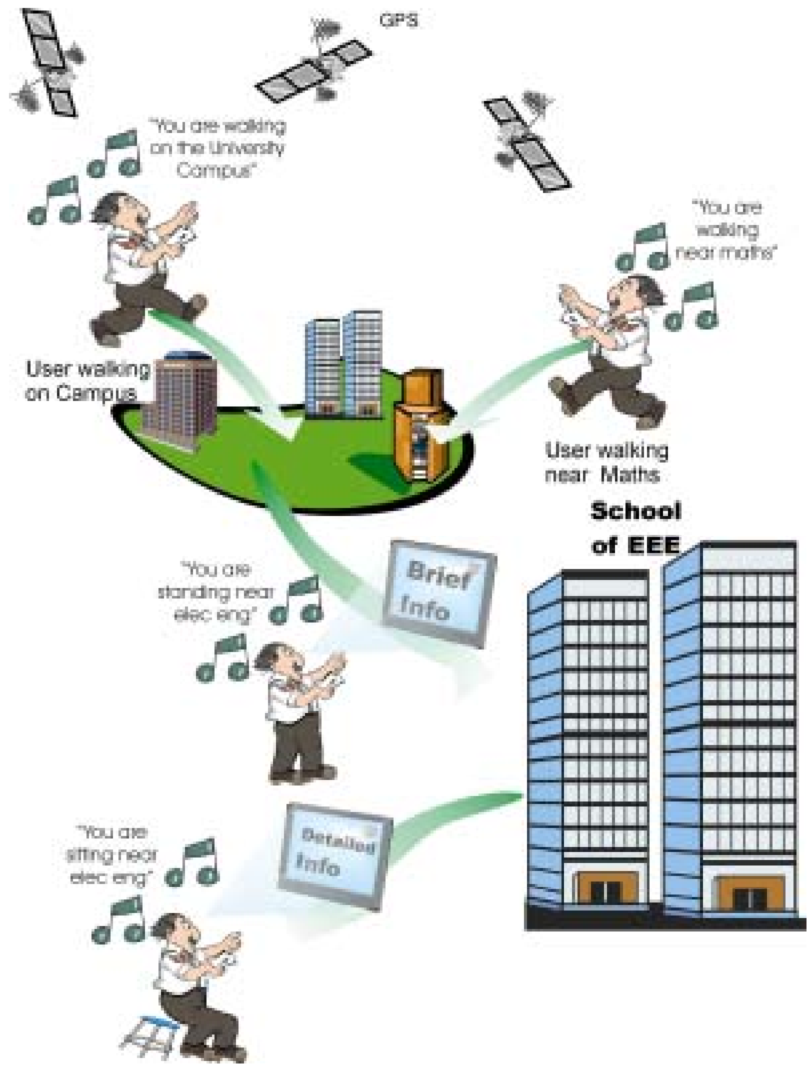


Figure 41 - General overview of the system used in the Posture and Movement experiment

The aim of the experiment was to determine whether a level-two[1] context-aware wearable computer would be useful for information retrieval tasks. It is hypothesised that adding a second level of context will perform better (faster and more accurately) than the level-one used in the Location experiment in Chapter 6.

The Posture and Movement experiment compares the use of a level-one location-based contextual system to a level-two Location and Posture and Movement-based contextual system. Similarly to the Location experiment, the task for the experiment was retrieving information and answering questions. Participants were asked to

---

[1] Level-one defines that a system can sense one Context Identifier. Level-two defines that a system can sense two Context Identifiers, etc.

complete the task in one of two conditions, condition one using the Location based system and condition two using both the Location and Posture and Movement based system. Both systems present the user with virtual (web based) information from which the participants can answer the given questions.

It is expected that adding a second level of context will improve user performance for a number of reasons. Interaction with a wearable computer on the move is difficult. There is unlikely to be a keyboard for entering Internet searches, therefore large numbers of thumb mouse clicks maybe needed. This results in more time being spent looking at pages that often have no relevance, therefore increasing the time searching and downloading information. These are things that should be avoided on mobile devices. Consider the example of using a WAP phone to find information about local cinema times. Searching using a WAP phone is difficult due to the limited input methods. Adding location based services, as has happened with GPRS, reduces the amount of searching, and thus interaction needed. The options of information available to the user are reduced and those believed to be relevant are presented. If this is done correctly the time spent by the user looking for the required cinema time is reduced. If the amount of interaction needed to complete the tasks can be reduced, the speed of the task completion can be increased. In addition, if participants find answers faster they are less likely to give up thereby the accuracy could increase. When participants do not find the information required within a given threshold time, they are likely to give up.

Presenting the information to the user in an appropriate way for their given context is expected to aid the user in finding the information more easily, hence making it more efficient. Giving a user a full page of information, in small print and in great detail while, walking is useless. No user will be able to comprehend it. However by giving, for example, an audio announcement with limited detail the user can easily attend to and comprehend it, making the information more useful. By changing the level of detail and the presentation method of the information depending on the context (in this case the participants' Posture and Movement), the information can be made more useful so improving task proficiency.

7.1.1 Hypothesis

It was hypothesised that the experiment would

- Show that a more contextually aware system increases the speed at which participants complete the task.
- Show that a more contextually aware system increases the accuracy of task completion.

7.2 Method

7.2.1 Participants

Ten electronic engineering undergraduate students participated in the experiment (9 male and 1 female) with a mean age of 19 years 1 month, (range: 18 to 22). None of the participants in this study took part in any of the previous studies.

7.2.2 Metrics

- Performance assessment was based on time (efficiency) and accuracy (effectiveness).
- The time taken to answer each question (in minutes) measured as the time taken from the user arriving at the location that the question relates to, to the time when the user has answered the question.
- The total task time, the answers and the information source were all recorded by the observer.
- The system recorded the title of web pages viewed by the user.

7.2.3 Procedure

The participants were randomly allocated to one of two conditions and asked to complete a task. The experimental task involved answering questions about buildings on the campus of The University of Birmingham. The condition denoted the type of information source to be used to answer all of the questions:

Condition One: (Location Only) Wearable Computer with level-one context
The user wore the χ3+ with the Version LBp Software installed, with the GPS attached but without the accelerometer turned on. Therefore Location only was sensed.

Condition Two: (Location and Posture and movement) Wearable Computer with level-two context The user wore the χ3+ with the Version LBp Software installed with the accelerometer and GPS attached. Therefore Location and Posture and movement were sensed.

A set of questions about buildings around the university campus was devised, comprising two questions for each building, six questions in total (See Appendix C). Each user was given a brief explanation of the task and an introduction to the equipment used. As in the Location experiment (Chapter 6) training was deliberately limited, as we wanted to see how people would cope with the novelty of the wearable computer. The questions were given to participants on a sheet of paper, and any queries regarding task or questions addressed. Each participant was assigned an observer who was given a record sheet. Each group was then told that they had thirty minutes to complete the task (although they were not stopped if they went over this time).

The time taken to answer each set of questions, taken to represent the time spent looking for information, was recorded on the record sheet by the observer. This allowed comparison to be made of the time taken to complete each individual question. The total time to complete the task and the answers to the questions were also recorded. In Chapter 6 the Location experiment, it was suggested that the source of information the participants used to answer each question was related to speed and accuracy of response. In this experiment, the participants were expected to answer the question using only the virtual source through the wearable computer. However some questions could have been answered from environmental sources such as walking into a building and reading notice boards. Therefore again the observers were asked to record whether they answered the questions making use of virtual or environmental information, and any problems they encountered. The system automatically recorded the web pages to which each participant, in all conditions, referred to find the answers, and the route to that page they took. Thus the number of pages that each participant went through to find the answer was recorded automatically. For example, a participant might have to go from the sports centre home page, to the booking squash courts page, to find what number to ring to book a squash court, this would be two pages.

When the participants had completed the tasks and returned to the starting point, all conditions were asked to fill in two CRS (Knight et al, 2002 C), firstly relating to the wearable computer and secondly relating to the head up display. At the end of the experiment, the answers were checked and the participants debriefed. A full set of results was made available to participants the week after the experiment.

7.3 Results

The results are divided into four parts. The first considers the effect of condition on performance time, and the second considers the effect of condition on the participants' ability to answer the questions. The third and fourth sections refer to the number of links/pages taken to get to an answer and the CRS results.

7.3.1 Effect of condition on time

Table 15 – Mean time taken to answer questions and to complete the task (Non download adjusted)

Time (Minutes: Seconds)		
	Condition One: Location Only	Condition Two: Location and Body
Mean time answering questions	20:12	08:00
Standard deviation	01:47	02:33
Mean task completion Time	28:00	14:24
Standard deviation task completion time	02:21	01:31

The results indicate the mean time taken to answer the questions decreased from 20:12 in condition one (Location Only) to 8:00 in condition two (Location and Posture and movement).

7.3.1.1 Download time adjusting

It was felt that a large amount of this time difference was due to the amount of information downloaded (more in condition one) and not due to the actual performance of the user or of the contextual feature of the system. While at present the amount of information downloaded, and the way it is downloaded, is of crucial significance for current mobile devices, it was felt that this will become less of a factor in the future and therefore it was important to separate the downloading from the change in user performance.

Therefore five participants were asked to complete an altered condition one (condition one-a) on a computer in the lab using a high-speed line with much less the download time. They were made to use the same thumb mouse and headset to simulate condition one. The mean time to answer the questions taken by the condition one-a was then subtracted from the mean time taken to answer the questions in condition one giving an estimate of the mean time spent downloading information (12 minutes, 13 seconds). The mean download time was then divided by the number of questions giving a mean download time per question of two minutes. The mean time answering questions and the mean task completion time were then adjusted to take account of the download time. For both condition one and condition two, the mean download times per question was multiplied by the number of questions that required information to be downloaded. In condition one all questions required downloading of information. In condition two less (depending on the way the participants answered the questions) questions required downloading since some of the information was stored on the hard drive. In most cases only two or three questions required downloading. The time taken downloading was subtracted from the time taken answering questions and mean task completion time. The means across participants were then recalculated and are shown in Figure 42. Thus this is believed to be a more accurate measure of performance.

Both the mean time answering questions and the mean task completion time were greater for the Location only condition than the Location and, Posture and Movement condition. This is reflected in the charts in Figure 42 and Figure 43. Kruskal-Wallis tests were carried out to determine whether the results produced by the two conditions were significantly different. A main effect of condition was found on mean answering time [$\chi^2 = 3.962$; df = 1; p <0.047] and on mean task completion time [$\chi^2 = 6.902$; df = 1; p <0.009].

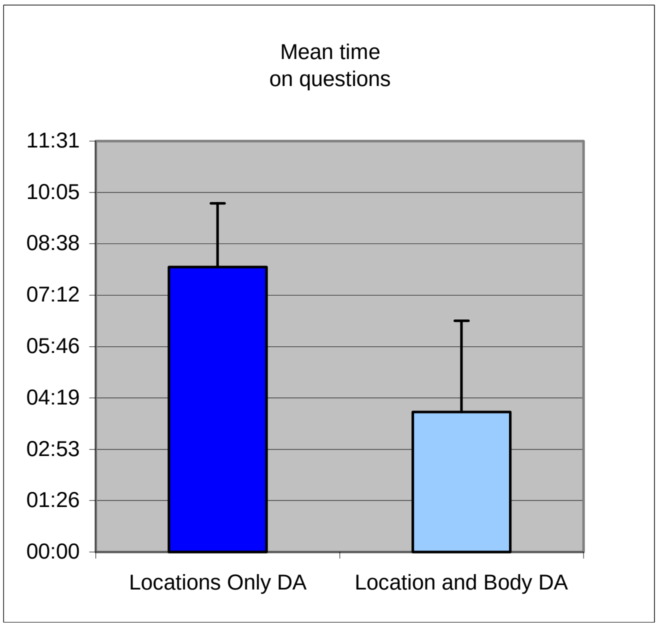


Figure 42 - Mean time answering questions (DA- Download Adjusted)

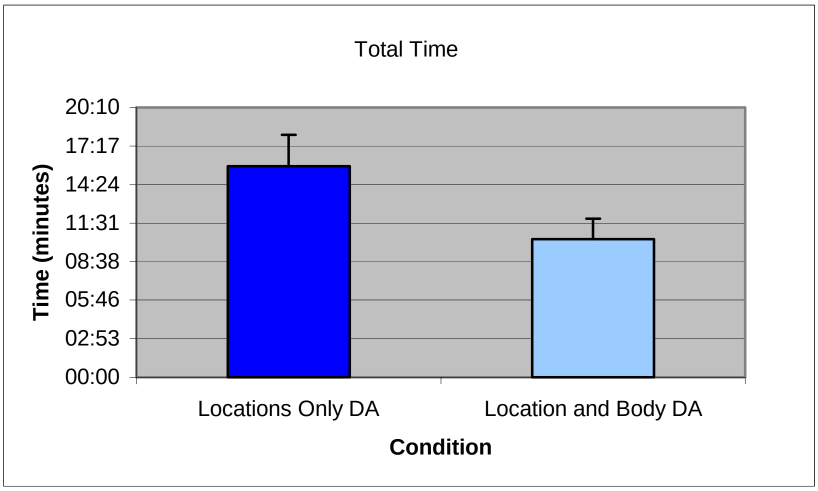


Figure 43 - Mean task completion time (DA- Download Adjusted)

7.3.2 Effect of condition on ability to answer questions

The ability of each condition to answer the questions was examined. The mean participant response was calculated for each condition. Figure 44 indicates the users in the Location and Posture and Movement condition performed 7.5% more accurately than the Location only condition. This difference was found to be not significant.

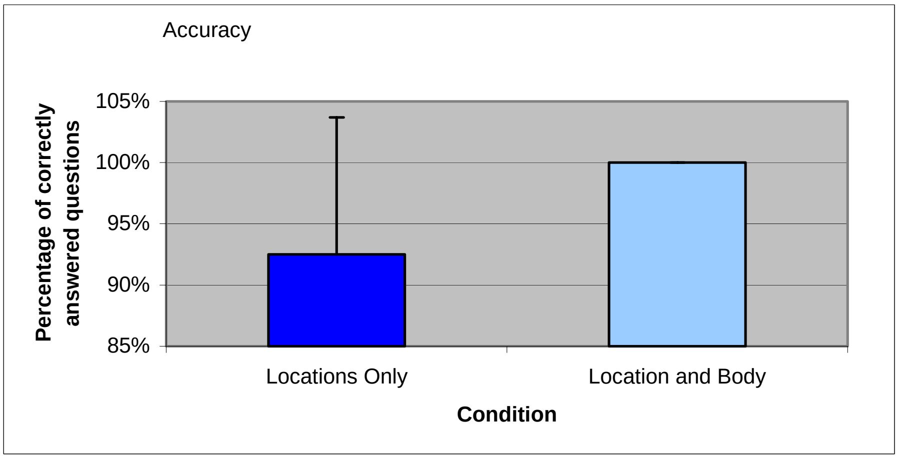


Figure 44 - Accuracy Results

7.3.3 Number of Links to find answer

The mean number of pages searched to find the answer was recorded. Table 16 shows the mean number of pages used in each condition.

The results in Table 16 suggest that less links were required to get to the answer in the Location and, Posture and Movement condition than the Location only condition.

Table 16 - Number of pages to get the used answer

	Mean number of pages required to get to the given answer
Condition one: Location only	2.9
Condition two: Location and, Posture and Movement	1.4

7.3.4 Comfort Results

From the comfort rating scales were used to consider the users' perception of comfort while using the wearable computer.

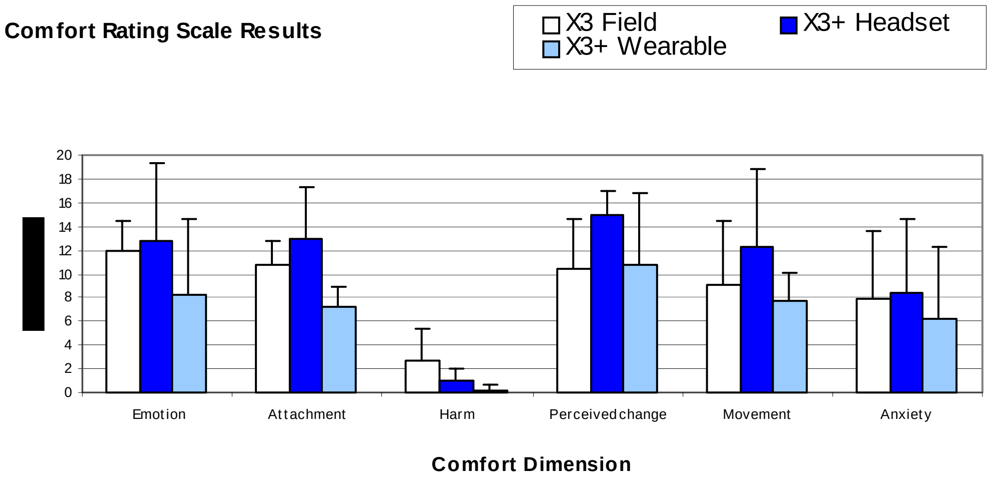


Figure 45 - Comfort Rating Scale results comparing the results from the Location experiment in Chapter 6 where users used the χ^3 (shown by the white bar) and the wearable computer and headset assessment during this experiment

If the white and light blue (or light grey) bars are compared, it can be seen that users assess that the comfort of the wearable computer design has been improved though the development of the χ^{3+} (in comparison with the χ^3 used in the previous Location experiment). A direct comparison between the comfort of the χ^3 and the χ^{3+} should not be made since the tasks carried out in each experiment were not identical. The tasks were similar and thus the results suggest a decreasing trend. The new headset used in this experiment is seen in the dark blue or black column and has caused some discomfort to the users.

7.4 Discussion and Conclusions

7.4.1 Effect of condition

The results suggest that by adding a second level of context, so that the system now measures Location and Posture and Movement, it is possible to improve further the performance of a user completing the given information retrieval task. It is proposed that this improvement is due to the reduction in the amount of searching for the required information as contextual features support the user by automating some of the searching. The participants in the experiment found the information more easily and faster, due to the presentation detail/method being more appropriate for the participants' context.

7.4.2 Time and efficiency

The mean time taken to answer the questions and the mean total time to complete the task has been significantly reduced by the addition of a second context level. It is proposed that in the main this is because the context features essentially doing some of the searching for the user. The user is, in effect, using their body as a mouse to navigate though the information to find the correct information by changing their Location and Posture and Movement. From the number of pages required to find the answer, we can see that the required number for the participants in condition two is less. If the participants needed to go though less pages then they essentially reduced the time that they were looking for the answer. Thus by the system using contextual features to help with the searching process, the time taken answering questions was reduced.

7.4.3 Ability to answer questions

No significant difference was found between the two conditions.

7.4.4 Comfort

Once again the effect of wearing the computer was assessed through the use of a comfort rating scale (see Knight et al 2002 C). The responses suggest that the participants were not physically restricted by the weight or size of the system, thus confirming the acceptable size and weight of the system and that the χ^{3+} is an improvement on the χ^{3} in all aspects but the HMD.

7.4.5 Discussion Summary

In summary it has been found that:

- The Location and, Posture and Movement condition (the level-two context aware system, sensing both Posture and Movement, and Location) significantly outperformed the Location-only condition in time. It is believed that this improvement can be accounted for by the level-two system essentially doing some of the searching for the user, or on the participants' behalf. The user reaches the correct information quickly, as the system removes information that is not applicable to the participants' context.
- The data also suggests that using a context aware system that displays contextual information can improve a participants' performance.
- In addition using a second level of context (or adding another Context Identifier, Posture and Movement) improved the system over the previous version that only sensed Location.

7.4.6 Specific problems

Fewer problems with the system materialised compared with Location experiment. Since the HMD was not translucent and even though it could be pushed up and down, some people found it hard to walk at a normal pace. If is difficult to tell if this impaired performance since it was common to both conditions. However from observations made by the participants, it would undoubtedly be easier to walk if the HMD was translucent. In the Location experiment in the previous chapter, users had found the text hard to read and the information difficult to interact with. However even though people still had problems with the HMD, the problems concerned comfort more than the detail or difficultly of interaction with the information. This could suggest that the addition of the second level of context and the way, in which the posture of the user has been used to control the detail of the information, has been a success. The second problem was the slow download speed of the mobile phone. This has been compensated for by the download adjustment performed in section 7.3.1.1 and therefore should not influence the results. However in the future the campus, and later the wider world, may be covered by high-speed wireless coverage, thus removing this problem altogether. Again GPS drift problems were experienced. These problems were avoided by selecting buildings more out in the open than others. In any case, the buildings were the same across both conditions therefore the GPS drift effects both conditions equally.

7.5 Chapter Summary

This chapter describes the second experiment using a more advanced contextual system in this thesis. A wearable computer system capable of measuring the participants Location, and Posture and Movement has been developed and been shown to work and be useful for the information retrieval tasks in this experiment. The experiment aimed, and showed, that adding a second level of context, improved the performance of participants over the simple location-based level-one contextual system.

Providing more different levels of detail of information resulted in the time taken to complete the given tasks being reduced significantly when wearing a level two context aware system.

The comfort of the system, measured using CRS (Knight et al C), has improved from the Location experiment (Chapter 6). In all fields of the CRS, the χ^{3+} wearable computer has decreased the unwanted effects. However the headset continues to cause problems in all aspects of the user comfort in particular the emotional aspects, how the user feels when other people sees them wearing it.

The next aim is to develop a system that is capable of measuring more contextual features and using the information ascertained from the participants context to aid them in a number of given everyday activities. The photograph diary study will again be consulted to select the next appropriate Context Identifiers to add to the system. The measures discussed in this chapter will then be used to assess how usable the users believe the system is.

Chapter 8 Complete Wearable Computer System

This chapter describes the complete wearable computer system (CWCS) and an experiment carried out using it. Continuing the design cycle, more Context Identifiers have been added to the wearable computer system. The system now incorporates measurement of Context Identifiers Location, Posture and Movement, Object and Time. Version LBpOT of the software, described in section 4.4, is installed on the wearable computer. An experiment is described that demonstrates the CWCS in use. Participants are asked to carry out a number of everyday tasks, selected from those tasks collated in the photograph diary study Chapter 3. Their performance in terms of time and workload are recorded. In addition, an automated photograph record of their progress through the experiment is created and an assessment of the usability of the system is made. This chapter addresses aim six, exploring the application of a context aware system to everyday tasks.

8.1 Introduction

In Chapter 7, the Posture and Movement experiment was described and discussed. The system with level two context awareness was shown to out perform the level one system. Following the design cycle of the research, see Figure 46 the photograph diary study was again consulted to find the next appropriate Context Identifiers that could be added to the system. In Figure 46 the current stage of development and the Complete Wearable Computer System (CWCS) experiment is highlighted as the work described in this chapter.

