The Smart House Intelligent Management System

A thesis presented in partial fulfilment of the requirements for the degree of

Master of Engineering

in

Information Engineering

at Massey University, Albany, New Zealand

Grettle Rayn Lomiwes

2004

Abstract

In October 2002, Massey University embarked on the Smart House Project. It was intended to be a test bed of different technologies that improve the safety and quality of life within the home.

This thesis presents the design and current status of the Smart House Intelligent Management System, a management system for processing the commands received in the Massey University Smart House. There will be two parts to this Management System: an Expert System which will be responsible for the supervision of the house, its rules and its devices, as well as a conversation module which will converse with the occupant/s of the Smart House. The system will receive voice or text commands from the user as input and process the information through performing database queries about the received command, to ascertain whether it is valid. Validity is dependent on the command's adhering to house rules, which have been set by the user beforehand. This Management System will communicate with three other modules: the Bluetooth Smart Watch, the Speech Recognition/Generation System and the Ethernet Switching System, which enables access to the house devices.

Acknowledgements

I would like to thank my project supervisor, Dr Chris Messom, for his guidance throughout the whole year.

I am also grateful to my colleagues Rafik Gadalla, Leon Kok and Vaitheki Yoganathan your patience and support throughout the whole year. Thank you for all the extra trips you took to uni and all the times you spent talking the problem through with me.

Thanks to my family for your support all the way through the year, even if you did not really understand what it was all about. Thanks heaps for the encouragement and concern.

And finally, I would like to thank God for giving me this opportunity.

Table of Contents

1. Introduction 1
   1.1 Smart Devices and Environments 4
   1.2 Pervasive Computing for the Disabled and Elderly 8
   1.3 The Massey University Smart House 13
   1.4 Smart Technologies, the Disabled and the Elderly 15
   1.5 Organisation of this Thesis 18
2. The Intelligent Management System Problem 19
   2.1 Desired Characteristics 20
      2.1.1 Intelligence 20
      2.1.2 Extensible 21
      2.1.3 Customisable 21
      2.1.4 Ease of use 22
   2.2 Module Communication 23
      2.2.1 Bluetooth Enabled Watch 24
      2.2.2 Speech Recognition/Generation System 25
      2.2.3 Ethernet Switching System 25
   2.3 Management System Assumptions and Limitations 26
      2.3.1 Input received is always correct 27
      2.3.2 Single Person Tracking 27
      2.3.3 Explicit Input 28
3. Intelligent Management System Solution 30
   3.1 Expert System 31
      3.1.1 The House Database 31
      3.1.2 Command Implementation 36
      3.1.3 Command Validation 38
      3.1.4 Extensibility and Customisation 40
   3.2 Chat Module 42

3.2.1 Stimulus – Response 43

3.2.2 Chat Module Implementation 44

3.2.3 Chat Module Memory 45

3.2.4 Information Retrieval 46

3.3 Inter-System Integration 47

3.3.1 Integration with the Speech Recognition/Generation System 48

3.3.2 Integration with the Ethernet Switching System 50

4. Discussion 54

4.1 The Current Management System 54

4.1.1 The Expert System 55

4.1.2 The Chat Module 57

4.1.3 Module Communication 59

4.1.4 Limitations of the Expert System 63

4.1.5 Limitations of the Chat Module 65

4.2 Future Work for the Smart House Management System 67

4.2.1 The Expert System 67

4.2.2 Chat Module 71

4.2.3 Inter-Module Integration 72

References 74

Appendix A 80

Appendix B 83

List of Figures

Figure 1.1	Basic Activities of a Human Being	2
Figure 1.2(a)	Smart Clothing	5
Figure 1.2(b)	Wrist Computer	6
Figure 1.3	Disability Rates by Age Group	9
Figure 1.4	PhiloMetron's Smart Band-Aid	11
Figure 1.5	Activity summary from the Home Assurance System	12
Figure 1.6	The (silent) robotic lawnmower	14
Figure 2.1	Inter-module communications in the Smart House	26
Figure 3.1	Database Table Relationships	36
Figure 3.2	Management System Flow Diagram	37
Figure 3.3	Conflict Resolution	39
Figure 3.4	Chat Module Flow Diagram	45
Figure 3.5	A Conversation with the Chat module	47
Figure 3.6	Management System Response Format	49
Figure 3.7	A Distinct Command Example	50
Figure 3.8	Ethernet Switching System Status for Room 1	51
Figure 3.9(a)	Sensor Warning messages (Management System)	53
Figure 3.9(b)	Sensor Warning messages (Speech Generation)	53
Figure 4.1	Checking Response Times of the Chat Module	58
Figure 4.2	Integration Test between the Management System and the Speech Recognition/Generation System	60
Figure 4.3	Implementing a command through the Ethernet Switching System	61
Figure 4.4	Updating the Management System's Database	62