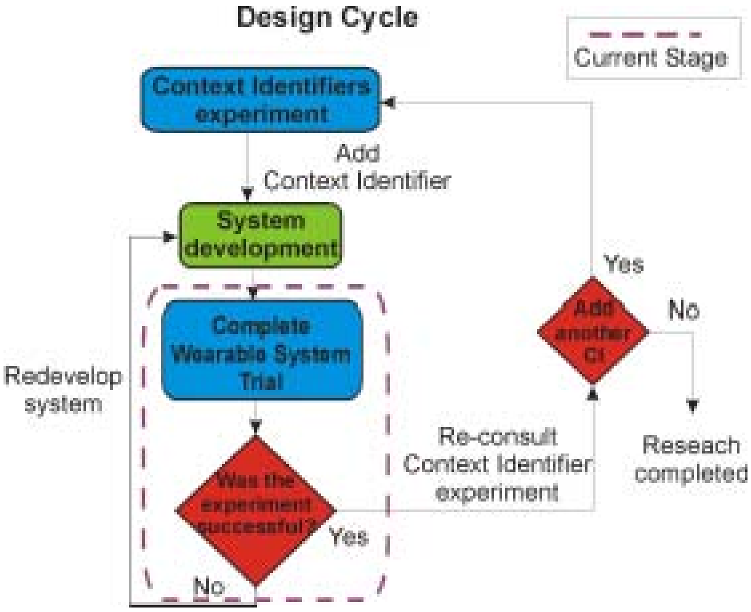


Figure 46 - Thesis design cycle, highlighting the current stage - CWCS experiment

The system used in the previous experiment, described in section 4.3, measured Location and Posture and Movement. From Table 7 in section 3.2.3, it can be seen that these are the top two most important Context Identifiers and account for forty percent of the components that make up context. The next two Context Identifiers are Object and People, which could be sensed in similar ways. The fifth most important Context Identifier is Time.

Therefore the CWCS has been developed to include the top five most important Context Identifiers that account for almost seventy percent of the components of context. The Object and Time were chosen to be the next Context Identifiers added to the system, to supplement Posture and Movement, and Location. People has been left out since if you can tag an object then you can also tag a person with similar technology. Therefore, from a technological point of view, people could be treated as objects.

The CWCS uses version LBpOT of the software (section 4.4). Like the pervious version, LBpOT is capable of ascertaining the user Location using a GPS; the Posture and Movement using an accelerometer mounted on the leg; the Object the user is interacting with using IR tags on specified objects, and the Time using the system time of the wearable computer. Figure 47 shows a general outline of how the system is designed to work.

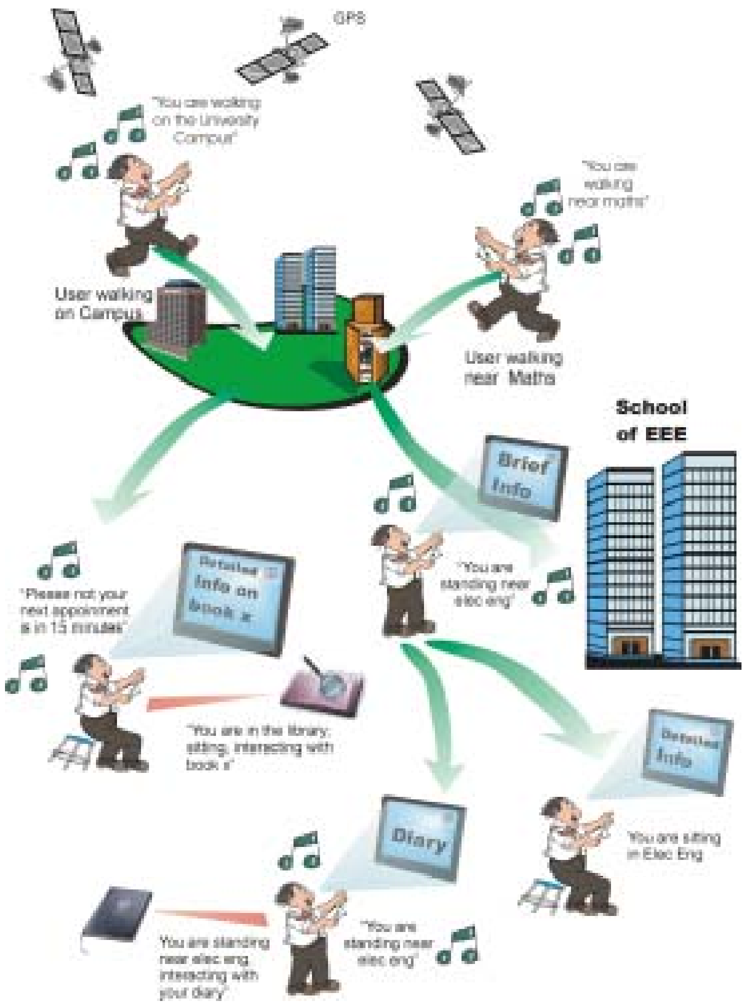


Figure 47 - General overview of system LBpOT used in Experiment 3

A User Case Scenario

Chris is sitting writing a paper in his office when he realises he need some information from a book in the main library. Chris notes down the book he needs and the page reference he has found for a quote. It is 4:45 and Chris leaves his office to go to the library to get a book and find some information from it, he has a train to catch at 5:10. As Chris walks in the vicinity of the library he is reminded by audio that the library closes at 5. Chris stands still just inside the library, when a map is displayed showing him the area he needs to go to find the required book. Chris can’t remember the name of the book or the library code, so he pulls his diary out and holds it in front of him. His notes are displayed on his head mounted display. Chris finds the book and sits down. The name and the book, the notes he previously made, and the page reference are displayed to aid him in finding the required section. Chris reads away happily. At five to five, Chris is reminded by audio that he needs to get to his train and the page of live train times is displayed so Chris can see if his train is delayed. Chris leaves the library and walks off to catch his train. Chris bumps into James on the way to the station and, as we know, James likes to talk. Chris gets delayed chatting. He reaches the platform as the train is pulling away. As usual the display boards at the station are not functioning. However the live departure boards are now displayed on his HMD. He sees there is a train in ten minutes time, which he catches in time to get home for dinner.

The Location can be recognised as one of eight known locations on the university campus or an unknown location. The accelerometer mounted on the leg is used to tell if the user is sitting, standing or walking. Five objects for use in the experiment are tagged with IR tags. The system could have up to 16 objects in the database at any one time. Users get shown different information depending on their current contexts. Each piece of content available has a tag for Location, Posture and Movement and Object. The CWCS searches though the content tags looking for some content whose tags match as many as possible of the current Context Identifiers correctly. Information associated with an object overrules the automated system for searching for context, for example, if the user interacts with their diary, then their To-Do and Task-List is displayed.

One Context Identifier significant by its absence in the photograph diary study, Chapter 3, was any indication of historical context, i.e. users previous contexts. This is obviously very important in building context models. In preparation for building context models that use past and present context states, the CWCS creates an automated record of all the contexts. In the future this could be used to build up statistical models of a user’s contexts and help in the prediction of their future contexts given their current and past contexts. The system also automatically recorded the content displayed to the user.

Experiment three, described in this chapter, aims to test the CWCS. The experiment compares participants completing a number of everyday tasks using conventional or typical methods and participants completing everyday tasks with the CWCS.

The participants were asked to complete a number of everyday tasks selected from those that were demonstrated during the photograph diary study (Chapter 3). The tasks were situated in different buildings around the university campus.

In the previous experiment measuring time and accuracy of task completion has assessed efficiency and effectiveness. Experiment three, in addition to these measures addresses user satisfaction by looking at Workload and the Usability of the software. The analysis compares the time taken to do each task, the total time taken doing the tasks, the workload experienced while doing the tasks and the software usability.

The participants' perception of usability of the system in tackling their tasks will be measured with the measures introduced in the previous chapter. The participants' workload is measured using the NASA TLX workload test (Hart and Staveland, 1988). In addition the usability of the version LBpOT software is assessed using the SUMI usability rating scale (Kirakowski, 1996).

8.1.1 Hypothesis

8.1.1.1 Workload

Since one of the measures in the experiment is time, and one of the aims of the CWCS is time reduction or at least a deduction in perceived temporal demand, then it was hypothesised that a difference in the temporal demand workload score will be seen between the two conditions.

If the CWCS does not perform favourably and the participants find it difficult to use then it is likely that greater frustration level and the effort ratings would be seen. Although the CWCS is a wearable device, it is still heavier and less comfortable than might be desired for everyday usage; therefore an increase in the physical effort might be seen in the wearable condition compared to the everyday condition.

Since the tasks are generally simple and not designed to be mentally challenging, then it is likely that low mental demand rating and a high performance rating will be recorded in both conditions.

In the case of this experiment, the tasks assessed are those near the beginning and end of the experiment. Since the participants could do the tasks in any order they please then each workload assessment may assess different tasks. It is hypothesised that participants using the CWCS subjective workload will decrease as the participants become more familiar with the system (thus the workload results later on in the experiment will be lower that those earlier) regardless of the order of task completion, but that some variation may been seen in the amount of reduction depending on the task order. For participants using typical everyday methods to complete the tasks, it is again hypothesised that the workload is likely to vary depending on the task order, but since the participants are using everyday skills that they are already familiar with, then a reduction over time is less likely.

A favourable outcome from the experiment would see an overall difference in the mean workload score between the two participant groups. Ideally a significant reduction in workload would be seen when using the CWCS, however given the limited training on the system it would seem likely that this will not be happen, however as the participants became more familiar with the system their performance would improve. However the time and expense to give the participants adequate training on the system is out of the realms of this experiment.

8.1.1.2 Software Usability

The SUMI questionnaire is to be used to measure the usability of the Version LBpTO software. The previous chapter reviewed an experiment showing that the SUMI scale worked as well for software on wearable computers as for software on desktop computers. “The mean for state-of-the-art commercial systems is set by SUMI at a score of 50 on Global and all other subscales” (Kirakowski, 1996). Therefore, ideally the participants in using the CWCS software would rate the system with a mean score of above 50, showing that the software is well designed and the participants have found it easy, functional, and helpful to use. However given that this is a prototype software system and it is being trialed on a wearable computer system with unfamiliar input and outputs devices, a lower score would not be unexpected.

One area in particular that may see low scores is the control aspects. The introduction of novel interaction devices and the proactive nature of the system may lead participants to feel they have less control over the system than if they were completing this tasks with different more familiar controls.

8.1.1.3 Time

The time taken to complete the tasks should decrease by using the CWCS. Two time metrics are being taken: firstly the total time to complete the experiment, and secondly the time taken to complete all the individual tasks, the times taken to complete each task added together. It was hypothesised that both the total time and the task time would decrease. The total time is likely to decrease simply because the task time decreases. The time taken to walk around campus between the different tasks (the total time minus the time taken doing the tasks at their location), is not likely to change when wearing the wearable computer, most people have an average walking pace. The task times should decrease because the system aids the participant in their task and makes it easier and faster to complete the task by providing the participants with the information they require in the context they require it. When the participant interacts with their diary the To-Do list and Task-List are shown. As discussed in section 4.4, the appointments and tasks at the current location are highlighted in red. This could allow participants to plan their non-time-dependent-task route in a more time efficient way. For example, they can easily see that three tasks are in the library; therefore they should do these at the same time, so they don’t walk from the library to the station and then realise that they need to go back to the library for the next task. Thus better planning of task route may save time.

8.1.1.4 Hypothesis Summary

1) A decrease in workload for participants using the CWCS compared to those using typical task methods.
2) A decrease in the time taken to complete the tasks when using the CWCS.
3) A reduction in workload over time for the participants using the CWCS.
4) A SUMI rating of the CWCS showing mean scores above 50.

8.2 Method

8.2.1 Participants

Ten people participated in the study (5 male, 5 female, mean age 28.8, StDev 5.7). None of the participants in this study took part in any of the previous studies.

8.2.2 Metrics

The following will be measured:

- Time (minutes).
- NASA TLX Workload score (score out of a possible 120, the lower the score the lower the workload, described in 2.7.2).
- SUMI Score (scoring system as described in 2.7.4.).
- Comfort rating scale to asses the comfort of the wearable computer.

8.2.3 Procedure

Two sets of participants were asked to become Secret Agents. Agent Ev-Bond and Cy-Bond. Each group was asked to complete a set of tasks. The tasks were taken from tasks recorded by participants in the photograph diary study, Section 3.2. The two conditions of the experiments denote the system used by the participants.

Condition one: Everyday system (thus agent Ev*eryday*-Bond) – participants competed the required tasks with the aid of any everyday system they chose e.g. a To-Do list on a piece of paper, or a To-Do list and calendar stored in Outlook etc.

Condition two: wearable computer system (agent Cy*ber*-Bond) – participants completed the tasks while wearing the CWCS, which aided them in their tasks and held their 'to-do' list and calendar.

Participants in the Everyday condition were emailed a Word document containing the list of five tasks, three meetings (with times) and the instructions for the experiment. Table 17 to Table 20 show the lists of meeting and tasks for each condition. They could plan their time in any way they pleased, using any methods that they would currently use. During the experiment they were required to record the order in which they did the tasks, the time taken at each task location and take a series of photographs that described the events that took place as they completed their tasks. While the tasks for each condition were the same, the instructions were presented differently. The Task-List in the everyday condition contained less information than that in Wearable condition. However as participant came into contact with required Objects, Locations, and Posture and Movements, additional information was presented to them in a just-in-time fashion, thus reducing the workload.

Participants in the wearable condition were given the CWCS and a diary with an IR tag. When the dairy was placed in front of the participant, the 'To-Do list and appointments were displayed on the HMD. The participants could decide to do the tasks in any order. As described in section 4.4, any appointments or tasks to be done at the participants current location were highlighted in red, and if the participant was at their current appointment it was highlighted in blue.

The mission for the participants was to complete the given tasks using the given system and collect the code words given at task completion. The code word was either given to the participant automatically by the CWCS in the wearable condition or in everyday condition the code words were given to the participant by the observer in each of the three meetings they attended. At the end of the experiment the participants were asked if they could fit all of the code words together into a sentence. A mark was awarded for a correct sentence. The code words were collected as an incentive to complete the tasks, not as a comparator to measure between the two conditions.

The tasks included in the experiment are as follows: 5 tasks (non-time-dependent) and 3 meetings (time-dependant)

Table 17 - Table showing CWCS experiment To-Do list (everyday condition)

To-Do List
Meeting 1 11:30 Meeting 2 12:00 Meeting 3 12:45 (The meeting will last about 5 minutes and will be in the Ed Tech lab).

Table 18 - Table showing CWCS experiment Task-List (everyday condition)

Task-List
Get a Red Brick (university paper) from the Guild and bring it to meeting three. Find The Manual of Bridge Engineering, Edited by M.J. Ryall, G.A.R Parke and J.E. Harding, The Institution of Civil Engineers, TG145M in the main library, go to page 34, Paragraph 2, line 6 Word 5 Record this word. Go to EIAC (first floor EECE) and find Proceedings of MLearn 2002 go to page 76, Introduction, line 11 Word 6. (You may need to ask for help). Record this word. Go to the station and buy a train ticket on a train to New St that leaves as close to 13:00 as possible. Go for coffee in the EECE common room, keep your can, coffee cup or food wrapper and bring it to meeting three. After the meeting go to the Ed Tech Lab and use your PC.

Table 19 - Table showing CWCS experiment To-Do list (wearable condition)

To-Do List	Location
Meeting 1 11:30 Meeting 2 12:00 Meeting 3 12:45	EEE EEE EEE

Table 20 - Table showing CWCS experiment Task-List (wearable condition)

Task-List
Get a Red Brick from the Guild. Find The Manual of Bridge Engineering, Edited by M.J. Ryall, G.A.R Parke and J.E. Harding, The Institution of Civil Engineers, TG145M in the main library. Go to EIAC (first floor EECE) and find Proceedings of MLearn 2002. Go to the station and buy a train ticket on a train to New St that leaves as close to 13:00 as possible. Go for coffee in the EECE common room. After the meeting go to the Ed Tech Lab and use your PC.

Some of the objects used or found during the experiment were also tagged with an IR tag e.g. both books required and the coffee cup was tagged.

For the Wearable condition the CWCS automatically collected the time taken to do the individual tasks, the total time taken and a series of the photographs describing how the tasks were done. A photograph was taken automatically every time some aspect of the participant's context changed, for example a picture was taken when the Location changed or when the participant interacted with a different Object.

In both conditions a set of questionnaires were answered during each meeting. For the everyday condition, the participants were asked to complete the NASA TLX workload test only. In addition, after the third meeting they were asked if they did the tasks in order, and if they used any type of electronic organiser to plan their time. During the meetings in the wearable condition again the NASA TLX workload test was completed, as well as a SUMI questionnaire to assess the software usability. The comfort rating scale (Knight et al, 2002 C) was used to assess the comfort of the HMD and the wearable. A few additional questions were used to assess specific known issues of the wearable such as the readability of the HMD. At the end of the experiment demographic information was collected from the participants.

8.3 CWCS Experiment Results

The results are considered in terms of the effect of condition on performance time, both total time and time spent on individual tasks, successful task completion and the NASA TLX Workload score. For the Wearable condition, the SUMI usability score and the CRS have been analysed.

8.3.1 Time

A number of mean times were calculated from the times recorded during the experiment. As stated in the method, overall time to do the experiment was recorded, as well as the times to do each of the tasks. For each condition the mean total task time was calculated. This is the sum of the times spent at each location. The total time refers to the time taken to complete the whole experiment including travelling time.

Table 21 - Mean total task time and mean total time for the Wearable and Everyday conditions

	Everyday condition (Hours: Minutes: seconds)	Wearable condition (Hours: Minutes: seconds)
Mean Total Task Time	00:40:24	00:34:12
Mean Total Time	01:55:24	01:35:12

In the Everyday condition the participants were not asked to fill in the SUMI questionnaire or the comfort assessments during the meeting, therefore spending considerably less time in the meetings, so the meeting times were removed for the mean times to give a more accurate comparison.

Table 22 - Mean total task time and mean total time, with time taken in meeting subtracted

	Everyday condition	Wearable condition
Mean Total Task Time (Not including meetings, (NIM))	00:27:00	00:12:24
Mean Total Time (NIM)	01:41:00	01:12:12

Mann-Whitney tests were carried out to compare the mean times in condition one and two. They show significant results for both the mean total task time, not including meetings (NIM) ($z = -2.41, p<0.05$) and the mean total time (NIM) ($z=-2.62, p<0.05$).

8.3.2 Task Completion

All tasks were completed correctly in both conditions and subsequently all participants came up with the correct sentence when asked to put the code words together in a sentence.

8.3.3 Task Order

Table 23 - Order in which each participant did the given tasks

	Participant	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 9
Condition 1	1	4	7	5	1	2	3	6	8	9
	2	7	2	1	4	5	3	6	8	9
	3	1	6	3	5	7	2	4	8	9
	4	2	4	5	1	7	3	6	8	9
	5	7	4	6	1	2	3	5	8	9
Condition 2	6	5	2	3	1	6	4	7	8	9
	7	1	4	2	6	7	3	5	8	9
	8	4	7	6	1	2	3	5	8	9
	9	1	4	2	6	7	3	5	8	9
	10	5	2	4	1	6	3	7	8	9

It can be seen from Table 1 that all of the other participants chose a route for themselves and did not follow the order in which the tasks were presented in the instructions. If the participants had completed the tasks in the order presented in the instructions then the line from Table 23 for that participant would read 1,2,3,4,5,6,7,8,9. The participants in either condition did not choose similar routes or task orders.

8.3.4 Workload

The workload scores were recorded using the NASA TLX at each meeting. Means of each NASA TLX question in each meeting have been calculated for both conditions. Total scores are calculated by adding up each question score. Question 4 is rated in the opposite direction to the others, when it is added into the total it is converted by subtracting it away from the maximum score of 20. Thus the lower values mean lower workload.

Table 24 - NASA TLX Workload scores for everyday condition

Everyday condition	Meeting 1	Meeting 2	Meeting 3
NASA 1	5.8	6.4	6.4
NASA 2	4.4	4.2	2.4
NASA 3	6	6.2	5.2
NASA 4	16.2	19.2	18.6
NASA 5	7.2	5.2	4.6
NASA 6	7	2.4	3.6
Total	**34.2**	**25.2**	**23.6**

Table 25 - NASA TLX Workload scores for wearable condition

Wearable condition	Meeting 1	Meeting 2	Meeting 3
NASA 1	6	4.8	2.4
NASA 2	5	3.6	1.6
NASA 3	6.8	7.8	2.8
NASA 4	17	17.4	19.6
NASA 5	7	6.8	4.4
NASA 6	6.8	4.8	1.6
Total	**34.6**	**30.4**	**13.2**

In Figure 48 the total results for condition one and two are compared. It can be seen that for both conditions there is a decrease in workload over time from meeting one to meeting three. Meeting one and three were approximately an hour apart; therefore this shows a difference in about an hours more experience at the tasks using either system.

Statistical analysis of the mean totals found no significant difference between conditions. Figure 48 shows the decrease of the mean totals over time.

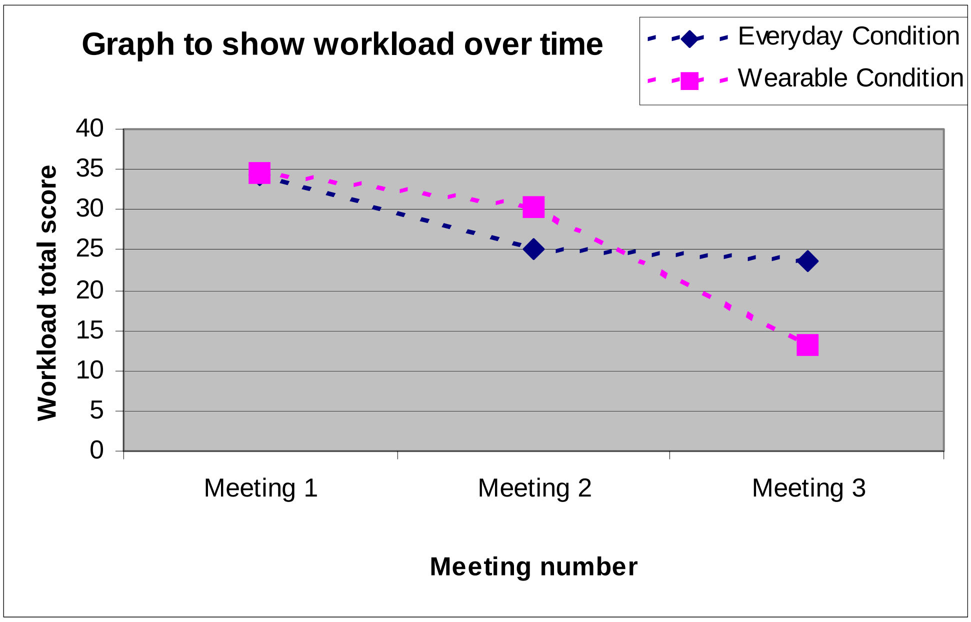


Figure 48 - Graph to show changes in workload over time for conditions one and two

8.3.5 SUMI

The SUMI test was only completed in the wearable condition, the SUMI test rates the software in 6 sections Global, Efficiency, Affect, Helpfulness, Control and Learnability. The SUMI analysis software calculates means based on the inputted values of the participants. The results are summarised in Table 26.

Table 26 - SUMI profile of Version LBpOT software Median valued quoted for each meeting

Scale	Meeting 1	Meeting 2	Meeting 3	Average
Global	57	65	65	62.33
Efficiency	50	61	65	58.67
Affect	49	61	61	57.00
Helpfulness	56	58	60	58.00
Control	58	68	68	64.67
Learnability	59	65	67	63.67

The SUMI results show a significant increase in the efficiency rating of the system when comparing results from meeting 1 to meeting 3. Mann-Whitney $p<0.05$. No significant improvement in the other SUMI scores over time was seen.

8.3.6 Comfort Rating Scale (CRS) Results

Figure 49 shows the CRS results for all the experiments. The final four columns of each comfort dimension, for example Emotion or Attachment, show the results for the three meetings in this experiment and average score (W*earable* M1, W M2, W M3 and W Avg.) During this experiment the participants were asked to complete a CRS for both the headset and the wearable computer. However, since most people did not wear the headset for any prolonged period and carried it most of the time, the results for the headset were not meaningful or complete and therefore have not been shown.

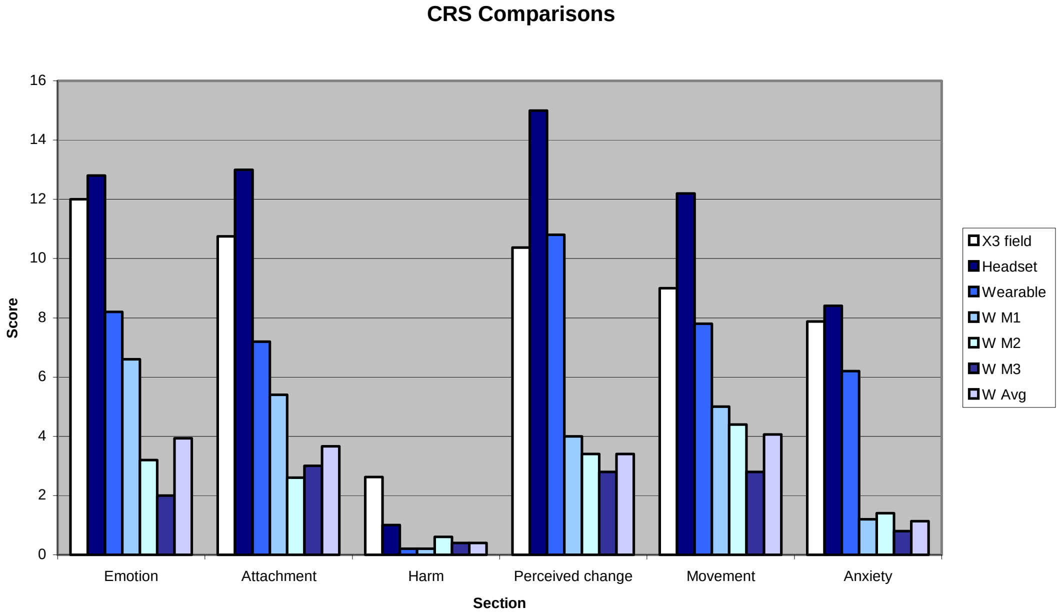


Figure 49 - CRS Results for all experiments

The devices shown on this graph are. χ^3 Field: The wearable computer used in the Location experiment (the first evolution of the wearable computer). Headset and Wearable: The wearable computer used in the Posture and Movement experiment, split into two ratings one for the HMD and one for the backpack. WM1, WM2, WM3 and WAvg all are ratings of the χ^{3+} used in the Complete Wearable Computer System experiment. WM1 is the CRS rating of the backpack after the first meeting in the experiment, WM2 is the CRS rating of the backpack after the first second in the experiment, WM3 is the CRS rating of the backpack after the first third in the experiment, WAvg is the average the these three results.

For each comfort dimension, the left hand side represents early systems and the right hand side represents later systems. The results suggest that the comfort of the wearable computer has continued to improve in all areas: This is indicated by each section of the graph having a downward trend in score.

8.4 Discussions and Conclusions

8.4.1 Effect of condition

The results indicate that using the CWCS (condition two) allowed the participants to increase the speed at which they complete the task, while not making the task harder or increasing the workload. The software was rated highly on the SUMI scale, suggesting the software has good usability. An increase in the measured usability can be seen as the participants' progress from the beginning to the end of the task and familiarity with the equipment, is gained.

8.4.2 Time

The more advanced system appeared to support increased performance. One of the biggest time savers of the system was the ability of the participant to complete the meeting in any location they chose. What is interesting, is that the participants in the wearable condition were told where the meeting were due to be held and what was to happen during the meeting, but decided that they could do what was required for the meeting at any location. It should be stressed that the participants made this choice. Saving time from having the meeting in any location is obviously not unique to this system and applies to all mobile devices (depending on the meeting requirements).

For the mean total time, not including meetings (NIM), some of the time difference can be explained by the participants being able to complete the meeting in any location, therefore less travelling between locations was needed, thus saving time. While this accounts for some of the time difference in mean total time (NIM), it does not in any way affect the mean total task time (NIM); this can be credited to the system making the task faster by providing the correct information in the right place at the right time.

8.4.3 Task Completion

All tasks were completed successfully, thus the tasks were set at an appropriate level for the experiment and equipment.

8.4.4 Task Order

Given that the CWCS highlighted all the tasks at the participants' current location, we may have expected that participants in the wearable condition who were using the system would have planned their task route better than the participants in the everyday condition. From the results it can be seen that no one out of either condition did the tasks in the order they were presented to them. Therefore everyone else made some choices about which order to complete the tasks. The choices that were made and the routes taken were not consistent across either condition and appear somewhat random. Therefore it is unlikely that task order had any effect on the speed of task completion. However given that the participants all had knowledge of the university campus (where the experiment was held), it was not unexpected that all participants would be efficient at planning their task route in a time conservative manner. Task order may account for some differences in workload rating given at each point. For example, if a participant completed all the tasks they thought were easiest (and found easiest) first then their first workload score would be low and at later ones higher as they proceeded to complete the tasks that they found required more work.

8.4.5 Workload

No significant difference was found in workload between the two conditions. More experimentation would need to be carried out to give conclusive proof of changes in workload.

8.4.6 Usability

The results suggest that the participants using the CWCS with version LBpOT of the software rated highly the usability of the software, using the SUMI scale. The mean scores for each set of SUMI results at each meeting were rated well above the average reference score of 50. It was hypothesised that the score might have been lower than this given that the SUMI scale is designed and validated for desktop software not wearable computer software, but this was not seen to be the case.

In terms of progression over time the sub-scales efficiency rating showed a significant increase, increasing from 50 to 65, from meeting one to meeting three. This suggests that the participants got better at using the software to help complete their task in a faster or more efficient manner. This is confirmed by the time results in section 8.3.1.

It is interesting to note that control, (defined as, the degree to which the participant feels they, and not the product, is setting the pace) was given the highest average SUMI score out of all subscales. Given that one key component of the software is that it is proactive and is a push system that pushes information at the participant as they go about their tasks, this could have resulted in a participant feeling a loss of control of the software. However the results would not suggest this. The results could imply that the participants liked the way in which they could control the software in an unconventional method, by changing their Location, Posture and Movement and Object, rather than solely using a mouse and keyboard.

8.4.7 Comfort

The comfort results not only show the results for this prolonged experiment, but also give a comparison with the CRS results from the previous experiments and the lab situation. Over the course of the development it can be seen that the comfort ratings of the device have improved. The HMD is still proving the most uncomfortable part of the system and is unlikely to improve until it can be produced much, much smaller and lighter. In contrast to other parts of the wearable computer, the HMD is entirely dependant on outside design.

8.4.8 Benefits of experimental design

One of the key objectives of the experiment, aside from the comparisons between the two conditions, was to see if the CWCS did in fact work at all, was functional, suitable for the application, and generally reliable. The technical challenges in getting a prototype mobile to device to work at all are not trivial. Therefore a large benefit of the experiment was to fully test the system and see it perform generally as designed. The previous experiments had shown that the system worked for short periods around half an hour. With a prolonged experiment the system was put through a more rigorous test. The batteries had shown in lab tests that they could last for long periods of time, however during the experiment the processing levels were higher than had previously been tested. The batteries were still shown to last long enough periods and easily coped with the experiment. The system was shown not to have any problems with failure due to over-heating. This is often a problem when putting systems on the body, which adds more heat to the system.

8.4.9 Specific Challenges

Observing people doing a task is always going to have an effect on how the task is performed. Informal feedback highlighted that a number of participants in the everyday condition in particular noted that they thought a lot more about the way that they were doing a task simply because they were required to record information about the task. Thus this may have had an effect on the workload in both conditions due to the added thought processes required to think about observing the task at the same time as doing the task.

The technological jump from the everyday tools available for aiding the tasks to the CWCS is large. The input method of a thumb mouse is unfamiliar to the participant, the HMD is hard to read, and can become uncomfortable after prolonged use. Participants have all had many years experience using paper lists, paper diaries or personal organisers. All of these factors will have influence the performance of the system.

As noted in the previous two experiments Chapter 6 and Chapter 7 the HMD has caused considerable problems with poor readability and obscuring users eyes as they walk. The same HMD was used as in the Posture and Movement experiment, Chapter 7. As it is not translucent if worn throughout the experiment, it can make walking at a normal pace difficult. However the majority of participants in this experiment found it uncomfortable and therefore elected to carry it or clip in to the chest strap of main wearable computer when it was not in use. This was made possible by the systems design that did not display any visual information when the participant was walking and only alerted the participant via audio. This design decision proved well justified and may in part have helped to gain participant acceptance and limited the workload increase of the system. Had the participant walked into two lampposts and a wall, they may not have been so inclined to use the system again!

A small problem arose trying to use the IR object tags outside. Depending on the amount of sunlight the sensors were prone to malfunction. Thus participants had to find a shady or indoor spot to interact with the object. This problem was not major and could be rectified by using radio tags instead of IR. During one experiment the object tags failed altogether, this experiment was abandoned and completed at a later date.

8.5 Chapter Summary

This chapter has discussed an experiment of the Complete Wearable Computer System. The experiment involved participants completing a number of everyday tasks selected from the task covered in the photograph diary study (Chapter 3) in one of two conditions. In the Everyday condition, participants were asked complete the tasks using everyday, familiar methods, and in the Wearable condition participants were asked to complete the tasks using the CWCS.

The results suggest that the CWCS can significantly decrease the amount of time taken to complete the task and reduce the workload experienced. The usability of the CWCS was assessed through the SUMI scale and has been shown to have a high usability score. The control aspect of the SUMI scale was given the highest score, suggesting unexpectedly, that uses felt well in control of the system and liked the proactive nature of the system.

The comfort of the system has been demonstrated as improved from previous versions, showing a successful design cycle incorporating lots of aspects important to wearable computers.

It has now been shown that a wearable computer is a viable means of displaying and supporting mobile information presentation. The wearable computer can sense some aspects of a participant’s context and has shown that context is useful in terms of increasing task speed, reducing their workload and making them more accurate. The system has been designed and shown in such a way as to augment the participants’ traditional methods for completing tasks, for example reducing their work load, rather than disrupting their usual behaviour.

Aims five and six of the system were to; explore design features of the system and their impact on system and user performance and to explore the application of a context aware system to everyday tasks respectively. Chapter 6, Chapter 7, and Chapter 8 have now addressed these aims. In addition though the use of an iterative design process for the context aware wearable computer systems and the continual measurement of their usability, the high usability of the system has been ensured. Thus achieving aim four.

In the next chapter a photograph sort will be carried out on the photographs taken during this experiment, to evaluate how well the system is capturing the components of context in comparison to how its human counterparts would capture the component

Chapter 9 Photograph Sort II & III

In this chapter two photograph sorting exercises are described. In the CWCS experiment in Chapter 8 photographs were taken both manually by participants and automatically by the wearable computer to capture the user's context. The first study aims to find any additional Context Identifiers that were missed in the original photograph sort in Chapter 3. The results from that experiment are concluded in Table 7, section 3.2.3. Participants sorted the manually taken photographs into similar groups, using the same method as the first photograph sorting experiment in section 3.2.2. A comparison can then be made between the Key Features of context found in both experiments. The final aim, aim seven, of the thesis was to compare the system's performance of collecting contextual features with a human's understanding of context. Thus the second study aims to compare the distribution of where the participants and the wearable computer in the CWCS experiment took their photographs and infer from this how similar the cues that trigger the recognition of context. The manually and automatically taken photographs from the CWCS experiment are sorted into activity groups. A comparison is drawn between the number of photographs taken manually and automatically for each activity to establish if similar cues are prompting photographs to be taken.

9.1 Introduction

One of the potential shortcomings of the original photograph diary study in Chapter 3 was that by taking snapshots more or less at random, lots of unrelated activities were captured, and some of the dynamic components of context might have been missed. The dynamic components are the features of past or future context may refine the current context. In contrast the photographs captured during the CWCS experiment follow a series of activities. The components of past and future context that might affect the current context may become visible on the pictures in this series. In this chapter, a photograph sort has been devised that follows the method described in sections 3.2.2 and 3.2.3 of the original photograph sort. It aims to see if any additional contextual features appear as a result of the photographs being considered as part of a time series.

It would be interesting to compare the pictures taken manually by the participants in condition one of the CWCS experiment, Chapter 8, with the automatically taken pictures by the CWCS system used in condition two. The people in condition one of the CWCS experiment were asked to capture events that occurred as they completed the task, therefore demonstrating changes in context. Humans are good at doing this (Tuner 1998). The CWCS was also collecting photographs when there was a change in context. This was based upon there being an altered state in one of the components of context they system can measure. If comparisons between the pictures collected by the two methods can be drawn, or they have been collected at similar points in time, then this suggests that the computer is accurately detecting when the human context changes.

This chapter describes two photograph sorts that have been carried out using the pictures collected in the experiment described in Chapter 8.

In summary the aims of the two photograph sorts are:

- Photograph sort two is to determine if by looking at a set of photographs that follow a series of linked activities any other Context Identifiers will be found. In particular ones that address the effects of past and future context on the present context.
- Photograph sort three is to determine whether the computer system and the human pick similar aspects of context to define an activity.

9.2 Photograph Sort Two: Examination of a Context Identifiers and any addition of dynamic Effects

The first photograph sort in this chapter, the second of the thesis, is identical in method to the photograph sort described in section 3.2.2. The only difference is the set of photographs that will be sorted. Participants will be asked to sort the manually captured photographs, from the previous CWCS experiment (Chapter 8), into contextually similar groups that they define, hence producing Context Identifiers. During this process they will name the groups and note the Key Features defining each photograph's membership of a group.

This process aims to determine similar groups or Context Identifiers to those found in the original photograph diary study (Chapter 3). Additional dynamic components of context are also expected that result from consideration of the previous and future context of a user to which the photographs refer.

9.2.1 Hypothesis Summary

A set of Context Identifiers will be produced from sorting the photographs into groups with similar features. From this it can be hypothesised that:

- The set will be similar to those found in photograph sort one, Table 7, section 3.2.3.
- There will be additional Context Identifiers that address the dynamic aspects of context.

9.2.2 Method

The first sort involves the participants sorting the manually captured photographs from the CWCS experiment (Chapter 8) into similar groups. During the CWCS experiment the five participants in condition one collected a total of 187 photographs. This is a large number of photographs and to reduce the amount of time the participants spent sorting them, one participants' set of photographs was chosen at random to be used in this experiment. A random number generator was used to select a number between one and five to pick the photograph set.

The method involved in this experiment is a rolling developmental method where the results of each phase are investigated before the method for the next phase is presented.

9.2.2.1 Photograph Sort Two - Phase 1: Photograph Sort

Participants: Three participants, two PhD students and a retired scientist took part in this experiment. Their ages were 25, 30 and 62.

Procedure: The same sorting procedure was adopted as used in the first photograph sort in section 3.2.2 of Chapter 3, where further details of the process can be found. Each participant was given identical verbal instructions to sort the photographs (from the randomly selected set) into similar groups. No definition of 'similar groups' was given; this was to be defined by the participant. The participants were then asked to give a heading to depict each of their sets (similar groups) and describe the Key Features that defined membership to the group. The participants completed this sorting process twice to maximise the number of Key Features elicited.

It is important here to recap and clarify the definitions of Key Features and Context Identifiers

Definition: Key Features – The common defining features of a set of activities.
Definition: Context Identifiers – Components of context. Context Identifiers define groups or themes of similar Key Features.

9.2.2.2 Photograph Sort Two - Phase 2: Post-It sort

The Key Features were written on Post-It notes and organised into groups. This Post-It sort had two purposes: Firstly to identify sets of similar Key Features identified by the three participants. These groups will again be called Context Identifiers. Secondly to give an importance weighting to each of the Context Identifiers found based on the number of occurrences of similar Key Features in each set.

Participants: In the Post-It sorting phases, the task was performed by the author rather than by participants.

Procedure: The elicited Key Features from the photograph sorts (section 9.2.2.1) were recorded on small yellow Post-It notes. These Post-Its were then stuck to a large piece of paper and organised into groups of connected features; that is ones that contained similar key words or themes. An inter-rater reliability study was carried out during Photograph Sort one, the sorting method is identical therefore additional inter-rater reliability has not been carried out.

Results: The Post-It sorting produced a concise set of themes or Context Identifiers, these included Location, Posture and Movement, Objects and others. The final groups of Post-Its can be seen below in Figure 50. The miscellaneous category includes terms that were too general to fit into any other category; generally they were terms that described an activity e.g. shopping, which is the activity rather than a component of the activity.

Figure 50 – Post-It sort phase one

The list of Context Identifiers found during this sort and the list found from the original sort in the photograph sort method in Table 7, section 3.2.3, will be compared to investigate if any other Context Identifiers are added when a sequence of photographs are looked at rather than pictures of separated unrelated activities.

The second part of the Post-It sort aimed to give a weighting to each Context Identifier, to indicate which items are more important to sense.

Participants: In the Post-It sorting phases, the task was performed by the author rather than by participants.

Procedure: Further analysis was undertaken by counting up the number of terms that were repeated in each group, for example 'books' might appear five times in the Object group. If only one occurrence of a term existed, then it stayed on the small yellow Post-It, if two to four occurrences existed the original Post-It were removed and were replaced by a small green Post-It with the term and the number of occurrences written on it. Similarly for five to nine occurrences a large green Post-It, ten to fourteen a small pink Post-It and finally fifteen to twenty two occurrences a large pink Post-It was used. This classification is summarised in Table 27. This allowed Context Identifiers to be weighted in two ways, firstly by number of occurrences and secondly by area of each colour. Therefore the larger the area of pink, the less possible states the Context Identifier has, thus it may be easier to sense. For example, objects that humans are interacting with may be difficult to sense because there are millions of them and everyone would need to be tagged in some way. Whereas, a users Posture and Movement have a small finite number of states and are the same for most people. The more occurrences, the more likely the Context Identifier is to provide information about the users context.

Table 27 - Post-It classification

Number of occurrences	Post-It size and colour
1 occurrence	Original yellow Post-It
2	Small Green
3 or 4	Large green
5 or 6	Small pink
7 or 8	Large pink

Results: Figure 51 shows the completed sorting process. It can be seen that people and Posture and Movement have equally large areas of pink and of green. This suggests that they would be the easiest Context Identifiers to sense, by a contextual wearable computer system, since they have few possible states.

Table 28 shows list of the ranked Context Identifiers, the top of the list being the most important. From Table 28 it can be seen that Object has the largest number of occurrences and can therefore be considered the most important Context Identifier. It occurred most frequently in the Key Features identified in the Photograph Sort and is most likely to regularly provide information about the users context.

In Table 28 the ‘percentage of total’ column shows the percentage of the total Key Features that was made up by the given Context Identifier. The higher the percentage, the more occurrences of the Key Features that make up that Context Identifier, and thus the more important the Context Identifier.

In Chapter 3 similar results are shown for the first photograph and Post-It sort in section 3.2.3.

Figure 51 – Post-It sort phase two

Table 28 - Shows the completed weighted list of Context Identifiers from Photograph Sort Two

Context Identifier	% of total	Possible States of the Context Identifier
Object	*26%*	*What object is being interacted with?*
Location	*20%*	*Is the location known?*
Posture and Movement	*15%*	*Is the person moving, walking, sitting, standing?*
People	*15%*	*How many/which people are involved?*
Indoors/Outdoors	*9%*	*Is the person indoors?*
Mood	*5%*	*Is the user relaxed/stressed?*
Aim of Task	*4%*	*Is the task being done for enjoyment/work?*
Cognitive Load	*3%*	*How mentally difficult is the task?*
Type of Interaction	*1%*	*How did the interaction between people of object take place?*
Weather	*1%*	*Good/bad weather?*

9.2.3 Photograph Sort Two Discussion

Table 28 shows the results from both photograph sort two and the results of photograph sort one are shown in Table 7, Chapter 3. The order of the table shows the importance of the Context Identifiers with the most important at the top. The percentage column shows the percentage of overall Key Features that make up each Context Identifier. It can be seen that the Context Identifiers that account for eighty to ninety percent of the total is the same. While the order has changed the Context Identifiers are still the same with the exception of Time, which is missing from he photograph two results. It is not unexpected that the order has changed as photograph sort two only looks at a small set of nine tasks from the CWCS experiment. These tasks were particularly focused around Object, Location and, Posture and Movement and therefore you would expect these three to be at the top of the list. Given the relatively short duration for the activities in photograph sort two, it is not surprising that Time is missing. It would be very difficult to see time changes of minutes in photographs compared to seeing changes in time sections of the day, for example morning to evening. In contrast, in photograph sort one, where eighty-four different activities were recorded, gave a more complete representation of the features that make up context.

The photographs taken in the two photograph sorts also differ in the way they were taken. In photograph sort one, an onlooker of the participant doing the task took a lot of the pictures rather than by the person doing the task. In contrast the photographs in photograph sort two were all taken by the participant of the task and most of the time did not include the participant, just aspects of the task. Therefore it seems likely that it was more difficult to see all the components of the activity in the set of photographs analysed in photograph sort two. Some of the Context Identifiers found in photograph sort one were not seen in the results of photograph sort two. This is probably due to the much smaller group of tasks analysed in photograph sort two, nine versus eighty-four. From this a smaller number of Key Features were found by the participants, four hundred versus ninety-nine. To use the same sized samples would have meant participants in the CWCS experiment each carrying out eighty-four activities. This would have taken an unrealistic amount of time involved and was beyond the technologies capabilities of the CWCS in terms of battery life.