List of Tables

Table 3.1	Primary Tables of the Smart House Database	32
Table 3.2	House Linking Tables	33
Table 3.3	Device Access Tables	34
Table 3.4	Rule Tables	35
Table 3.5	Wizards in the Smart House Management System	41

Chapter 1

Introduction

The home is central to the life of each individual. It provides shelter, one of a human being's basic needs. Apart from its role as a residence, it is also a place of familiarity, rest and a place where a person can be "at home." Within it, we find a place of safety and comfort. In the home is also performed all the necessary routine activities of everyday living. These have been defined into nine groups (Himanen & Himanen):

- Care and keeping fit
- Eating
- Hygiene and dressing
- Recreation, Communication and self-actualisation
- Sleeping and resting
- Gardening and maintenance
- Housework
- Personal business and mobility
- Storage.

A person's activities in life can be divided into three groups. These are domestication (which includes the activities above), the working life (how we generate income or what we do for a living) and other specialised activities (such as art, entertainment, or religious and spiritual services). All the activities mentioned above are focused on domestication or the routine actions of day-to-day life. These three groups of human activity are linked together by interlinking activities (Transport, Communication, information) as shown in Figure 1.1.

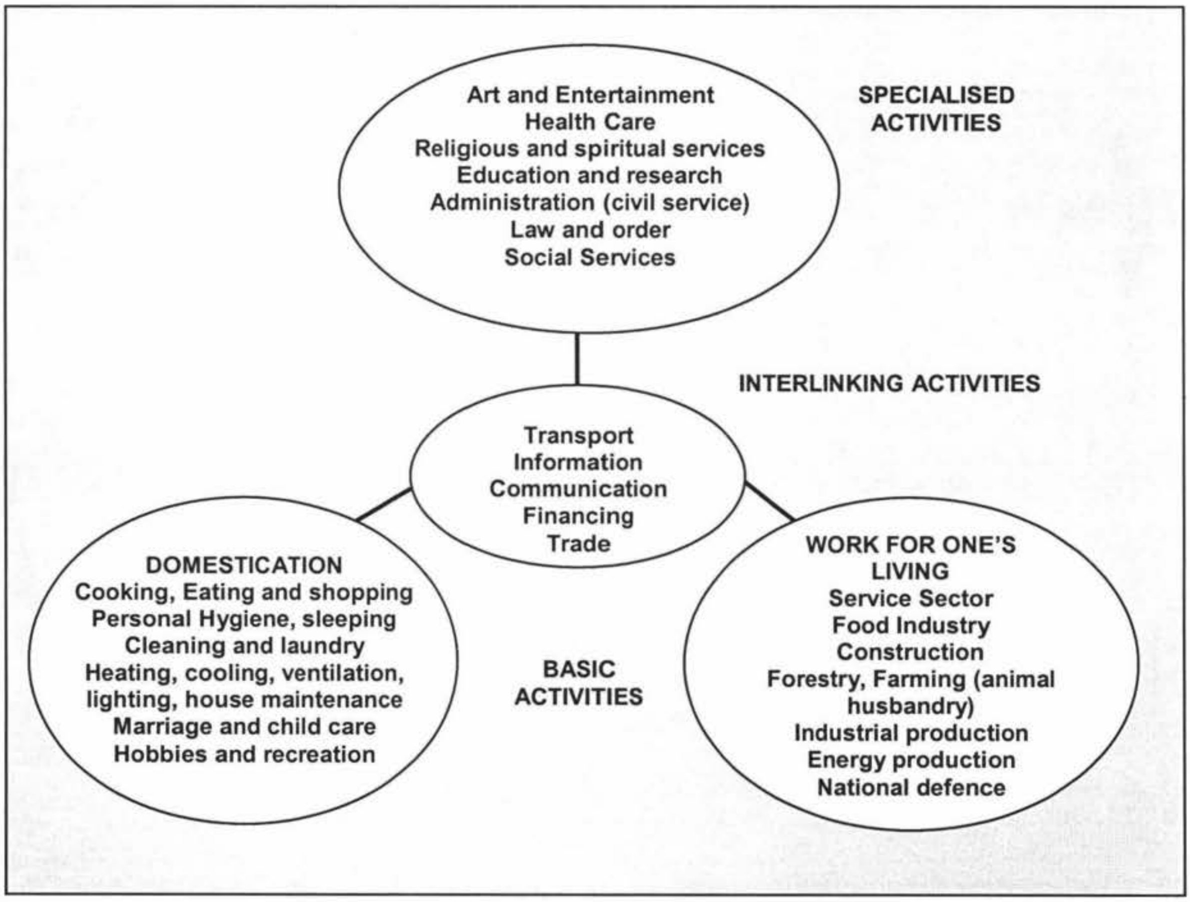


Figure 1.1 Basic Activities of a human being (Himanen & Himanen)

The working life and specialised activities (especially entertainment) are areas where we have found computers and their applications to be most useful and enjoyable. In the workplace, computers have proven to be of great importance in a wide range of fields including business and industry such as medicine, archaeology, e-marketing, mathematics, and security. Computers have also enhanced the entertainment field through various ways such as games, the Internet (through on-line groups, email, chat rooms and information on virtually every topic under the sun), and digital photography. The music and the recording industry have benefited through effects processors such as Pro Tools (Digidesign, 2004), Cakewalk (Cakewalk, 2004) and Adobe Audition (Adobe, 2003).

Now computers have found their way into the home in a new way. As computers become smaller, cheaper and more powerful, their useful applications in the home have become more diverse. Their intention is no longer limited to word processing, playing games and Internet access. They now have more functionality than ever. Sophisticated home automation systems can now be designed for house security alarms, lighting and entertainment systems.

All these systems are designed to create more convenience within the home, allowing the residents to think less about the more basic running of the home. The Massey University Smart House will be such a home. The Management System of the house will ensure that the house, if desired by the user, may do chores automatically.