One of the aims of this experiment was to see if any additional Context Identifiers were found as a result of analysing a set of activities that were connected in sequence. This was not found to be the case. This may be because more Context Identifiers do not exist and the original list was a complete one. Alternatively it is possible that these more dynamic components of context were not found as a result of static pictures being used as the record of the activities. While these pictures contain large amounts of information about the activities recorded they do not contain everything dynamic. In the future other methods could be used to record and then analyses activities to add more Context Identifiers to the list.

9.3 Photograph Sort Three: Comparison of human and automatic recognition of context changes and features

In photograph sort three, the second in this chapter, the third of the thesis, participants were given the list of activities carried out in the CWCS experiment (Show in Table

17 and Table 18), and then asked to sort either the manually captured (condition one) or the automatically captured (condition two) photographs into activity groups. An example of a set of each photographs can be seen in Appendix D and E. A comparison can then be drawn between the photographs that the computer automatically collected and those the participants manually collected, and common features and differences determined. This is interesting because the manually taken pictures were collected when people thought something in their context had changed. The pictures taken automatically by the computer were collected when the computer thought something in the users context had changed. If as Tuner (1998) noted, "Humans are exquisitely attuned to their context", and the automatically collected photographs are similar in distribution and essence to the manually collected photographs, then we have a computer that is well attuned to it's context - the ultimate aim.

9.3.1 Hypothesis Summary

In this Photograph sort, it was hypothesised that sorting two sets of photographs, one manually collected and one automatically collected, based on the illustrated activity, should produce a similar distribution of photograph numbers between activities.

9.3.2 Method

A within subjects design was used where participants sorted the photographs twice, once is each condition.
Manual condition - In condition one the participants sorted the manually captured photos.
Automatic condition – In condition two they sorted the automatically captured photos.

In the Complete Wearable Computer System (CWCS) experiment 748 photographs were captured, the computer (condition two) took 561 automatically, and the remainder were taken manually by the participants (condition one). As this is a very large number to sort, a set of photographs relating to just one participant in the experiment were randomly selected. There were 58 manually captured photographs, and 118 automatically captured photographs. These were given to all of the participants.

Participants: Three participants took part in this experiment, a PhD Student and two Research Fellows. Their ages were 28, 26 and 26.

Procedure: Each participant was given identical verbal instructions to sort the photographs. They were asked to assign them to groups. The group headings were pre-defined as the activities from the CWCS experiment (section 8.2, Table 17 and Table 18). These are ‘In a meeting’, ‘Getting a redbrick from the guild’, ‘Getting the manual of bridge building from the library’, ‘Buying a train ticket at the station’, ‘having a coffee’, ‘working at your pc’ and ‘Finding a conference preceding in EIAC’. Two additional groups were added; ‘Other activity’, and ‘Don’t know’. The Other group was for pictures that were a discrete activity but the participant did not think it was specifically one of the pre-defined activities headings. The ‘don’t know’ group was to be used if the participant could not determine the activity occurring in the photograph. The order in which the participants sorted the sets, for example first the manually taken photographs then the atomically taken photographs or visa versa, was chosen at random, using a random number generator. Figure 52 shows a participant completing the sorting process.

Figure 52- Photograph sorting by activity

9.3.3 Results

The results are considered in terms of the number of pictures assigned to each activity in each condition.

Table 29 shows the number of photographs assigned to each activity by the participants in the experiment.

Table 29 - Results of photograph sort three, showing the number of pictures assigned by the participants to each activity

	Manual			**Automatic**		
Participant	**Participant 1**	**Participant 2**	**Participant 3**	**Participant 1**	**Participant 2**	**Participant 3**
Activity	Number of photos			Number of photos		
Meeting	5	2	1	5	2	2
Get a red brick	8	6	5	6	0	5
Main library	14	17	17	26	19	26
Station	4	5	3	3	6	13
Coffee	3	3	7	7	5	12
PC	1	0	1	4	4	4
EIAC	4	7	7	12	10	12
Other	19	17	17	30	52	32
Don't know	0	1	0	25	20	12
Total	58	58	58	118	118	118

From these results the average percentage of photographs sorted into each activity group was calculated in both conditions.

Table 30 - Average percentage of photographs sorted into each activity group

	Percentage of photographs in each activity group	
Activity	**Manual**	**Automatic**
Meeting	4.6%	2.5%
Get a red brick	10.9%	3.1%
Main library	27.6%	20.0%
Station	7.0%	6.2%
Coffee	7.5%	6.8%
PC	1.2%	3.4%
EIAC	10.3%	9.6%
Other	30.5%	32.2%

The 'Don't know' category was then removed from the analysis, as these are pictures where the error is in the picture, for example too much light or very blurred, not an error in the contextual features captured. Following this removal, a Pearson correlation was completed to assess the correlation between the two conditions. The results show significant correlation (R^2 = 0.876, n=9, $p<0.05$). From this result and Figure 53 the high correlation can be seen. The trend line is a graphical representation of the regression equation.

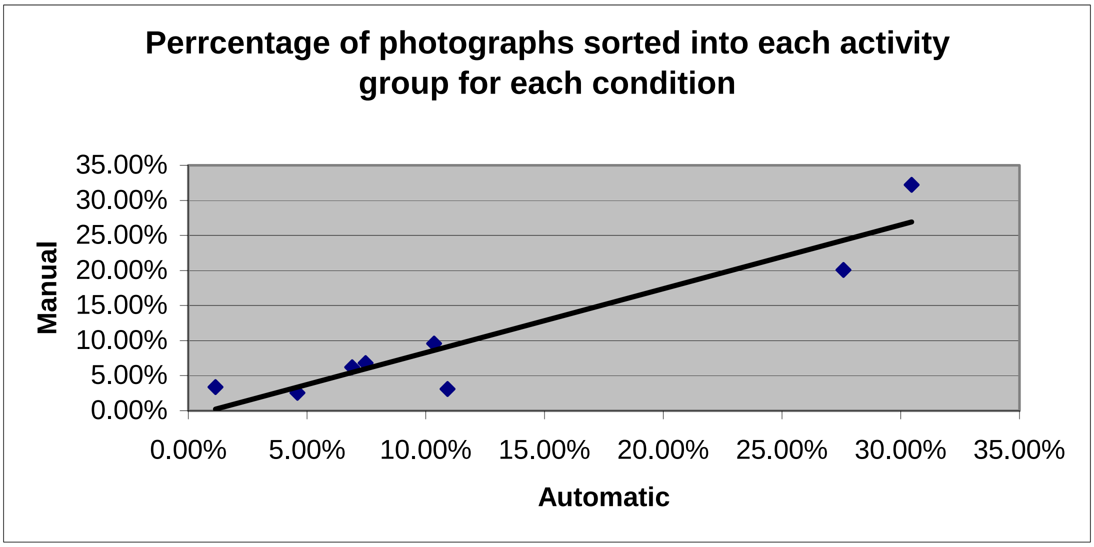


Figure 53 - Graph showing the results of the automatic condition plotted against the results of the manual condition for each activity group

The results suggest a high correlation between the numbers of photographs taken during each activity in the two conditions in the CWCS experiment, condition one being the manually taken photographs and condition two being the automatically taken photographs. This result is based on the sets that were sorted in this experiment. The results suggest that the distribution of pictures taken per activity is similar for both conditions.

9.3.4 Photograph sort three Discussion

The correlation results suggest that there is a high correlation between the numbers of photographs sorted into each activity category in the two conditions. For example, it can be seen that in manual condition, condition one the most number of photographs assigned to an activity (other than the 'other activity' group) were assigned to the library; this was also true for the automatic condition, condition two. From this it is suggested that the activities where the human manually captured lots of pictures the computer automatically captured a large number of pictures as well. As expected, the automatic condition had many more photographs sorted into the 'don't know' category, this is likely to be because the computer was taking the photographs and therefore was not composing the photographs, meaning that some of them were blurred or unrecognisable as an activity. The sorting process was only carried out on one set of manually taken photographs. This set has chosen at random. On subsequent visual inspection this set is thought to be indicative of all the sets. In the future a more extensive photograph sort might be carried out on all the sets of photographs taken in the CWCS experiment. However this would be very time consuming and labour intensive and therefore has not been carried out at this stage.

During the CWCS experiment participants in condition one were asked to take photographs that explained how they completed the activity, therefore they needed to pick out the Key Features, of that activity that would allow people to look at the photographs and tell what the activity was. The computer in condition two of the CWCS was trying to do the same. From the photograph sorting experiment B and the resulting analysis it can be seen that when the humans picked out and photographed lots of Key Features the computer did the same. If these Key Features of the activities are important in a users context as suggested in Chapter 3, then the computer is detecting features of the users context, in a similar way to the humans.

9.4 Chapter Summary

In this chapter two photograph sorting experiments have been described.

In the first, a set of photographs taken manually during the CWCS experiment was sorted twice into similar groups based on Key Features defined by the participants. These Key Features produced by all of the participants were then sorted into similar groups and the number of occurrences of each feature determined. From this classification system, a ranked list of Context Identifiers was created. This list was then compared to the list created in photograph sort one and shown in Table 7, section 3.2.3. The lists were found to be very similar. The top four Context Identifiers that account for sixty to seventy-five percent of occurrences of Key Features were consistent in both lists. This suggests that these Context Identifiers, body Posture and Movement, Location, Object and People are indeed important for telling a person's context. No additional features were found by sorting photographs from a sequence of activities. This could suggest the original list is complete and contains all necessary features. It could also suggest that dynamic components of context, the effects of past and future context are not visible in a static picture and that some other method is needed to find these features.

In the third photograph sort two sets of photographs taken during the CWCS experiment were compared. Participants in the experiment had manually collected one set and the other had been automatically collected by the computer. The two sets were sorted into activity groups by a set of participants. The activity groups were those completed in the CWCS and so pre-defined by the experimenter. The number of photographs assigned by the participants to each activity was recorded and compared across conditions. A correlation was found between each activity group in each condition and the number of photographs. Suggesting that a similar proportion of the total number of photographs was taken of each activity in the two conditions. This would suggest that the humans and computers are taking photographs based on similar cues. Thus the computer is collecting data about the users context in a similar way to how humans collect data about their own context. Thus aim seven of the thesis; to compare the system's performance of collecting contextual features with a human's understanding of context has been completed.

In the next concluding chapter the research as a whole will be discussed and conclusions drawn. Each chapter's aims and conclusions will be summarised. How this research fits with other research and possible future work will be discussed.

Chapter 10 Conclusion

In this final chapter a summary of the thesis work and conclusions is presented. The value of the hardware and software systems as well as the experimental work is discussed. The state of the art literature on context-aware mobile computing is reflected upon and the ways in which the existing knowledge base has been expanded upon and novel approaches taken is explained. Further work that would contribute to the progression of new technology in context aware computing and further advance the results presented in the thesis is suggested.

10.1 Introduction

The concluding chapter will begin by re examining the aims and objectives of the thesis laid out in the introduction, Chapter 1. How these aims have been addressed and the resulting conclusions will be presented. The contributions to the field are suggested and possible future work is then discussed.

This thesis could be loosely split into four parts. Firstly a definition of context is suggested. The definition is derived from a detailed analysis of everyday activities, and is suggested in terms of the components that make up context. Secondly a wearable computer and supporting software has been developed that can sense or detect, and react to, some of the suggested components of context. The wearable computer is one of very few Windows based wearable computers. Thirdly the usability of three iterations of the created system is tested. The usability is tested in terms of effectiveness, efficiency and user satisfaction. The system is shown to have a high usability compared to conventional methods for doing similar tasks. Fourthly and finally the way in which the final system collects or recognises contextual features is compared to the way in which humans collect or recognise contextual features of everyday activities. The system is shown to recognise contextual features in a similar fashion to humans.

10.2 Thesis aims revisited

In Chapter 1 the specific thesis aims were laid out as; the thesis aims to:

1. Examine the nature of context in everyday activities.
2. Develop and demonstrate new software that interprets the context detector states and infers aspects of a user's context.
3. Develop and demonstrate hardware for a wearable computer, that includes some context detectors.
4. Ensuring the system is highly usable.
5. Explore design features of the system and their impact on system and user performance.
6. Explore the application of a context aware system to everyday tasks.
7. Compare the system's performance of collecting contextual features with a human's understanding of context.

To this end Chapter 3 examines the nature of context in everyday activities (aim one). It discusses a study carried out during this research that investigated a large number of everyday activities, analysed then for similar features and from this presented a list of contextual features, whose states describe each activity, called Context Identifiers. Photographs were taken of participants doing each activity. The photographs were then grouped into similar groups by judges. The judges then defined the groups in terms of the Key Features that made up each group. Groups of similar Key Features were found and labelled as Context Identifiers. The Context Identifiers found in the photograph study were weighted to give users of the list an idea of the importance of each Context Identifier. The weighting was based on the number of occurrences of the Key Features that make up each Context Identifier group. Table 31 shows the list of Context Identifiers found. This definition produces a more specific and structured definitions than the literal based definitions. It is more comprehensive than creating a definition of context for specific applications based on the available technology, and is backed up by the detailed study of everyday activities. Thus this definition should be applicable to many situations and applications and gives designers, of context aware applications, an idea of the importance of different components of context.

Table 31 - Context Identifiers ordered top to bottom by decreasing importance

Context Identifier	**Possible States of the Context Identifier**
Posture and Movement	*Is the person moving, walking, sitting, standing?*
Location	*Is the location known?*
Object	*What object is being interacted with?*
People	*How many/which people are involved?*
Time	*What time or day is it?*
Mood	*Is the user relaxed/stressed?*
Indoors/Outdoors	*Is the person indoors?*
Type of Interaction	*How did the interaction between people of object take place?*
Aim of Task	*Is the task being done for enjoyment/work?*
Physiological Indicators	*Is the heart rate high?*
Cognitive Load	*How mentally difficult is the task?*
Weather	*Good/bad weather?*
Frequency	*How frequently is the task done?*
Time Critical?	*Is the task length (time) constrained?*
Planning?	*Is the task planned/spontaneous?*

Based on these findings a software solution was developed to capture, record and react to the top five Context Identifiers. These Context Identifiers were Posture and Movement, Location, Object, People and Time. Chapter 4 describes the development of new software that interprets the context detector states and infers aspects of a user's context (aim two). Chapter 5 demonstrates hardware for a wearable computer that includes some context detectors (aim three). Chapter 4 looked specifically at the iterative development of the software to interpret the sensor or context detector states and present context related information to the user whilst mobile. The software went though three development cycles. Each evolution adding extra features and improving based on experiments using the last evolution. The first evolution detected and reacted to Location only. The second detected the Location and Posture and Movement of a user. The third and final system detected and reacted to the Location, Posture and Movement, Time and Object. In addition the final evolution gave users a greater degree of control of the information presented to them. Each piece of information was given a weighting dependent on the number of the user's current context features that matched those of the description of the information. In addition it captured a picture the users context every time it changed.

To support the software and based on principles found in current literature, section 2.3, of wearable computer technology a wearable computer was designed and built. The hardware and software system could then allow experiments to demonstrate how a wearable context aware computer could be used to present mobile contextual information. A mobile system was created that would present different information or change the way the information was presented depending on a users Location, Posture and Movement, Time and Object. Chapter 5 explains how the wearable computer was produced in terms of the hardware required and developed. As with the software three iterations of the wearable computer were built. In line with the software, the sensors required to detect more Context Identifiers were added during the design process. In addition the underlying hardware was improved in terms of faster and more reliable systems. The improvements and additions added to both the hardware and software in each iteration were as a result of, firstly the photograph diary study and secondly the results of the experiments using the previous versions of software and hardware.

The final hardware and software mobile system detected the user Location, Posture and Movement, Time and Object. The wearable computer then displayed information based on the users context and captured a snap shot of the users context every time it changed.

To tackle aim four, ensuring the system is highly usable, ISO 9421-11 (ISO, 1998) was used as form factor for usability. Through Appendix B, Chapter 6, Chapter 7, and Chapter 8 the usability of the system was considered. Following the development of the first version or iteration of the system (hardware and software), consideration was given to how to measure the usability of the system in terms of effectiveness, efficiency and satisfaction. Time and accuracy are obvious measures of effectiveness and efficiency. The NASA TLX and SUMI software usability scale have been introduced as measures of satisfaction. While the NASA TLX, time and accuracy have all been shown to task independent measures the SUMI scale is specifically designed for measuring the usability of desktop based software. An experiment was therefore carried out to test how the SUMI scale rated Microsoft Excel and both a desktop and a wearable computer. The results from this experiment suggested that the SUMI scale worked equally well for rating software on a wearable computer as a desktop and therefore was an appropriate measure for rating the software written during this research.

By using the completed systems in experiments and comparing this system with various control systems it can be seen that the system is highly usable. Very few other research projects have assessed their systems in terms of the usability of the system.

The three different iterations or versions of the system are experimented in Chapter 6, Chapter 7, and Chapter 8 respectively. These chapters explore the design features of the system and their impact on system and user performance, (aim five), in doing so and though the iterative design process they ensure the system is highly usable (aim four). Chapter 6 looks specifically at the first version of the system, which detects the users Location and presents information related to that Location. The system is compared to two control conditions completing similar tasks. The three conditions are compared in terms of time and accuracy of task completion. Thus looking at the effectiveness and efficiency of the system. The results showed that the first system showed a high degree of usability and out performed or was more usable, in terms of time and accuracy, than the two control conditions. Similarly to Chapter 6, Chapter 7 looks at the second system's usability in terms of time and accuracy of task completion.

The final system user study in Chapter 8 explores the application of the context aware system to everyday tasks. Chapter 8 like Chapter 6 and Chapter 7 addresses aims four and five. Chapter 8 goes further and explores the application of a context aware system to everyday tasks (aim six). In the experiment described in Chapter 8 the final system is used to aid users completing a selection of everyday tasks, thus explore the application of a context aware system to everyday tasks. The completed system is compared in the experiment to participants completing the same everyday activity with out the aid of the context aware system. Time, accuracy, the NASA TLX are all used to compare how well participants using the system perform in comparison to the control participants. In addition the SUMI scale is used to measure user satisfaction with the system. The results of the experiment suggest that by using a context aware system to aid everyday activities, the speed and accuracy of the task can be increased and the workload felt by the users while doing the tasks can be reduced.

Finally Chapter 9 compares the system's performance of collecting contextual features with a human's understanding of context. In doing this Chapter 9 describes two experiments. The first experiment was very similar to the photograph sorting in Chapter 3. This was done to look for any additional Context Identifiers that may have been missing the original experiment. The second experiment in Chapter 9 addressed aim seven more specifically. During the experiment described in Chapter 8 both the humans and context aware wearable computer collected pictures that described the events that took place as they completed to required tasks. In effect both were collecting pictures when significant changes in their environment took place. By comparing the photographs taken by both the humans and the context aware system a comparison of how similarly the two parties collected contextual features could be made. It was found that the system performed very well and photographed the very similar events to those recorded by the humans.

10.3 Placing the research in 'context'

The first section of this thesis addresses the question of the nature of the context of everyday activities and how the context can be defined in terms of the components that make up the context of everyday activities. No other research found has looked specifically at the components that make up context by analysing everyday activities. Many researchers Abowd and Mynatt, (2002), Baber et al, (1999), Dey et al, (1999), Dey, (2001), and Schmidt, (1999) have all suggested definitions for context. The majority of these have been based on the literal definition of context and have not been supported by experiment studies of everyday context. These suggested definitions define context very well in an all-incorporating manner, however their wide spectrum and imprecision make them difficult to use when linking the definition of context to the detection though technical means. The study of everyday activities in this research bridges the gap between the all-encompassing definition and the very specific definitions of, for example, location-as-context used for specific applications. In addition the definition of context based on the components that make up context, suggested in research, is backed up by empirical data from the study of activities in Chapter 3.

While many other researchers (Feiner et al 1997, Ashbrook and Starner 2002, Randell and Muller 2000 , Dey et al 1999, Farringdon et al 1999, Van Laerhoven et al 2002, Kern et al 2002, Lee and Mase 2002, Cheok et al 2002 and Ogawa et al 2001) have looked at using GPS, accelerometers and other devices for detecting specific aspects of context very few have considered multiple (more than two) different types of sensors for detecting different aspects of context on the same system. One exception might be Park et al (2002) who have successfully integrated many sensors into a system. Most of these projects had concentrated on more complex modelling on the collected data rather than many different sources of data.

A number of research institutes and commercial companies have produced semi wearable computers of various types. It could be argued that the χ^3 produced at The University of Birmingham is the most powerful Windows based wearable computer. Based on the literature the χ^3 has performed as well as any other published wearable computers in both power and battery life. In addition the ergonomics and comfort of the computer have been assessed. Very few other wearable computers have been tested in this way.

One of the novel approaches of this research has been to evaluate the created wearable computer system in terms of its usability compared to other types of technology or current method for completing tasks. Although many projects have used user trials to look at the performance of their systems, or more often whether the technology worked, they have not taken a usability approach and have mainly not compared their systems to current alternatives. This use of at least one control condition in the experiment in Chapter 6, Chapter 7, and Chapter 8 is very important in answering the question, is context awareness really useful. The experiments have shown that context aware systems can improve user performance and therefore are useful. Had a control condition not been used all that would be known is that the system preformed, but not how well.

In conclusion this research suggests a structured context definition that could be used by context aware system designers. The definition is backed up by the study of everyday activities. A wearable computer and context aware software has been created that could be used as a design for a concept-demonstrating platform for other projects. A novel approach has been taken to the assessment of context aware systems and shows how important it is to assess not just whether a system works but how well it performs and how usable it is. It has been shown that it is possible to create a computer-based context aware system that recognises users contexts in similar ways to users (as a humans) recognising their own contexts.

10.4 Future Work

Future work could take a number of different routes. The most obvious route to take would be to continue the design cycle adding more sensors or context detectors until the completed system was able to detect all the Context Identifiers elicited. In some cases this would involve the development of new detectors or implicit input from users. Sensors that could easily be interfaced to a wearable computer that detect users mood or the weather have not yet been created. In some cases it may be more economical to infer some Context Identifier states from others that are easier to sense. Figure 6 in Chapter 3 aims to suggest some of the links between different Context Identifiers however for this to be used constructively more research into the links needs to be carried out. In addition some changes to the environment that the system would be used in may need to take place before a really useable complete system could be made. At present objects or people are detected by the tags placed on them. At present only the objects used in the experiments have these tags. Therefore until all objects and people have tags, which may happen as a result of people carrying mobile phones or all objects becoming wi-fi enabled, the majority of objects and people around a user will not be detected.

However these technological advances seem to be the small steps. The biggest advances may come in the development of more complex models of context. As more sensors are added to system the decision processes associated with choosing content to present or simply what you want the system to do become much more complex.

The complexity increases almost exponentially the more sensors you add. Currently the system created in this thesis has a simple pragmatic context model that only looks at the present context state. There are three sections to a context modelling system all of which are complex, firstly the detection of the current context state, secondly the record of previous context states, and finally the prediction of future contexts based on a combination of the previous and current states.

One way to attack the problem of more complex models might be to break it down into two parts. Part one the detection or inference of the Context Identifiers elicited in this research and part two a user model. A context model could be created from these two parts. The context detection would detect all the Context Identifiers elicited in this research. The user model would then contain other user preference that could not be detected, for example, the users name or age. It could also contain the users past contexts and reactions to those contexts. This would then allow a context model to be created that could then predict the users actions based on their current context state and their reactions to previous context states, be it the same context state and thus the same reaction or a guess at the reaction based on past contexts that are similar to the current context. However this is a large amount of work and was outside the domains of this research. A lot of the technology required to implement this kind of system is not available. Technology does not exist for a number of the suggested Context Identifiers; for example, detecting a users mood is nigh on impossible. As suggested before the modelling process is also very complex. Therefore it may be some time before models like this exist.

Some of the underlying work of collecting the current context state has been carried out in this thesis. However as has been noted, a lot of technology does not yet exist to capture all of the suggested Context Identifiers. So problem one is detecting all of the Context Identifiers. Problem two comes when trying to interpret the current context from all of the current Context Identifiers. The states of the Context Identifiers change at different rates and have different types of states. For example, body Posture and Movement has discrete states a person is standing or sitting, moving or not moving. In contrast, a person mood runs on a continuum from a very bad mood to a very good mood, or anywhere in between. How to combine the different states of the Context Identifiers into a meaningful current context model is very difficult. In addition the importance of Context Identifiers has an influence on the current context state. This research has addressed the ranking of the Context Identifiers which plays an key roles in deciding the importance of any current Context Identifier states.

When recording the previous context state a number of new problems will occur. The previous context states would need to be recorded, but also the user's reactions to those states. Without the reactions you could not predict future reactions to context states. This is not a trivial problem. Understanding the way someone has reacted in a conversation, for example, based on new people that have entered it would be very difficult for a computer to achieve. When recording the previous context states a designer would need to decide if they wanted to record the state in terms of the states of each of the Context Identifiers, as it had been detected, or would the gist of the context be recorded. If the gist were to be recorded then the system would need not only to detect the context but also to understand it. This could require some form of artificial intelligence, again not a trivial problem.

The third section of a context modelling system would be the prediction based on the context model. Here lies another problem. What is the prediction for? Is the prediction, like in this research, used to predict the best information to be displayed? Is the prediction to be used to choose which type of device on which to display information?

Currently few people are really looking at complex models of context based on large numbers of different sensors. Researchers such as Ashbrook and Starner (2002) have been investigated more complex hidden Markov models to model user's movement using GPS, however this has only looked at one sensor. Similarly Van Laerhoven et al, (2002) have used neural networks to create complex models of large amount of accelerometer data, again this only uses one type of sensor. Other statistical modelling methods could be used, for example, Bayesian networks, Probabilistic networks or Knowledge Maps but these have yet to be reported in the literature in relation to context models. Since, as noted earlier not all of the Context Identifiers have discrete states, in theses cases a statistical modelling technique might not be the most appropriate method and new methods may need to be found.

Further into the future there are many possibilities for applications of the context work carried out.

There are a large number of uses for contextual applications in the learning environment, be it the standard classroom domain or the wider everyday learning and development that continues throughout ones life. Applications are already being investigated for widening the classroom to allow learners to be taught lessons in context or to support lessons in remote locations with contextual teaching or support information. These could be further supported by better context detection and modelling. In the military support and attack systems could use context modelling to provide the very latest up to date, context specific information allowing the military to be more effect and reduce collateral damage. In the business domain there are sure to be additions to the typical electronic calendar and reminder systems. Systems that could remind users of details about associates or clients as they meet them would all need to be have underlying context modelling to function. Equally systems that automatically collected data to annotate meetings or keep track of phone conversations and allow easy indexing of them based on contextual features would need to use context modelling.

This thesis has identified the components that make up everyday context though a empirical analysis of everyday activities. The components, Context Identifiers, have been rated on how likely they are to tell a system something about a users context. A context aware wearable computer has been created that reacts to the five most important Context Identifiers. The usability of the wearable computers, at various stages of its development, has been assessed though user trials. During the experiments the efficiency, effectiveness and satisfaction of the participants has been measured. The context aware wearable computer has been shown to be very usable in comparison to conventional method for carrying out similar tasks. Finally a comparison of the wearable computers ability to accurately detect context changes compared to a human’s ability has been carried out. The wearable computer has been shown to detect context changes in a similar way and at similar times to a human

The uses of context modelling and context aware devices are wide and at present in their infancy. In the future computers may use context to help them act appropriately as often as humans do. This research has gone some way to investigating the challengers faced in context awareness for wearable computers.

Glossary

3G	3rd Generation mobile telephone technology
Aim of Task	Context Identifier
CI	Context Identifier
CIS	Context Information Service
Cognitive Load	Context Identifier
Context Identifiers	Components of context. Context Identifiers are headings for groups of similar Key Features.
CRS	Comfort Rating Scale
CWCS	Complete Wearable Computer System
Frequency	Context Identifier
g	g the standard acceleration due to gravity ($9.80665ms^{-2}$)
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communication
HMD	Head Mounted Display
HMM	Hidden Markov Model
HUD	Head Up Display
I/O	Input/Output
IMT-2000	(International Mobile Telecommunications-2000) is the global standard for third generation (3G) wireless communications as defined by the International Telecommunication Union.
Indoors/Outdoors	Context Identifier
IR	Infra Red
Key Features	The defining features of a set of activities that make those activities belong to that set.
L	Location
LBp	Location, Body Position
LBpOT	Location, Body Position, Object, Time
Location	Context Identifier
Mood	Context Identifier
NIM	Not Including Meetings
Object	Context Identifier
PDA	Personal Digital Assistant
People	Context Identifier
Physiological Indicators	Context Identifier
Planning?	Context Identifier
Posture and movement	Context Identifier
Time	Context Identifier
Time Critical?	Context Identifier
Type of Interaction	Context Identifier
URL	Uniform Resource Locator

WAP	Wireless Application Protocol
Weather	Context Identifier
Widget	Widgets are “a component of a user interface which operates in a particular way” (The New Oxford Dictionary of English 1998 C). Widgets are usually used to hide the technical components of one section of a system from the designers of another section, thus simplifying the design process and allowing for easy upgrade ability and system changes.
Wi-fi	802.11b or g wireless networks

References

Abowd, G. D. and Mynatt, E. D., (2002), Charting past, present, and future research in ubiquitous computing, In J.M. Carroll (ed) *Human-Computer Interaction in the New Millennium*, Boston, MA: Addison Wesley, pp 513-536.

Allport, D. A., Antonis, B., Reynolds, P., (1972), "On the Division of Attention: A Disproof of the Single Channel Hypothesis," *Quarterly J. Experimental Psychology*, vol. 24, pp. 225-235.

Aoki, H., Schiele, B., Pentland, A., (1999), "Realtime Personal Positioning System for a Wearable Computer," *Third International Symposium on Wearable Computers*, Los Alamitos, CA: IEEE Computer Society, pp 37-43.

Ashbrook, D., Starner, T., (2002), "Learning Signification Locations and Predicting User Movement with GPS", *The Sixth International Symposium on Wearable Computer,* Los Alamitos, CA: IEEE Computer Society, pp 101-108.

Baber, C., Haniff, D., Woolley, S. I., (1999) Contrasting Paradigms for the Development of Wearable Computing, *IBM Systems Journal*, Vol. 38, Number 4., pp 551-565.

Bergman, E., *Information Appliance and Beyond*, San Francisco: Morgan Kaufmann Publishers, 2000.

Biotrack, UK, (2004), http://www.biotrack.co.uk/body_radio_tags.html, Accessed 9/1/2004.

Botman, H. (1996). "Do-it-yourself usability evaluation: Guiding software developers to usability." In Jordan, P. W.; McClelland, I. L. and Thomas, B. (eds.). *Usability evaluation in industry*. Taylor & Francis, London, 59-66.

Brewster S., Murray, R., (2000 A), "Presenting Dynamic Information on Mobile Computers", *Personal Technologies,* Vol 4(2), Academic Press, pp 209-212.

Brewster, S.A., Walker, W.A., (2000 B), "Non-Visual Interfaces for Wearable Computers", *IEE Workshop on Wearable Computing*, (00/145).

Bristow, H. W., Knight, J. F., Baber, C., Schwirtz, A., (2002), "Evaluating contextual information for wearable computing", *The Sixth International Symposium on Wearable Computers,* Los Alamitos, CA: IEEE Computer Society, pp 65-72.

Brown, B. A. T., Sellen, A. J., O'Hara, K. P., (2000), "A Diary Study of Information Capture in Working Life", *CHI '2000,* pp 438-445.

Bushey, R., Mitchell Mauney, J., Deelman, T., (1999), "The Development of Behaviour-Based User Models for a Computer System", *User Modelling: Proceeding of the Seventh International Conference, UM99*, Banff Centre, Banff, Canada, 20-24 June 1999, pp 109-118 http://www.cs.usask.ca/UM99/Proc/bushey.pdf

CampusProgram.com, (2004), http://www.campusprogram.com/reference/en/wikipedia/3/3g/3g.html Accessed 5/9/04

Chapanis, A. (1991). "Evaluating usability." In Shackel, B. and Richardson, S. (eds.). *Human factors for informatics usability*. Cambridge University Press, Cambridge, 359-398.

Charmed, http://www.charmed.com/, Accessed 17/3/03

Cheok, A. D., Kumar, K. G., Prince, S., (2002), "Micro-Accelerometer based Hardware Interfaces for Wearable Computer Mixed Reality Applications," *The Sixth International Symposium on Wearable Computers,* Los Alamitos, CA: IEEE Computer Society, pp.223-230.

Conversay, (2002), http://www.conversay.com/Products/Browsers/VS/default.asp, Accessed 15/1/03.

Cross, J. (2000 A), "Electronic Engineering Challenges in the Design of a Wearable Ubiquitous Computer System, Based on a Pentium™ PC/104." http://www.eee.bham.ac.uk/wear-it/files/ECpaper.pdf, Access 5/8/2002.

Cross, J., (2000 B), "WearCAM Personal Imaging", MEng Final Report, School of EECE, The University of Birmingham.

D. Hix and H. R. Hartson. (1993) "Developing User Interfaces: Ensuring Usability through Product and Process." John Wiley and Sons, New York.

Davis, F. D. (1993). "User acceptance of information technology: system characteristics, user performance and behavioural impacts." *International Journal of Man-Machine Studies*, vol. 38, 475-487.

Dey, A. K., (2001), "Understanding and Using Context", *Personal and Ubiquitous Computing*, vol. 5, pp 5.

Dey, A. K., Salber, D., Abowd, G. D., and Fetakwa, M., (1999), "The Conference Assistant: Combining Context-Awareness with Wearable Computing," *Third International Symposium on Wearable Computers*, Los Alamitos, CA: IEEE Computer Society, pp. 21-28.

Dey, A., (2000), “Enabling the Use of Context in Interactive Applications”, In the CHI 2000 Doctoral Consortium, *Proceedings of the 2000 Conference on Human Factors in Computing Systems (CHI 2000)*, April 1-6, 2000, pp 79.

Ekahua Finland, (2003), http://www.ekahau.com/, Accessed 16/9/03.

Eysenck, M., Keane, M., (1995), *Cognitive Psychology: A Student's Handbook*, 3rd ed. Hove, UK: Lawrence Erlbaum Associated.

Farringdon, J., Moore, A.J., Tilbury, N., Church, J. and Biemond, P.D., (1999), “Wearable sensor badge and sensor jacket for contextual awareness”, *Third International Symposium on Wearable Computers*, Los Alamitos, CA: IEEE Computer Society, pp107-113.

Feiner, S., MacIntyre, B., Hollerer, (1997), "A Touring Machine: Prototyping 3D Mobile Augmented Reality System for Exploring the Urban Environment," *The First International Symposium on Wearable Computers*, Los Alamitos, CA: IEEE Computer Society, pp 74-81.

Feiner, S., MacIntyre, B., Hollerer, T., Webster, A., (1997), “A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment”, *The First International Symposium on Wearable Computers*, Los Alamitos, CA: IEEE Computer Society, pp 74 – 81.

Garmin International Inc., http://www.garmin.com/products/gps35/, Accessed 5/8/04

Hart, S. G., Staveland, L.E., (1988), "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research," *Human Mental Workload, Edited by Handcock, P. and Meshkati, N.*, pp. 139-183 North-Holland, Amsterdam.

Hong, J. I., Landay, J. A., (2001), "An Infrastructure Approach to Context-Aware Computing." *Human-Computer Interaction*, Volume 16: pp. 287-303.

International Standards Organisation, (1998), “ISO9241-11 Ergonomic requirements for office work with visual display terminals (VDTs) – Part 11: Guidance on usability”, First Edition 1998-03-15, International Organisation for Standardisation Geneva.

Kern, K., Schiele, B., Junker, H., Lukowicz, P., Troster, G. (2002) "Wearable Sensing to Annotate Meeting Recordings", *The Sixth International Symposium on Wearable Computer,* pp 186-193, The University of Washington, Seattle, USA, October 2002.

Kirakowski, J., "The software usability measurement inventory: background and usage," in *Usability evaluation in industry*, P. W. Jordan, Thomas, B., Weerdmeester, B. A., McClelland, I.L., Ed.: Taylor & Francis, 1996, pp. 169-177.

Kirsh, D., (2001), "The Context of Work" *Human-Computer Interaction*, vol. 16, pp. 305-322.

Knight, J. F., (2002 A), "Ergonomics of wearable computer: implications for musculosketetal loading," *PhD Thesis in School of Mechanical Engineering*. Birmingham: The University of Birmingham, pp. 265.

Knight, J. F., (2002 B), Personal communication – "Comfort Scales of Wearable computers". H. W. Bristow.

Knight, J. F., Baber, (In Press), "A Tool to Assess the Comfort of Wearable Computers".

Knight, J. F., Baber, C., (In Review) "A tool to assess the comfort of wearable computers".

Knight, J. F., Baber, C., Schwirtz, A., Bristow, H. W., (2002 C), "The Comfort Assessment of Wearable Computers" *The Sixth International Symposium on Wearable Computers,* Los Alamitos, CA: IEEE Computer Society, pp 65- 72.

Kozulin, A., (1986), "The concept of activity in Soviet psychology", *American Psychologist*, Vol 41(3), pp 264-274.

Kuuti, K., (1991), "Activity theory and it application to information systems research and development" In H.-E.g. Missen, ed., *Information Systems Research,* Amsterdam: Elsevier Science Publishers, pp 529-549.

Kymissis, J., Kendall, C., Paradiso, J., Gershenfeld, N., (1998), "Parasitic Power Harvesting in Shoes", *The Second International Symposium on Wearable Computing,* Los Alamitos, CA: IEEE Computer Society, pp 132-139.

Landay, J., and Kaufmann, T. (1993) "User interface issues in mobile computing." In *Proc. Fourth Workshop on Workstation Operating Systems* (Napa, CA, October 1993).

Lee, S-W., Mase, K., (2002), "Activity and Location Recognition Using Wearable Sensors", *Pervasive Computing*, Vol 1(3), pp 24-32.

Lehikoinen, J., (2001*),* "An Evaluation of Augmented Reality Navigational Maps in Head-Worn Displays" *Human-Computer-Interaction INTERACT '01*, pp 224 – 231.

Leonhardi, A., Kubach, U., Rothermel, K., Fritz, A., (1999) "Virtual Information Towers – A Metaphor for Intuitive, Location-Aware Information Access in a Mobile environment", *Third International Symposium on Wearable Computers*, Los Alamitos, CA: IEEE Computer Society, pp 15- 20.

Leont'ev, A., (1974), "The Problem of activity in psychology", *Soviet Psychology*, Vol 13(2), pp 4-33.

Lum, W.Y., Lau, F.C.M., (2002), "A Context-Aware Decision Engine for Context Adaptation", *Pervasive Computing*, Vol 1(3), pp 41 – 49.

Lund, N., (2001), *Attention and Pattern Recognition*: Routledge, East Sussex, UK.

Mann, S., (1997) "On the bandwagon or beyond wearable computing", *Personal Technologies*, Vol 1(4), pp 203-207.

Mann, S., (1998) "Definition of Wearable Computer"" Taken from *Mann, S., Key notes Address entitled "Wearable Computing as mean for personal empowerment", The Second International symposium on Wearable Computing, Fairfax VA, May 1998,* http://wearcomp.org/wearcompdef/html, Accessed 5/8/03.

MB Solutions, (2000 A), http://mbinfo.digitalrice.com/1981-84.htm, Accessed 26/8/03.

MB Solutions, (2000 B), http://mbinfo.digitalrice.com/1985-89.htm, Accessed 26/8/03.

McKirdy, J., (1999), "Choosing the UI Tool Which Best Suits Your Needs", *Presented at Interact '99*, Edinburgh Conference Centre, Riccarton, Edinburgh, Scotland, 30th August - 3rd September 1999, http://www.dcs.gla.ac.uk/~jo/PhD/Interact99/interact99.pdf

Meyer and Schvaneveldt, (1971), "Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations", *Psychology,* Vol 90, pp 277-234.

Microsoft, (2004), http://www.microsoft.com/windowsxp/pro/evaluation/sysreqs.mspx, Accessed 15/08/04

Nardi, B. A., (1996), "Studying Context: A comparison of Activity Theory, Situated Action Models, and Distributed Cognition," in *Context and Consciousness*, B. A. Nardi, Ed. Cambridge, Massachusetts: London, England: The MIT Press, 1996, pp. pp 69 - 102.

Newman, N., (1998), http://wearables.essex.ac.uk/sulawesi/introduction.html, Accessed 16/9/03.

Nielsen, J. (1993). *Usability engineering,* Academinc Press Inc., Boston.

Norman, D. A. (1988). *The psychology of everyday things,* Basic Books, New York.

O2 TXT Alerts, (2003), http://www.o2.co.uk/txt/alerts, Accessed 27/7/2003.

O2, (2003), http://www.o2.co.uk/productsservices/xda_index/0,,170,00.html, Accessed 10/9/03.

Ogawa, A., Konishi Y., Shibazaki R., (2001), "Identification of human activity modes with wearable sensors for autonomous human positioning system," *ACRS 2001 - 22nd Asian Conference on Remote Sensing, Vol (2),*pp.1275-1278, Singapore, 5- 9 November 2001.

Palen, L., Salzman, M., Youngs, E., "Discovery and Integration of Mobile Communications in Everyday Life," *Personal and Ubiquitous Computing*, vol. 5(2), pp. 109-122, 2001.

Palmer, S. E. (1975), "The effects of contextual scenes on the identification of objects." *Memory and Cognition,* 3: pp 519 - 526.

Panasonic, (2003), http://www.panasonic.com/computer/notebook/html/01a_18.htm, Accessed 26/8/03.

Park, S., Locher, I., Savvides, A., Srivastava, M. B., Chen, A., Muntz, R., Yuen, S., (2002), "Design of a Wearable Sensor Badge for Smart Kindergarten," *The Sixth International Symposium on Wearable Computers,* Los Alamitos, CA: IEEE Computer Society, pp.231-238.

Pascoe, P., Ryan, N., Morse, D., (1999) “Issues in Developing Context-Aware Computing”, *Handheld and Ubiquitous Computing*, pp 208-221.

Picard, R.W., (1997), *Affective Computing,* The MIT Press, Cambridge: MA.

Piekarski, W., Thomas, B., (2001), "Tinmith - Augmented Reality With Wearable Computers Running Linux." *2nd Australian Linux Conference*, Sydney, NSW, Jan 2001.

Plantronics Ltd,

http://www.plantronics.com/europe_union/en_GB/catalog/display_product_detail.jhtml?rootId=cat1200109&productTypeId=cat1200109&prodId=prod440042, Accessed 5/8/04

Progressive Grocer, (2002), http://www.progressivegrocer.com/progressivegrocer/profitguides/beer/images/powerpoint/beer_sales_by_month_00_01.ppt, Accessed 16/12/2003.

Randell, C. and Muller, H., (2000), The Shopping Jacket: Wearable Computing for the consumer, *Personal Technologies*, Vol 4, pp 241 –244.

Redhat, (2004), http://www.europe.redhat.com/software/linux/hardware.php3, Accessed 15/8/04

Rhodes, B., (1997), "The Wearable Remembrance Agent: A system for augmented memory," *The First International Symposium on Wearable Computers,* Los Alamitos, CA: IEEE Computer Society, pp 123-128.

Rugg, G., Corbridge, C., Major, N.P., Burton, A.M.,(1992) "A Comparison of Sorting Techniques in Knowledge Acquisition," *Knowledge Acquisition*, vol. 4, pp. 279-291.

Salber, D., Dey, A.K., Abowd, G.D., (1999) “The Context Toolkit: Aiding the Development of Context-Enabled Applications”, *Proceeding of CHI’99*, pp 96-103.

Schmidt, A., Beigl, M., Gellersen, H. W., (1999 B), “There is more to Context than Location”, *Computers & Graphics-UK,* Vol 23(6), pp893-901.

Schmidt, A., Gellersen, H.W., Beigl, M., (1999 A) “A Wearable Context-Awareness Component: Finally a Good Reason to Wear a Tie”, *Third International Symposium on Wearable Computers*, Los Alamitos, CA: IEEE Computer Society, pp 176-177.

Sharples, M. (2003) “Disruptive Devices: Mobile Technology for Conversational Learning.” *International Journal of Continuing Engineering Education and Lifelong Learning*, 12(5/6), pp. 504-520.

Sinclair, M., (1995), “Subjective assessment”, *In J.R. Wilson and E.N. Corlett (eds.) Evaluation of Human Work*, London: Taylor and Francis, pp 69-100.

Somervell, J., Chewar, C. M., McCrickard, D. S., Ndiwalana, A., (2003), “Enlarging usability for ubiquitous displays.” In *Proceedings of the ACM-SE Conference*

Starner, T., (1996), “Human Powered Wearable Computing”, *IBM Systems Journal,* Vol 35 (3&4),

pp 618-629.

Starner, T., (2001), “The Challenges of Wearable Computing: Part 1”, IEEE Micro, 21(4), July 2001, pp 44-52.

Starner, T., (2002), "Attention, Memory, and Wearable Interfaces," *IEEE Pervasive Computing*, vol. 1 (4), pp. 88-91.

Starner, T., (2002), “The Role of Speech Input in Wearable Computing”, *IEEE Pervasive Computing,* Vol 1(3), July 2002, pp 89-93.