Pervasive or ubiquitous computing is now an area of serious research that is truly thriving. The idea of a home that is "smart," loaded with all imaginable conveniences and able to perform a range of domestic tasks is only true in the realms of science fiction motion pictures. HAL 9000 from 2001: A Space Odyssey (Kubrick, 1968) has been the inspiration many of today's applications, including the ReBa system (Kulkarni, 2002) chatter bots (Web Hal) and digital secretaries/assistants (Ultra Hal) from Zabaware.

1.1 Smart Devices and Environments

Mark Weiser coined the term "ubiquitous computing" (Weiser, 1991). The word ubiquitous means the technology will be omnipresent or present everywhere. According to Weiser, "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." He put forward an idea – instead of the human entering the world of computers (through user interfaces such as the keyboard, mouse and monitor), computers should fit into the human environment and communicate through human interfaces such as speech and vision.

Computers will adapt to the human means of communication instead of the other way around. In the Smart House, this means that they will actively participate in the running of the home. It will be the Management System's job to do just that. It will supervise chores that need to be done within the house, as specified by the residents of the home, while keeping itself invisible.

An earlier implementation of a ubiquitous system was the Active Badge (Roy Want, Hopper, Falcao, & Gibbons, 1992), which was designed and prototyped between 1989 and

1992. This technology was worn by the users on their clothing and was created to replace pagers and tags when trying to trace people in a campus or hospital location. It was designed to be discrete in size so as not to be noticeable. When it was first developed, Active Badge transmitted a unique five-bit code every fifteen seconds to give information about the person's location. The updated device now transmits a unique infrared signal every ten seconds.

Other earlier attempts include smart clothing (Mann, 1996) as shown in Figure 1.2 (a), the wrist computer (Matias et al., 1996) in Figure 1.2 (b) and the Xerox ParcTab system (R. Want et al., 1995). All the above research required the user to wear some device in the form of Wearable Computing.

Figure 1.2(a) Smart clothing. Smart wearable devices worn include the wearable multimedia computer/personal visual assistant. The eyeglasses include a miniature computer screen and sensor array. The equipment also supports an Internet connection (Mann, 1996)

Figure 1.2(b) The wrist computer (Matias, MacKenzie, & Buxton, 1996)

More recent wearable technology include the Spot Wearable Computer (Dorsey, Gemperle, Gollum, Martin, & Siewiorek, 2002) and the wearable tactile display (Gemperle, Ota, & Siewiorek, 2001).