Starner, T., Mann, S., Rhodes, B., Levine, J., Healey, J., Kirsch, D., Picard, P., Pentland, A., "Augmented Reality Through Wearable Computing," *Presence*, vol. 6 (4), 1997, pp 386-398.

Stein, S., Ferrero, S., Hetfield, M., Quinn, A., Krichever, M., (1998), "Development of a commercially Successfull Wearable Data Collection System.", *The Second International Symposium on Wearable Computers*, Los Alamitos, CA: IEEE Computer Society, pp 18-25.

Tang, J. C., Yankelovich, N., Begole, J, Kleek, M.V., Li, F., Bhalodia, J., (2001), "ConNexus to Awarenex: Extending awareness to mobile users," *CHI 2001,* pp.221-228, Seattle, WA, USA, March 21- April 4.

The New Oxford Dictionary of English, (1998 A), *The New Oxford Dictionary of English*, Judy Pearsall Eds, Oxford University Press, pp 397.

The New Oxford Dictionary of English, (1998 B), *The New Oxford Dictionary of English*, Judy Pearsall Eds, Oxford University Press, pp 1693.

The New Oxford Dictionary of English, (1998 C), *The New Oxford Dictionary of English*, Judy Pearsall Eds, Oxford University Press, pp 2110.

Tolmie, P., Pycock, J., Diggins, T., MacLean, A., Karsenty, A., (2002), “Unremarkable Computing”, *Chi ’02,* Vol 4(1), pp 399-406, Minneapolis, Minnesota, USA 20-25 April 2002.

Turner, R. M. (1998), "Context-mediated behaviour for intelligent agents." *International Journal Human-Computer Studies*, 48: pp 307 - 330.

Urnes, T., Hatlen, A. S., Malm, P. S., Myhre, O. (2001), “Building Distributed Context-Aware Applications”, *Personal and Ubiquitous Computing*, vol. 5, pp 38-41.

Van Laerhoven, K., Aidoo, K., Lowette, S., (2001) “Real-time Analysis of Data from Many Sensors with Neural Networks”, *Fifth International Symposium on Wearable Computers*, Los Alamitos, CA: IEEE Computer Society, pp 115-121.

Van Laerhoven, K., Schmidt, A., Gellersen, H., (2002), “Multi-Sensor Context Aware Clothing”, *The Sixth International Symposium on Wearable Computer,* Los Alamitos, CA: IEEE Computer Society, pp 49-56.

VanVeenendaal, E.P., (1998), “Questionnaire Based Usability Testing”, *Proceedings of QWE’98*, pp 118-134, Brussels, Belgium, 9-13 November.

Vavoula, G., (2003), “KleOS: A Knowledge and Learning Organisation System in Support of Lifelong Learning”, *in School of Electronic, Electrical and Computer Engineering,* Birmingham: The University of Birmingham, Chapter 3.

Vodafone UK Ltd, (2003) ,http://www.vodafone.com, Accessed 1/2/03

WAP Forum Organisation, http://www.wapforum.org, Accessed 10/9/03.

Wikipedia, (2004), http://en.wikipedia.org/wiki/IMT-2000, Accessed 5/9/04

Winograd, T. (2001). "Architectures for Context." *Human-Computer Interaction,* Volume 16: pp. 401-419.

Xybernaut, (2003), http://www.xybernaut.com/home.asp, Accessed 26/8/03.

Appendix A Context Software Code

For Appendix A please see the attached cd-rom.

Appendix B Usability

ISO 9241-11 (ISO, 1998) suggests measuring usability on three levels effectiveness, efficiency and satisfaction. Time and accuracy are obvious measures for effectiveness and efficiency. This chapter introduces usability and investigates the NASA TLX (Hart and Staveland 1988) workload scale and the SUMI software usability scale (Kirakowski, 1996). The SUMI Scale is a well-validated scale for rating the usability of software. It has however, only been applied to software used on desktop computers. An experiment is described that has been carried out to compare how users rate a common piece of software when used on a wearable computer and a desktop computer. The aim being to investigate whether the SUMI scale can be used for rating usability of software regardless of the hardware the software is used on. The results indicate that the SUMI scale rates the usability of the software similarly whether it is used on a desktop or a wearable computer. Aim four of the research was to ensure that the system is highly usable; by assessing suitable usability measures this may be possible.

Introduction

In Chapter 2, section 2.7 the idea of usability and user acceptance was discussed. When designing new technology, it is important to think about how usable a design is and how easily users will accept it. For a piece of new technology to be accepted it must either be very usable or the benefits from the technology must be very great, and preferably both. ISO 9241-11 (ISO, 1998) suggests measuring usability on three levels Effectiveness, Efficiency and Satisfaction. A number of measures of usability were suggested in Chapter 2, section 2.7. This section looks at the SUMI scale in particular and how well it can be applied to wearable computers.

Table 32 - ISO 9241-11(ISO, 1998) usability suggestions

Usability objective	Effectiveness measures	Efficiency measures	Satisfaction measures
Overall usability	Percentage of goals achieved; Percentage of users successfully completing task; Average accuracy of completing tasks	Time to complete a task; Tasks compared per unit of time; Monetary cost of performing the task	Rating scale for satisfaction. Usage rate over time; Frequency of complaints.

SUMI Conversion Experiment

A usability scale does not currently exist for the evaluation of software used on wearable computers. The SUMI rating scale "is a rigorously tested and validated method to measure software quality from a participant perspective" (VanVeenendaal 1998). One of the possible problems with the SUMI scale is that it has been designed and validated for desktop software packages only. It is not immediately clear if the scales are applicable to wearable devices, where novel input and display methods are involved. Most Windows-based software is designed with the prerequisites of a screen, keyboard and mouse. Without these it is unknown whether the scale would still be valid.

Therefore an experiment was designed to investigate application of the SUMI scale to software being used on a wearable computer.

Participants were asked to complete simple tasks in Microsoft Excel, for example creating a graph of previously entered data and calculating some means and standard deviations. The aim was to compare, in terms of usability, a familiar piece of software being used on a desktop computer and on a wearable computer. If it was shown that the usability of the software was rated similarly when used on both platforms, then it should indicate that the scale is suitable for assessing the usability of software on both platforms. Therefore the validity of the SUMI scale shown on desktop computer is also applicable to software used on wearable computers.

B.1.1 Hypothesis

It is hypothesised that the usability of Microsoft Excel will be rated more highly when the software was presented to the participants on the desktop platform than on the wearable computer. The wearable computer introduces novel interaction devices, which are unfamiliar to the participants, for example HMDs and thumb mice. It is expected therefore that reported usability will be lower.

Method

B.1.2 Participants

Twenty-four undergraduate students participated in the experiment (one female, twenty-three male), with a mean age of twenty (standard deviation two). All participants were familiar with the Excel package.

B.1.3 Procedure

The participants were randomly assigned to one of the two conditions and were asked to complete a set of tasks using Microsoft Excel.

In condition one they used a standard desktop PC with monitor, keyboard and mouse. In condition two they used the wearable computer (χ^{3+}), with the head-up display and thumb mouse and no keyboard. The two computers were of similar specifications, 600 or 700 MHz with 256Mb of RAM and ran at round about the same speed.

The participants were given standardised instructions. Each participant was given a standard data set and asked to manipulate the data in a number of ways. They were asked to calculate the average and standard deviation of columns of data. Then to produce a pie chart and a bar-graph of data subsets to which they had to add additional data and titles and labels. This involved using multiple Excel worksheets. The experimental instructions and tasks can be seen in Appendix F.

The participants were given a fifteen-minute time limit to complete the experimental tasks. Following task completion each participant completed the SUMI questionnaire (Described in Section 2.7.4)

SUMI Scaling Results

The SUMI results were compared between the two conditions.

Table 33 – mean SUMI results for all participants in each subscale, for condition one and two

Condition		SUMI Scales					
1.Desktop		Global	Efficiency	Affect	Helpfulness	Control	Learnability
	Mean	45.75	49.00	43.75	47.75	49.58	47.25
	SD	9.95	9.52	11.69	9.75	13.30	11.59
2.Wearable Computer							
	Mean	43.33	45.08	38.67	47.25	39.08	46.25
	SD	11.40	12.00	14.31	12.26	16.74	8.02

The mean scores for each category shown above in Table 33 are below the suggested performance score of fifty, set by SUMI for usable pieces of commercial software.

A Mann-Whitney test was carried out on each of the six sub-scales, with condition as the grouping variable.

Table 34 - Test results of Mann-Whitney performed on SUMI subscales

	Global	Efficiency	Affect	Helpfulness	Control	Learnability
Z	-0.58	-1.0	-0.81	-0.15	-1.67	-0.52
Asymp. Sig. (2-tailed)	0.563	0.340	0.419	0.885	0.094	0.603

No significant difference between the conditions was found in any subscale. Figure 54 is a graphic representation of the results. Whilst no significant difference in any subscale has been found, in all cases it can be seen the users rated software slightly lower when used on the wearable computer.

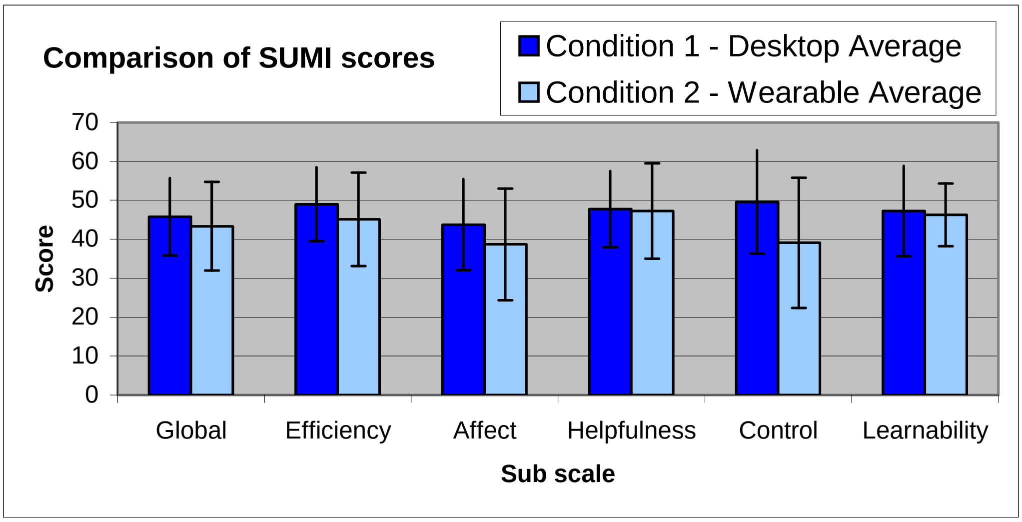


Figure 54 - Chart of the mean SUMI scores

SUMI Scaling Discussion

Unexpectedly the results suggested that participants did not rate the usability of software, in this case Excel, any differently when using it on a wearable computer or on a more familiar platform, the desk top computer. No significant difference was found between the two conditions, but the wearable computer rating is always lower even if not significant.

It was expected that the participants would find Excel much harder to control and use on the wearable computer due to the decreased screen size and unfamiliarity of the thumb mouse and on screen keyboard. Given that the average score given for all sub scales in both conditions is under fifty, then one explanation might be that the participants simply did not like Excel in any form and that, whatever the input devices or display type they would never find this piece of software useable. However it is also possible that the participants found enough familiar about the wearable computer, for example Excel and Windows looked similar to traditional Excel and Windows. Therefore the other sections of the wearable computer did not detract from the usability of the software.

Importantly, the results would suggest that the SUMI scale is valid for wearable devices and does not need to be scaled or altered in any way to rate the use of software on wearable computers. Therefore the validity of the SUMI scale demonstrated on numerous pieces of software still holds true for assessing wearable software.

Chapter Summary

The time, accuracy, the SUMI scale and the NASA TLX have been introduced as measures of effectiveness, efficiency and satisfaction. ISO 9241-11 suggests effectiveness, efficiency and satisfaction as components of overall usability. Time, accuracy and the NASA TLX are technology independent; it was not clear however if the SUMI scale would work as well for software used on wearable computers, as it has been shown to work for software used on desktop computers. By using these measures the usability of the systems can be assessed by basing the development of each iteration of the system on the assessment of usability of the previous system, aim four, ensuring the system is highly usable, can be achieved.

The SUMI scale has been used to compare the same piece of software on a wearable computer and a desktop computer. No difference has been found in the participants' ratings of the software. Therefore the results suggest that the SUMI scale can be used to rate software on wearable computers in the same way as for desktop computers.

Appendix C Location Questions and Answers

Each participant was given this table, without the answers.

Location:	**Arrival time at building**	**Departure time at building**	**Answer**	**How did you get it?**	**Any Problems?**
Library					
Q1: In what year did Queen Elizabeth lay a stone in the library?			1957	Look at stone, or read the library web page.	
Q2: How many shields are above the main doors?			3	http://www.is.bham.ac.uk/mainlib/about.htm or go and look	
Psychology					
Q1: Name of buildings			Frankland, Hills	http://psg275.bham.ac.uk Look at buildings	
Q3: What colour (mainly) are these buildings?			Red	Go and look or look at picture on the web.	

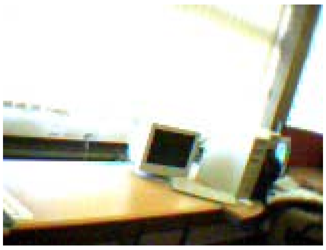
Aston Web					
Q1: Who are the three central statues above the front door of?			Plato, Shakespeare, Newton	Look at the statues or look at a picture on the web.	
Q2: What year was the university opened?			1900	http://www.about.bham.ac.uk or ask the attendant	
EEE					
Q1: How many degree courses does the department offer?			4	http://www.eee.bham.ac.uk or ask in the office	
Q3: How many floors does this building have?			6 plus the roof	Look at a picture on the web or look at the building.	

Appendix D Posture and Movement Questions and Answers

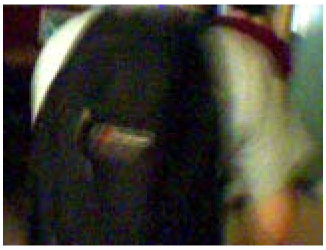
Location:	**Arrival time at building**	**Departure time at building**	**Answer**	**How did you get it? What was your body position?**	**Any Problems?**
Library					
Q1: Which University building is the first B on the list of services			Barber Fine Art Gallery	Is>a-z of services Bulleted list	
Q2: What are the opening hours of the main library (Monday to Thursday)			900-2100	Is>Information for visitors>enquiries Bulleted list	
Munro Sports Centre					
Q1: What number should you ring to book a squash court?			01214144117	Munro page>booking information & Bulleted list	

Q2: What and where is the outdoor centre?			RAYMOND PRIESTLEY CENTRE FOR OUTDOOR PURSUITS AND FIELD STUDIES CONISTON, CUMBRIA	Munro page>outdoor centre	
EEE					
Q1: When is IEE Eurowearable			3/4/5th September 2003	Main page>news and events & Sound	
Q2: What are the two research headings?			Interactive Electronic and Communication Systems. Emerging Device Technology	Main screen>research profile	

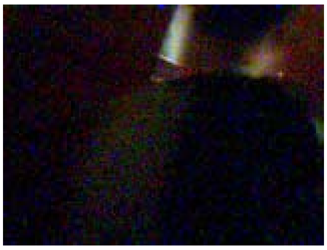
Appendix E Example of automated picture collection



The School of Electronic and Electrical Engineering. 14:06:00 Standing 14:06:00 Diary 14:06:00



The School of Electronic and Electrical Engineering. 14:06:00 Standing 14:06:00 14:06:00

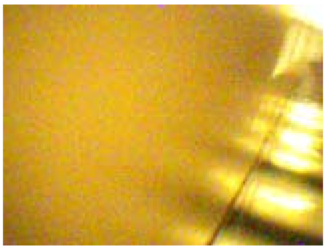


The School of Electronic and Electrical Engineering. 14:06:00 Walking 14:06:00 14:06:00

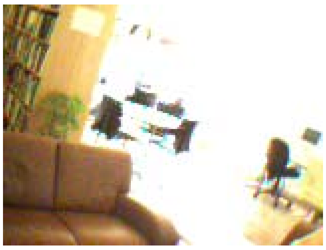
The School of Electronic and Electrical Engineering. 14:07:00 Standing 14:07:00 14:07:00

The School of Electronic and Electrical Engineering. 14:07:00 Walking 14:07:00 14:07:00

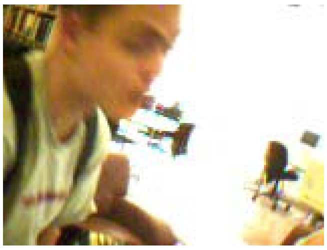
The School of Electronic and Electrical Engineering. 14:08:00 Standing 14:08:00 14:08:00



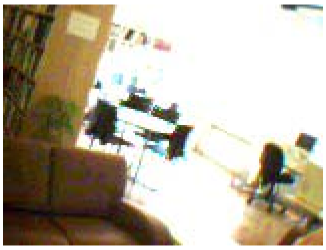
The School of Electronic and Electrical Engineering. 14:08:00 Walking 14:08:00 14:08:00



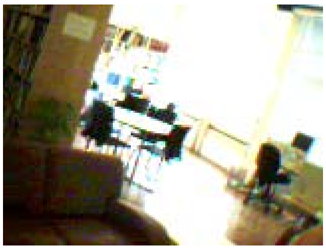
The School of Electronic and Electrical Engineering. 14:08:00 Walking 14:08:00 Book 14:08:00



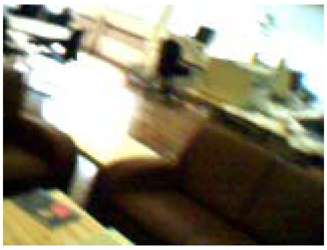
The School of Electronic and Electrical Engineering. 14:09:00 Walking 14:09:00 14:09:00



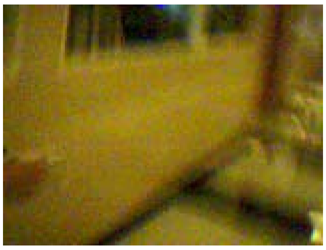
The School of Electronic and Electrical Engineering. 14:09:00 Standing 14:09:00 14:09:00



The School of Electronic and Electrical Engineering. 14:09:00 Standing 14:09:00 Book 14:09:00

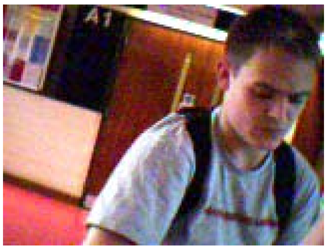


The School of Electronic and Electrical Engineering. 14:09:00 Standing 14:09:00 14:09:00

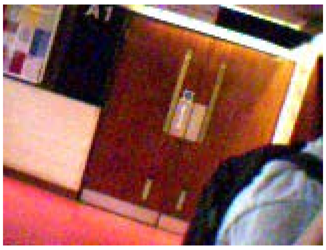


The School of Electronic and Electrical Engineering. 14:10:00 Walking 14:10:00 14:10:00

The School of Electronic and Electrical Engineering. 14:10:00 Walking 14:10:00 Diary 14:10:00

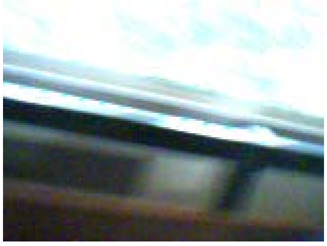


The School of Electronic and Electrical Engineering. 14:10:00 Walking 14:10:00 14:10:00

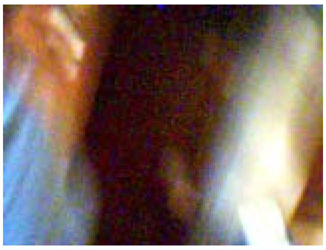


The School of Electronic and Electrical Engineering. 14:11:00 Standing 14:11:00 14:11:00

The School of Electronic and Electrical Engineering. 14:11:00 Standing 14:11:00 Diary 14:11:00



The School of Electronic and Electrical Engineering. 14:11:00 Standing 14:11:00 14:11:00



The School of Electronic and Electrical Engineering. 14:11:00 Walking 14:11:00 14:11:00

The School of Electronic and Electrical Engineering. 14:11:00 Standing 14:11:00 14:11:00

The School of Electronic and Electrical Engineering. 14:12:00 Walking 14:12:00 14:12:00

The School of Electronic and Electrical Engineering. 14:13:00 Standing 14:13:00 14:13:00

The School of Electronic and Electrical Engineering. 14:14:00 Walking 14:14:00 14:14:00

An Unknown Building 14:14:00 Walking 14:14:00 14:14:00

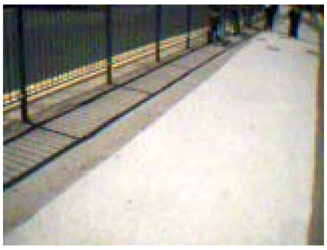
The Munro Sports Centre. 14:15:00 Walking 14:15:00 14:15:00

The Munro Sports Centre. 14:16:00 Standing 14:16:00 14:16:00

The Munro Sports Centre. 14:16:00 Walking 14:16:00 14:16:00

An Unknown Building 14:20:00 Walking 14:20:00 14:20:00

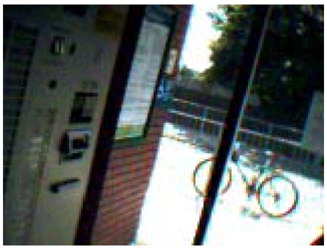
The University Station. 14:22:00 Walking 14:22:00 14:22:00



The University Station. 14:22:00 Standing 14:22:00 14:22:00

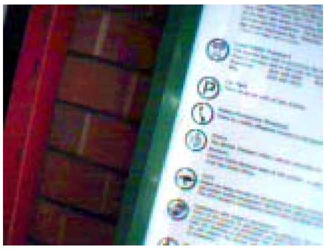
The University Station. 14:22:00 Walking 14:22:00 14:22:00

The University Station. 14:22:00 Standing 14:22:00 14:22:00



The University Station. 14:23:00 Standing 14:23:00 Diary 14:23:00

The University Station. 14:23:00 Standing 14:23:00 14:23:00



The University Station. 14:23:00 Walking 14:23:00 14:23:00

An Unknown Building 14:24:00 Walking 14:24:00 14:24:00

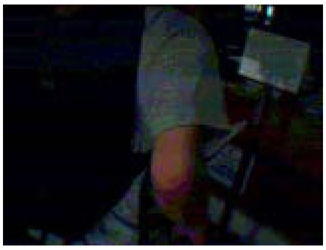
The Main Library. 14:30:00 Walking 14:30:00 14:30:00