Ubiquitous computing has also been applied to home automation to produce intelligent environments or smart homes. The focus was to merge the technology with the ordinary life in a way that is seamless and non-intrusive. This means that the technology will be embedded into the home and be part of the daily life of the home without changing the day-to-day atmosphere of the home. The hardware of the system should be as much a part of its environment as possible. For example, wearing a lapel microphone to speak to the house might be considered an inconvenience.

Smart rooms and smart houses have been the result of adapting the computer to increase the comfort and convenience in the home. The Massey University Smart House will be such a home. The computer is invited to participate in the mundane activities of everyday. The features on offer include location tracking (you can keep track of where the children are), house modes (such as holiday mode when you are away on vacation or secure mode at night), and reactive characteristics (so the Fire Services get called automatically when the fire alarm goes off). More sophisticated systems even include conservation controls within the home. Accomplishments towards this end include the neural network house (Mozer, 1998) which automatically controls the heating and ventilation systems, MIT's Intelligent Room (Coen, 1998) and the House of the Future Project (Alves, Saur, & Marques, 2004). Internet controllable systems are also available; these include the home automation (HA) system developed at the National Taiwan University (Liang, Fu, & Wu, 2002), the Java-Based Home Automation System (Al-Ali & Al-Rousan, 2004), and the Internet Application for Home Automation (Nunes & Delgado, 2000).

Earlier developments of smart environments have been directed towards people without disabilities. Their main purpose was to increase the level of comfort and convenience within the home. Recently, there has been a drive towards using the same technology to assist those with special needs – namely the disabled and elderly. The aim is now to improve the quality of life of those who need assistance to perform basic activities in their daily lives. The Intelligent Management System will be part of this endeavour.

1.2 Pervasive Computing for the Disabled and Elderly

The World Health Organisation (WHO) has defined disability as "... any restriction or lack (resulting from impairment) of ability to perform an activity in the manner or within the range considered normal for a human being."

Disability can be further divided into physical disability (restriction of movement or loss of agility), sensory disabilities (sight and hearing disabilities), 'other' disabilities (difficulty in speaking, learning or remembering), psychiatric or psychological disabilities and mental disabilities.

One in every five people (743,800 in 2001) in New Zealand is disabled (Stewart, 2002). Among all these, physical disabilities are the most common types affecting adults. Over one-third of disabled adults living in households use some kind of special equipment, such as a voice amplifier, a computer to communicate, or a guide dog. It is also a fact that the proportion of all disabled adults using special equipment and disability increases with age (Figure 1.3).

The elderly group (or grey population) is composed of those who are sixty-five and over. It is a group that makes up a large and growing portion of New Zealand's population. At the time of the 2001 Census, they made up around twelve percent of the total usually resident population (Pink, 2004). By 2026, this figure is expected to rise to twenty percent; and increase further to twenty-five percent by 2051. There will then be 1.18 million people aged sixty-five and over by 2051, which will account for about one out of four New Zealanders.