The Main Library. 14:30:00 Standing 14:30:00

The Main Library. 14:30:00 Walking 14:30:00

14:30:00

14:30:00

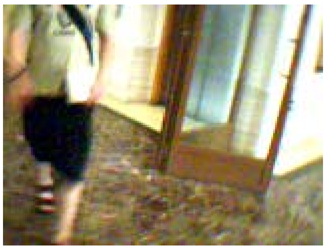


The
Main Library. 14:30:00 Standing
14:30:00 14:30:00

The Main Library. 14:31:00
Walking 14:31:00
14:31:00

The Main Library. 14:31:00
Standing 14:31:00
14:31:00

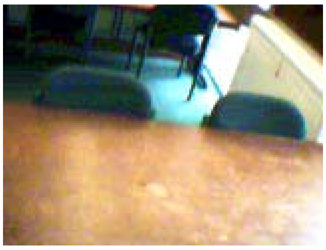
The
Main Library. 14:31:00 Standing
14:31:00 Diary 14:31:00



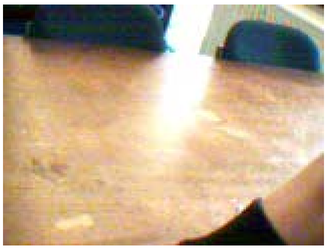
The Main Library. 14:31:00
Standing 14:31:00
14:31:00

The Main Library. 14:31:00
Walking 14:31:00
14:31:00

The
Main Library. 14:32:00 Standing
14:32:00 14:32:00

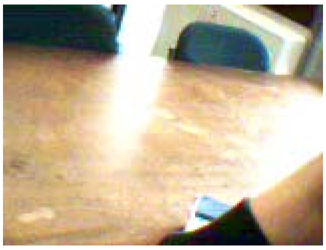


The Main Library. 14:32:00
Walking 14:32:00
14:32:00

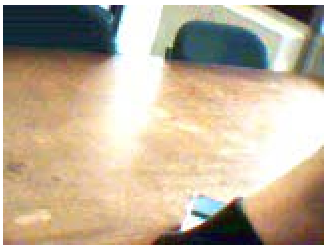


The Main Library. 14:33:00
Walking 14:33:00
Book 14:33:00

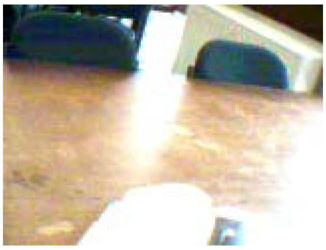
The
Main Library. 14:33:00 Walking
14:33:00 14:33:00



The Main Library. 14:33:00
Walking 14:33:00
Book 14:33:00

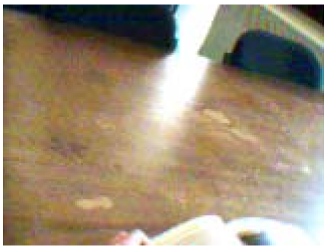


The Main Library. 14:33:00
Sitting 14:33:00
Book 14:33:00



The
Main Library. 14:33:00 Sitting

The Main Library. 14:34:00

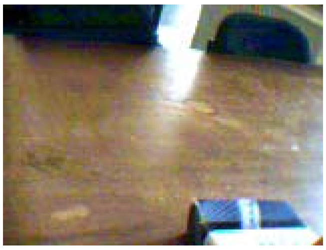


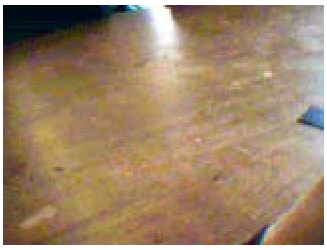
The Main Library. 14:34:00

14:33:00 14:33:00

Sitting 14:34:00
Book 14:34:00

Sitting 14:34:00
14:34:00





The
Main Library. 14:34:00 Sitting
14:34:00 Book 14:34:00

The Main Library. 14:34:00
Sitting 14:34:00
14:34:00

The Main Library. 14:40:00
Sitting 14:40:00
Diary 14:40:00

The
Main Library. 14:41:00 Sitting
14:41:00 14:41:00

The Main Library. 14:41:00
Walking 14:41:00
14:41:00

The Main Library. 14:42:00
Standing 14:42:00
14:42:00

The
Main Library. 14:42:00 Walking
14:42:00 14:42:00

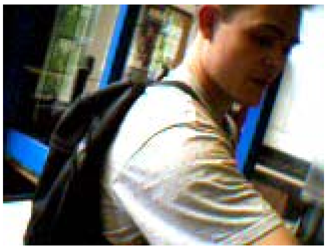
An Unknown Building 14:44:00
Walking 14:44:00
14:44:00

The Guild of Students. 14:45:00
Walking 14:45:00
14:45:00

The
Guild of Students. 14:46:00 Standing
14:46:00 14:46:00

The Guild of Students. 14:47:00
Walking 14:47:00
14:47:00

The Guild of Students. 14:47:00
Standing 14:47:00
14:47:00



The

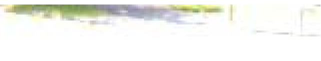
Guild of Students. 14:47:00 Walking 14:47:00 14:47:00

The Guild of Students. 14:47:00 Standing 14:47:00 14:47:00

The Guild of Students. 14:48:00 Standing 14:48:00 Diary 14:48:00

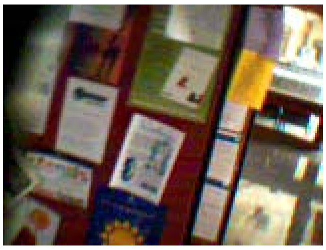
The Guild of Students. 14:48:00 Standing 14:48:00 14:48:00

The Guild of Students. 14:48:00 Walking 14:48:00 14:48:00

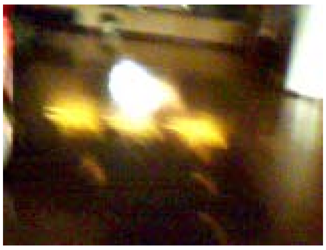


An Unknown Building 14:50:00 Walking 14:50:00 14:50:00

An Unknown Building 14:53:00 Standing 14:53:00 14:53:00

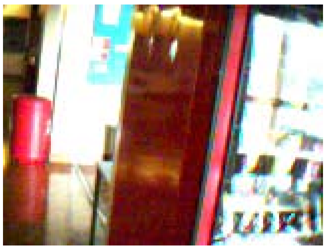


An Unknown Building 14:53:00 Walking 14:53:00 14:53:00



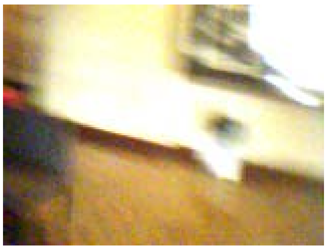
The School of Electronic and Electrical Engineering. 14:54:00 Walking 14:54:00 14:54:00

The School of Electronic and Electrical Engineering. 14:55:00 Standing 14:55:00 14:55:00



The School of Electronic and Electrical Engineering. 14:55:00 Walking 14:55:00 14:55:00

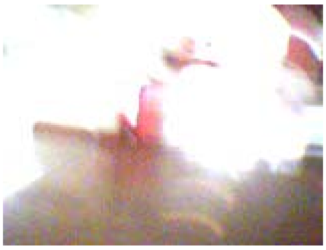
The School of Electronic and Electrical Engineering. 14:55:00 Standing 14:55:00 14:55:00



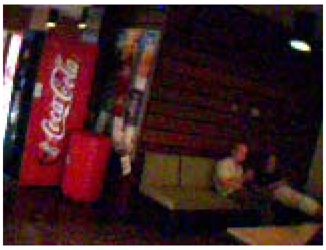
The School of Electronic and Electrical Engineering. 14:56:00 Walking 14:56:00 14:56:00

The School of Electronic and Electrical Engineering. 14:56:00 Standing 14:56:00 14:56:00

The School of Electronic and Electrical Engineering. 14:56:00 Walking 14:56:00 14:56:00



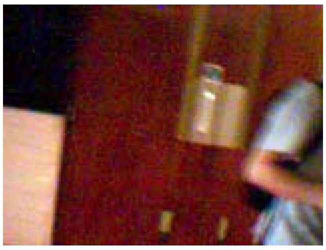
The School of Electronic and Electrical Engineering. 14:56:00 Standing 14:56:00 14:56:00



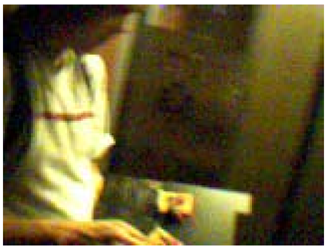
The School of Electronic and Electrical Engineering. 14:56:00 Standing 14:56:00 Coffee Cup 14:56:00

The School of Electronic and Electrical Engineering. 14:56:00 Standing 14:56:00 14:56:00

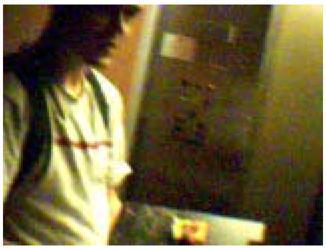
The School of Electronic and Electrical Engineering. 14:57:00 Walking 14:57:00 14:57:00



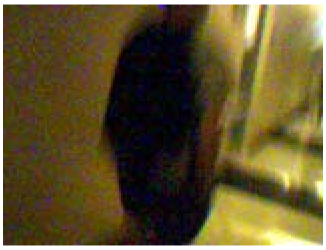
The School of Electronic and Electrical Engineering. 14:57:00 Standing 14:57:00 14:57:00



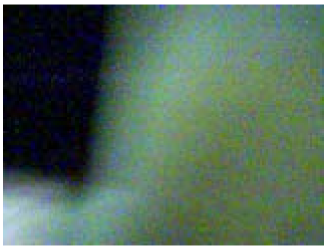
The School of Electronic and Electrical Engineering. 14:57:00 Walking 14:57:00 14:57:00



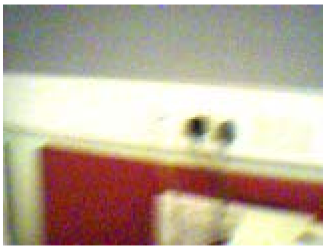
The School of Electronic and Electrical Engineering. 14:57:00 Standing 14:57:00 14:57:00



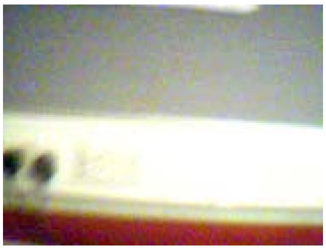
The School of Electronic and Electrical Engineering. 14:58:00 Walking 14:58:00 14:58:00



The School of Electronic and Electrical Engineering. 14:58:00 Standing 14:58:00 14:58:00

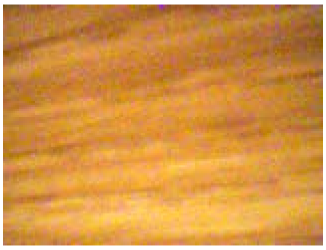


The School of Electronic and Electrical Engineering. 14:58:00 Walking 14:58:00 14:58:00

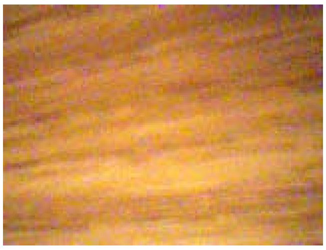


The School of Electronic and Electrical Engineering. 14:58:00 Standing 14:58:00 14:58:00

The School of Electronic and Electrical Engineering. 14:59:00 Walking 14:59:00 14:59:00

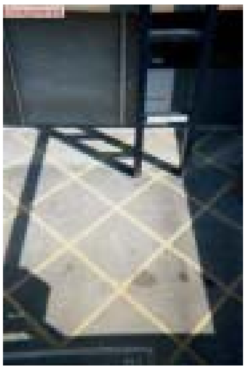


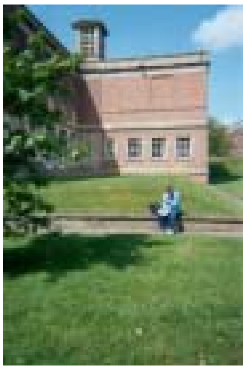
The School of Electronic and Electrical Engineering. 14:59:00 Sitting 14:59:00 14:59:00



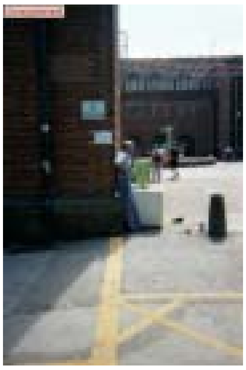
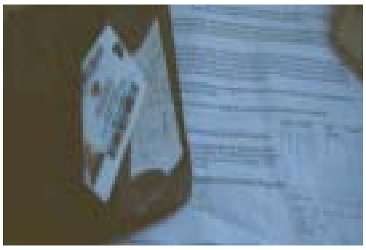
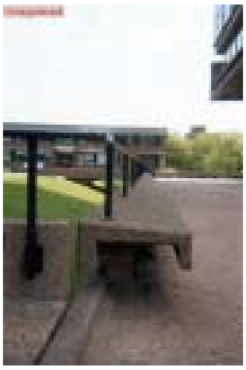
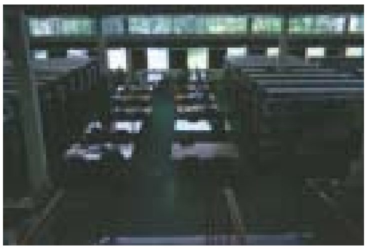
The School of Electronic and Electrical Engineering. 15:00:00 Walking 15:00:00 15:00:00

Appendix F Manual picture capture

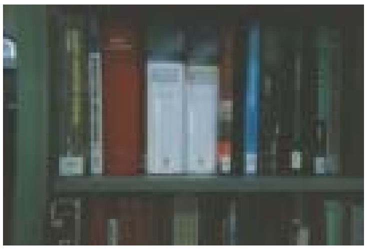


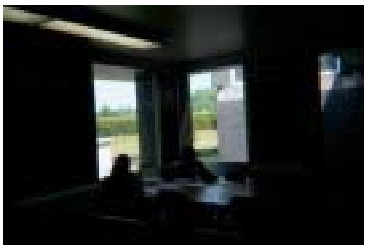
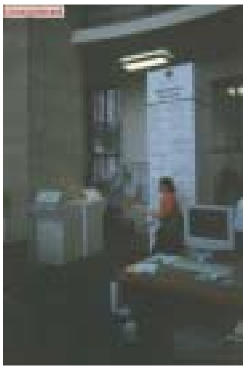



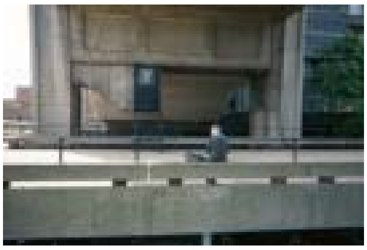
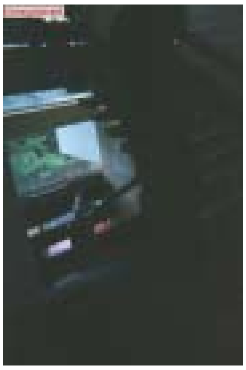
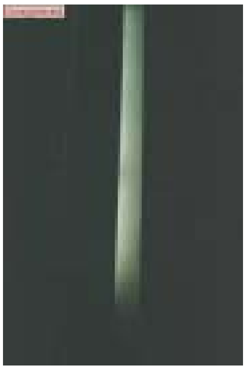






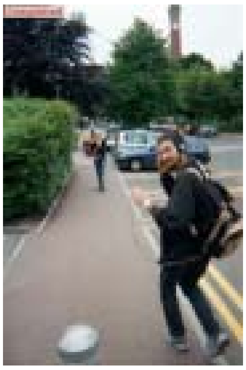
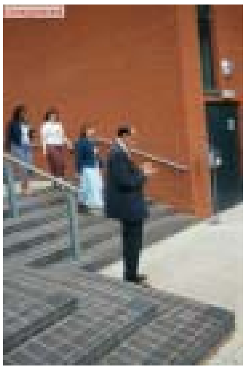




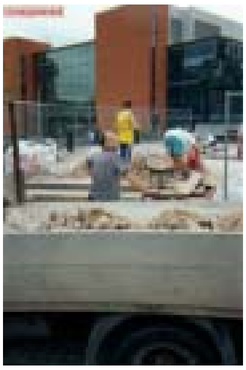
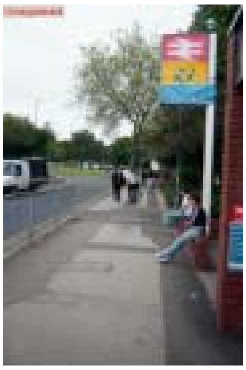




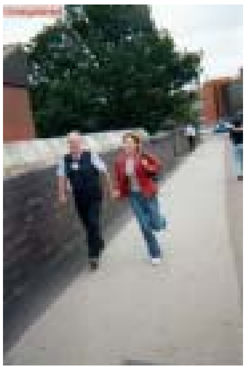


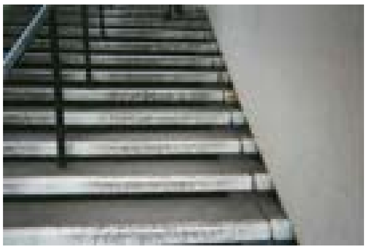


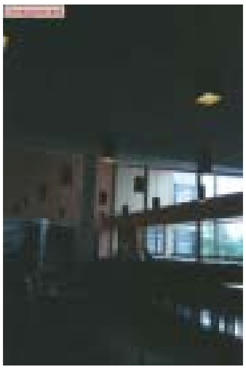






Appendix G SUMI conversion task sheet

Please read all instructions before starting the task!

Calculate the average and stdev of the given data on sheet 1, for each median.

Produce a pie chart of date against cash on sheet 2, first converting the integer values to currency values, and put it on a new sheet (sheet3). Produce a bar graph of the total amounts of cash for each week (7days) in January. Place this on sheet 2. Calculate the average and stdev amount of weekly cash in January and add y error bars showing the stdev to the bar graph. Give the bar graph a title and label the axis.

You can use the help if you need

User Number

Experience of excel (please circle)

Novice intermediate expert

General Computer Experience (please circle)

Novice intermediate expert

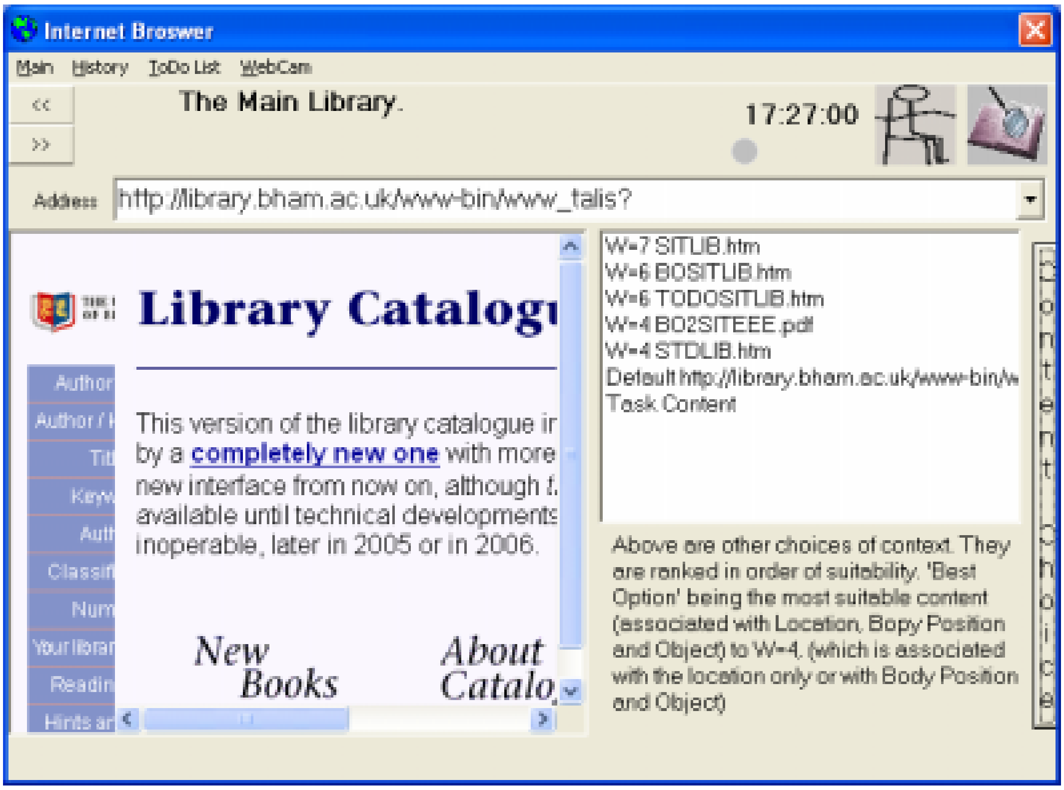
Age

Sex
Occupation

Appendix H χ^{3+} Screen Shots for the CC

This appendix contains some example screen shots of a user in different positions that they may have encountered during the CWCS experiment described in Chapter 8.

1. User sitting in the university library with a book



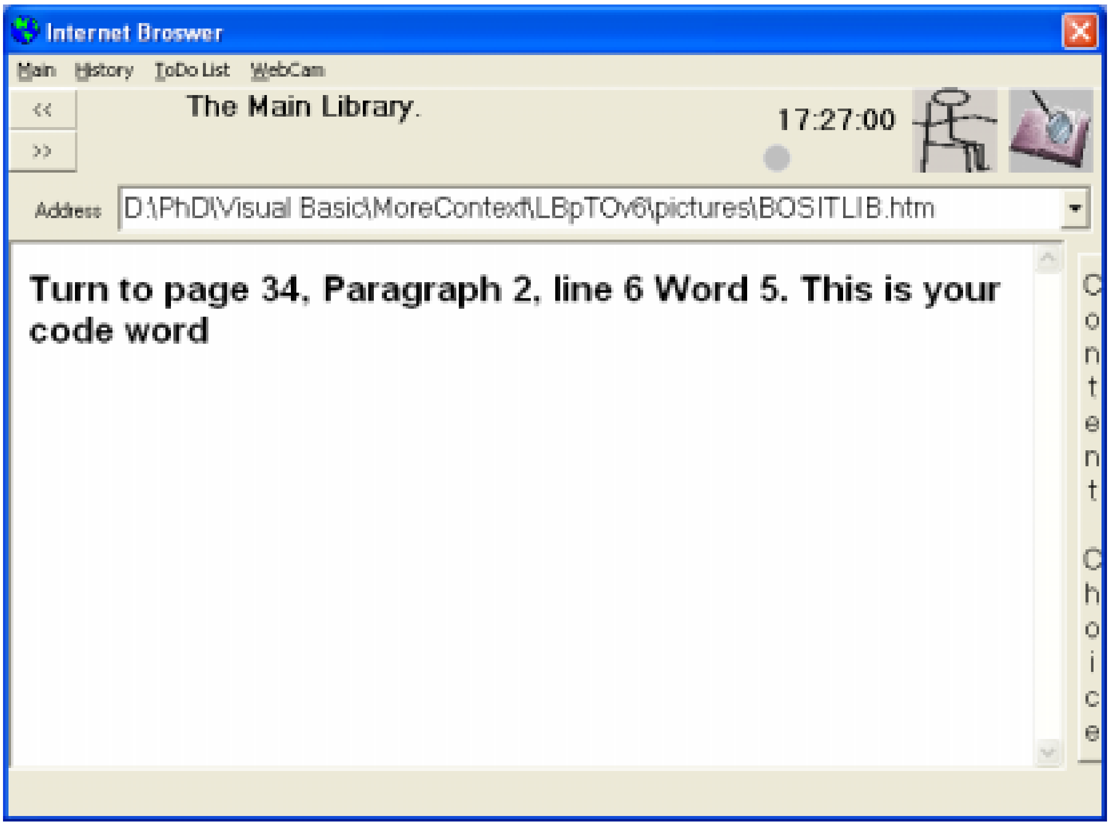
http://library.bham.ac.uk/www-bin/www_talis?

This version of the library catalogue ir by a completely new one with more new interface from now on, although f available until technical developments inoperable, later in 2005 or in 2006.

W=7 SITLIB.htm
W=6 BOSITLIB.htm
W=6 TODOSITLIB.htm
W=4 BO2SITEEE.pdf
W=4 STDLIB.htm
Default http://library.bham.ac.uk/www-bin/w
Task Content

Above are other choices of context. They are ranked in order of suitability. 'Best Option' being the most suitable content (associated with Location, Bopy Position and Object) to W=4. (which is associated with the location only or with Body Position and Object)

2. User sitting in the university library with the book asked for in the experiment



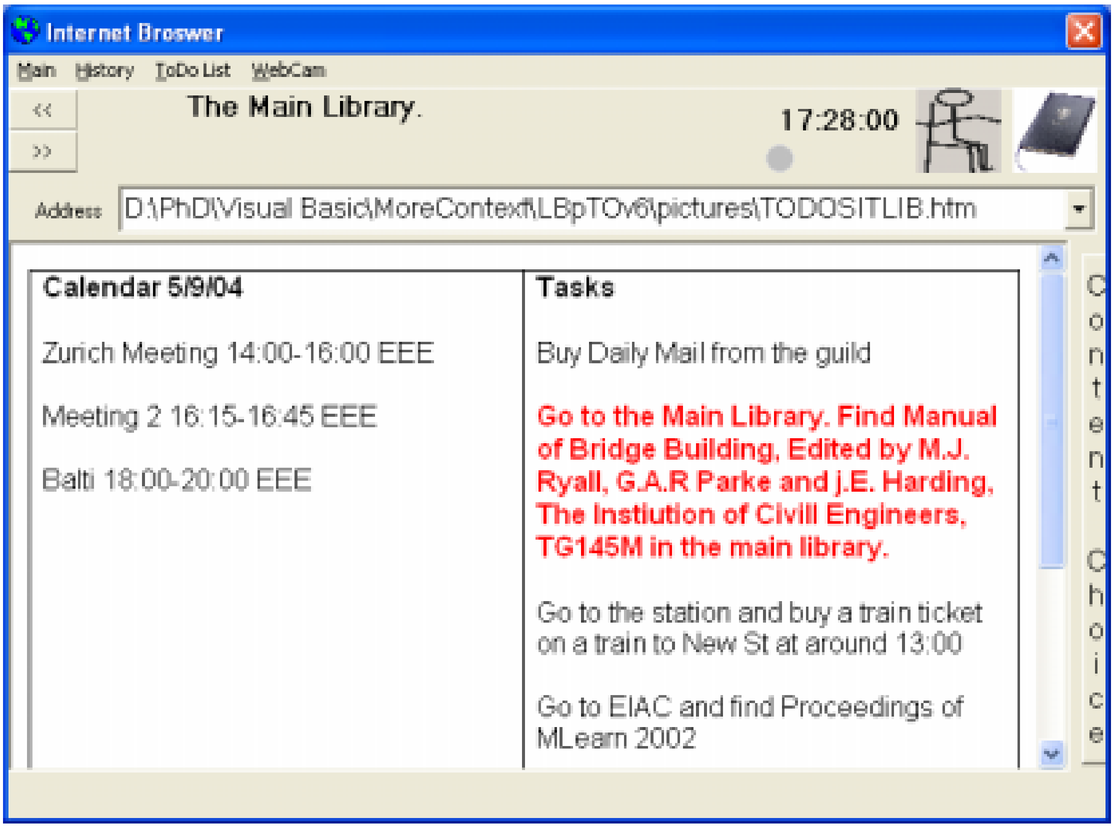
The Main Library.

17:27:00

Address D:\PhD\Visual Basic\MoreContext\LBpTOv6\pictures\BOSITLIB.htm

Turn to page 34, Paragraph 2, line 6 Word 5. This is your code word

3. User sitting at the university library with their diary



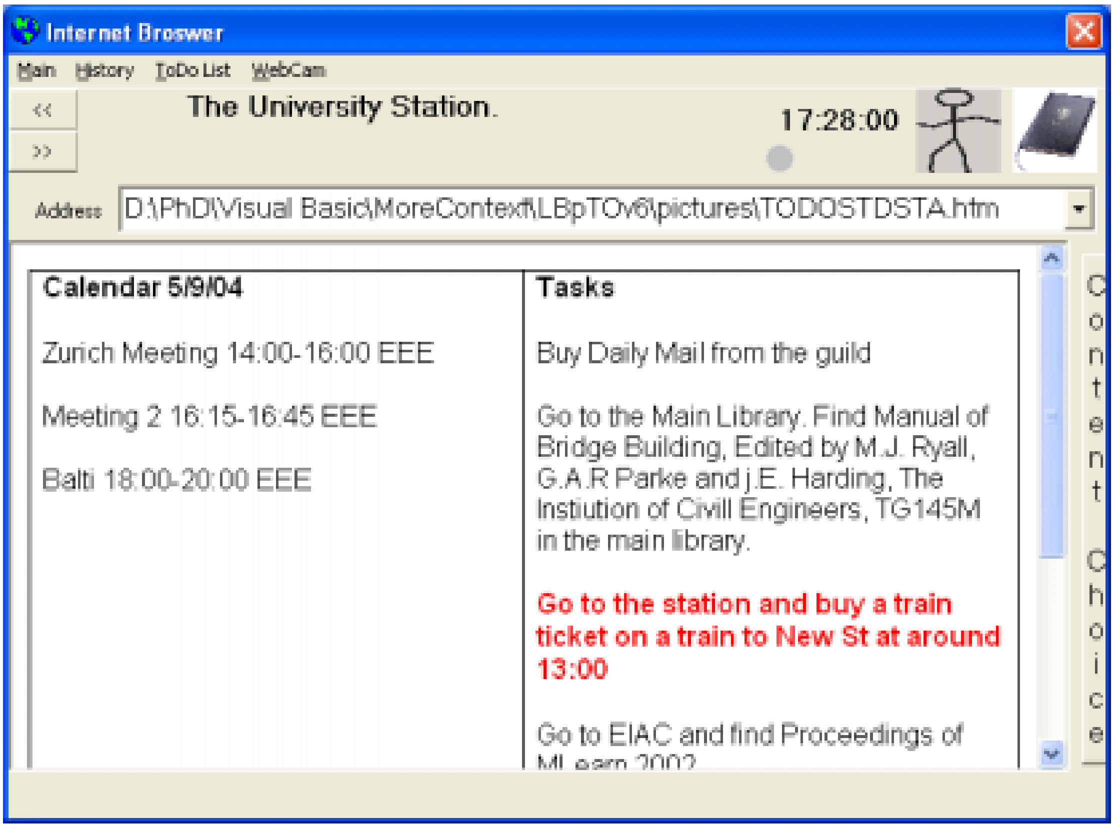
The Main Library.

17:28:00

Address D:\PhD\Visual Basic\MoreContext\LBpTOv6\pictures\TODOSITLIB.htm

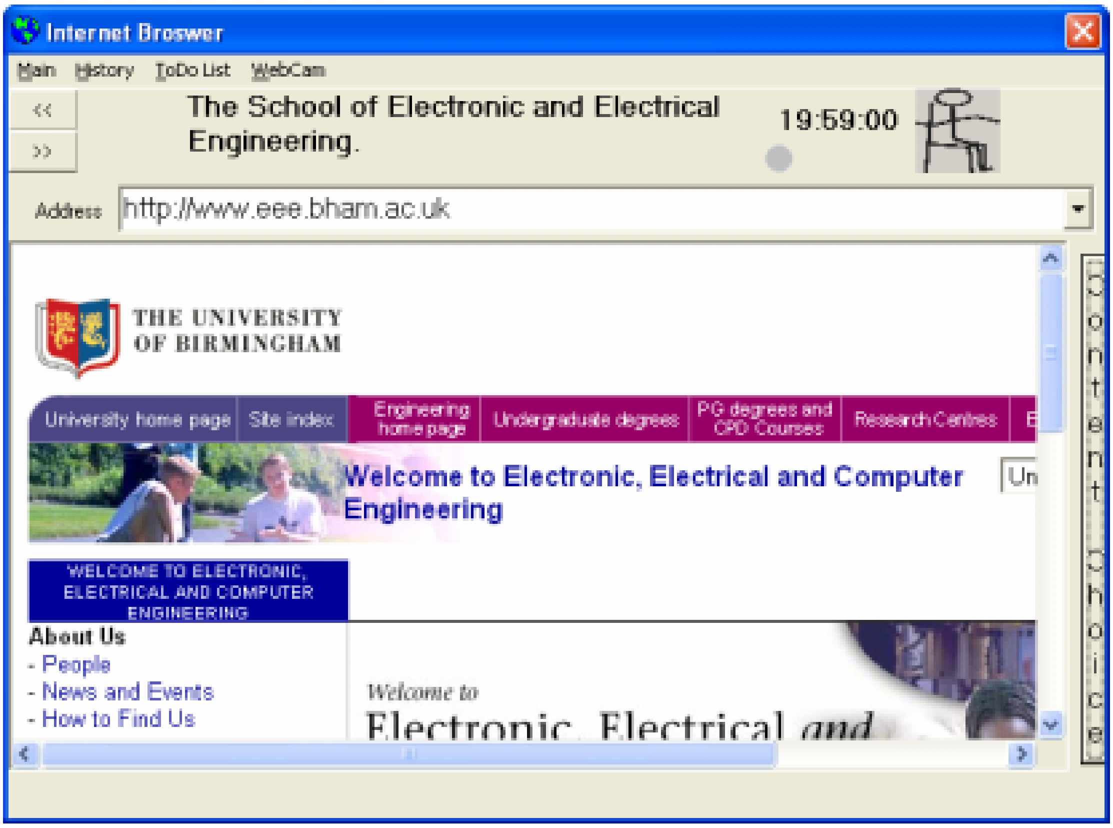
Calendar 5/9/04	Tasks
Zurich Meeting 14:00-16:00 EEE	Buy Daily Mail from the guild
Meeting 2 16:15-16:45 EEE	**Go to the Main Library. Find Manual of Bridge Building, Edited by M.J. Ryall, G.A.R Parke and j.E. Harding, The Instiution of Civill Engineers, TG145M in the main library.**
Balti 18:00-20:00 EEE	Go to the station and buy a train ticket on a train to New St at around 13:00
	Go to EIAC and find Proceedings of MLearn 2002

4. User standing at the university station



Calendar 5/9/04	Tasks
Zurich Meeting 14:00-16:00 EEE	Buy Daily Mail from the guild
Meeting 2 16:15-16:45 EEE	Go to the Main Library. Find Manual of Bridge Building, Edited by M.J. Ryall, G.A.R Parke and j.E. Harding, The Instiution of Civil Engineers, TG145M in the main library.
Balti 18:00-20:00 EEE	Go to the station and buy a train ticket on a train to New St at around 13:00
	Go to EIAC and find Proceedings of MLearn 2002

5. User sitting at the School of Electronic and Electrical Engineering.



The School of Electronic and Electrical Engineering.

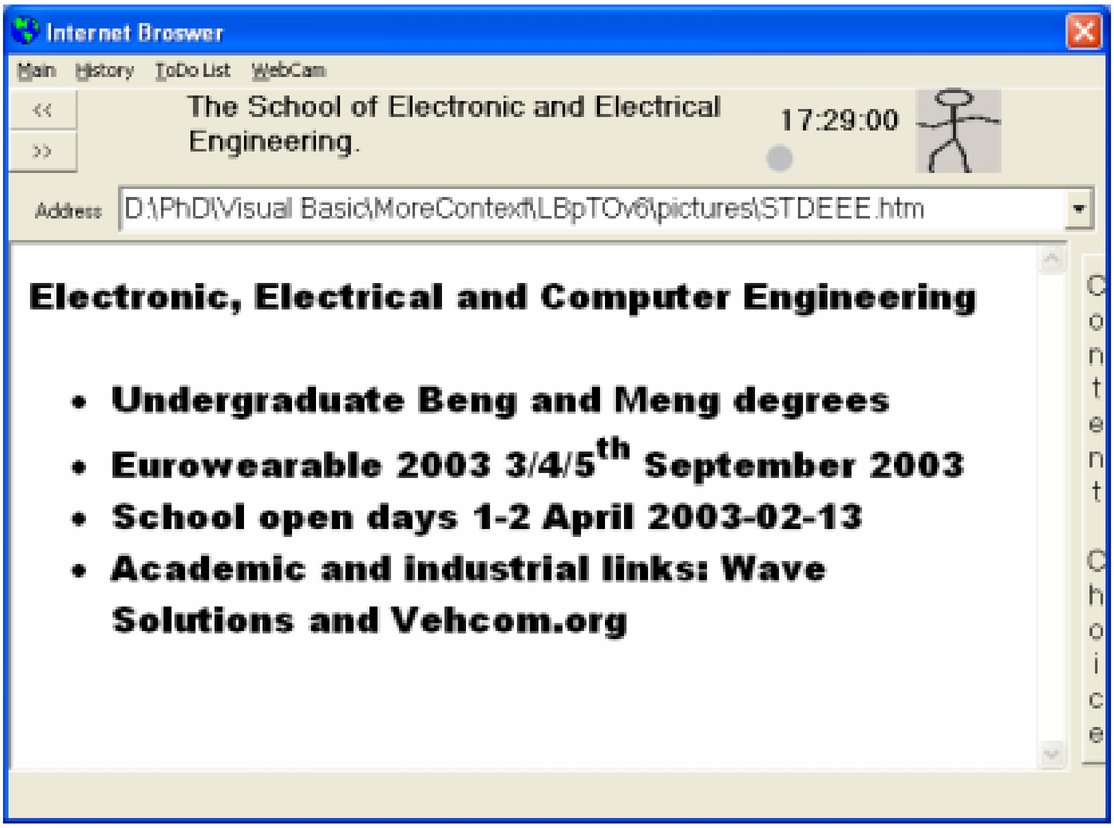
19:59:00

Address: http://www.eee.bham.ac.uk

Welcome to Electronic, Electrical and Computer Engineering

Welcome to Electronic, Electrical and

6. User standing at the Electronic and Electrical Engineering building



The School of Electronic and Electrical Engineering.

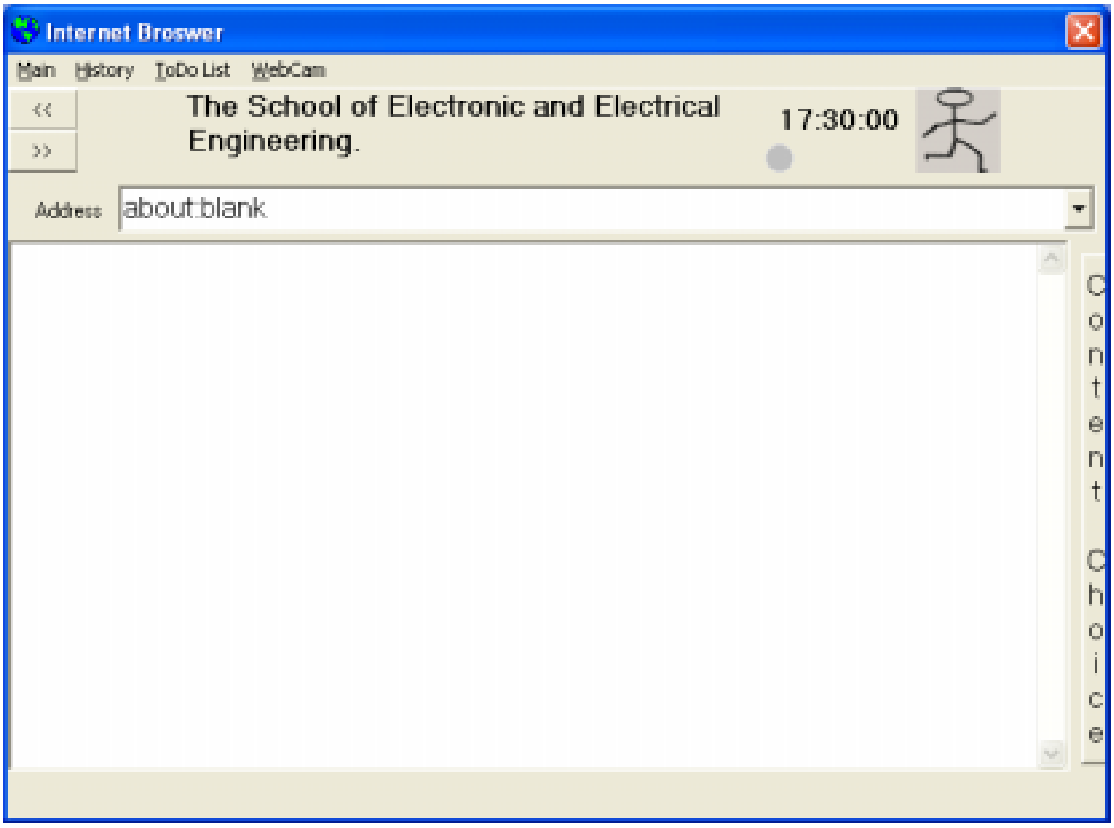
17:29:00

Address: D:\PhD\Visual Basic\MoreContext\LBpTOv6\pictures\STDEEE.htm

Electronic, Electrical and Computer Engineering

- **Undergraduate Beng and Meng degrees**
- **Eurowearable 2003 3/4/5th September 2003**
- **School open days 1-2 April 2003-02-13**
- **Academic and industrial links: Wave Solutions and Vehcom.org**

7. User walking near or around the Electronic and Electrical Engineering building. In addition to the blank screen they would hear an audio announcement telling them that they were walking near the School of Electronic and Electrical Engineering.

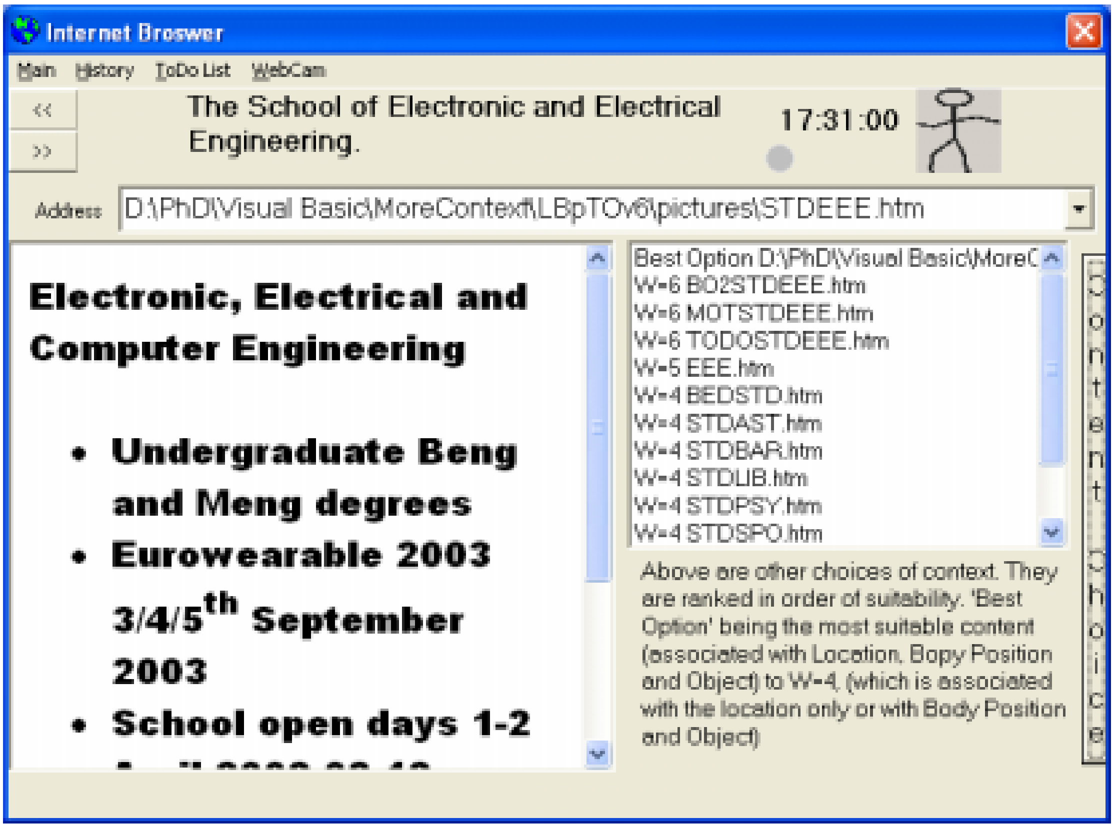


The School of Electronic and Electrical Engineering.

17:30:00

about:blank

8. User standing near to the Electronic and Electrical Engineering building. However the user has decided that the information automatically presented to them, while considered the best option by the system is not appropriate. They have therefore click the content choice button and are being shown a list of other possible content ranked in order of context fit.



The School of Electronic and Electrical Engineering.

17:31:00

D:\PhD\Visual Basic\MoreContext\LBpTOv6\pictures\STDEEE.htm

Electronic, Electrical and Computer Engineering

- **Undergraduate Beng and Meng degrees**
- **Eurowearable 2003 3/4/5th September 2003**
- **School open days 1-2**

Best Option D:\PhD\Visual Basic\MoreC
W-6 BO2STDEEE.htm
W-6 MOTSTDEEE.htm
W-6 TODOSTDEEE.htm
W-5 EEE.htm
W-4 BEDSTD.htm
W-4 STDAST.htm
W-4 STDBAR.htm
W-4 STDLIB.htm
W-4 STDPSY.htm
W-4 STDSPO.htm

Above are other choices of context. They are ranked in order of suitability. 'Best Option' being the most suitable content (associated with Location, Bopy Position and Object) to W-4, (which is associated with the location only or with Body Position and Object)