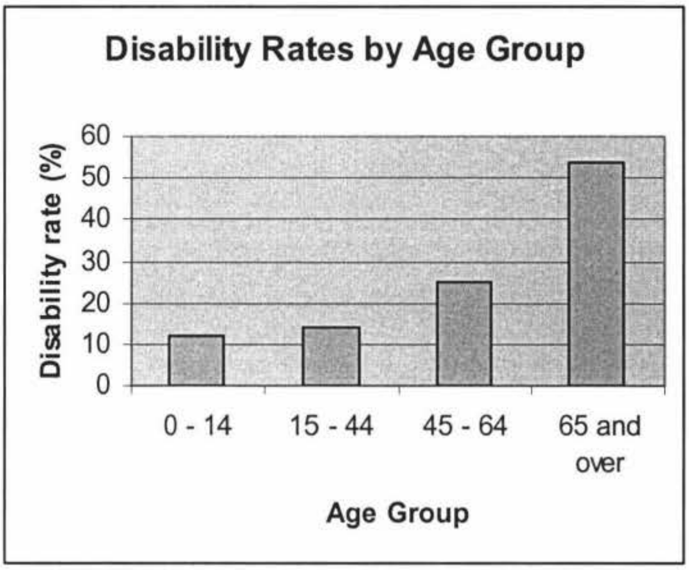


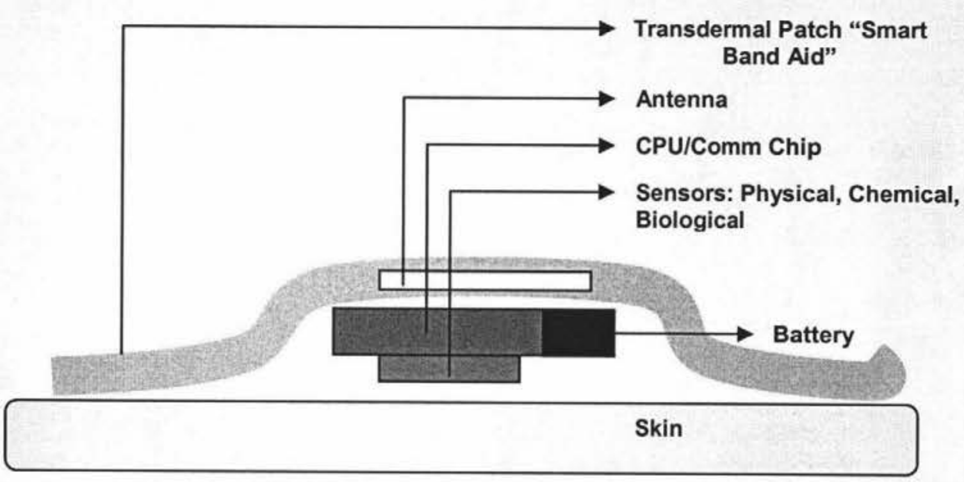
Figure 1.3 Disability Rates by Age Group (Stewart, 2002)

This growth is partially caused by the increasing life expectancy in New Zealand. This has resulted in the reduction in mortality. About eighty-nine percent of newborn girls and eighty-three percent of newborn boys are now expected to live to sixty-five years of age. For females, this means that they can expect to live for another 19.9 years on average and another 16.5 years for the males.

It is also estimated that the elderly make up thirty-six percent of all adults with disabilities. Despite their disability, eighteen percent of disabled live in one-person households (these include the elderly disabled). Among the elderly, people who are aged sixty-five years or more are expected to make up forty-seven percent of people in one-person households in 2021.

As the disabled and elderly become increasingly frail, their increasing disability will affect their ability to manage their lives by themselves. Wearable Devices have been designed with the disabled and elderly in mind. These devices will assist their users to maintain their autonomy and independence. Although physical modifications may be added to the home (such as rails to provide extra safety), they are not always enough to meet the communication needs of their users.

One of these wearable devices is the Camera Mouse (Betke, Gips, & Fleming, 2002), which is used to assist in the communication of severely disabled people such as those who are quadriplegic or non-verbal. It can track movement from the tip of the nose or the finger of the user and use these movements to communicate with the computer. The Ring sensor (Rhee, Yang, Chang, & Asada, 1998) is another example of a wearable device that provides continuous monitoring of the patient's arterial blood flow from their finger in a way that is non-intrusive and comfortable. Vivago has also developed the WristCare (Sarela, Korhonen, Lotjonen, Sola, & Myllymaki, 2003), which raises the alarm when the user has prolonged periods of immobility or passivity. Even a person's posture (Yoshida, Yonezawa, Sata, Ninomiya, & Caldwell, 2000) and postural changes (Najafi et al., 2003) such as sitting-to-lying and turning of the body in bed can be measured by a sensor. Another innovative and non-intrusive sensor is PhiloMetron's "smart Band-Aid" to monitor the healing progress of a wound. It automatically issues an alert if an infection is detected (see Figure 1.4)



Source: Larry Smarr, the 21st Century Internet, PhiloMetron

Figure 1.4 PhiloMetron's smart Band-Aid

The other kind of smart devices created for the disabled and elderly are those that are not attached to their person. These are devices that are seamlessly embedded into the environment of the user to measure its parameters. A study conducted at the Hospital Centre of Grenoble, France (Rialle, Lamy, Noury, & Bajolle, 2003) has this approach. It has a series of sensors with a movement detector, a multi-function fall sensor and recognition of help calls. Other research in this area include the Telemedicine Remote Monitoring (Celler, Ilsar, & Earnshaw, 1996), Telecare (Curry, Tinoco, & Wardle, 2003) and the Home Assurance System(P. I. Cuddihy, Ganesh, Graichen, & Weisenberg, 2003) from GE Global Research. The Home Assurance System has an activity summary (see Figure 1.5) that gives information on the user's activity patterns. Quiet times are shown as peaks that grow higher when the home is quiet. The gaps between the peaks indicate that the user is busy and the smaller peaks show periods of quiet or inactivity during the day.

The statistics of each day are stacked behind the previous days to show a pattern of activity and highlight unusual behaviour.

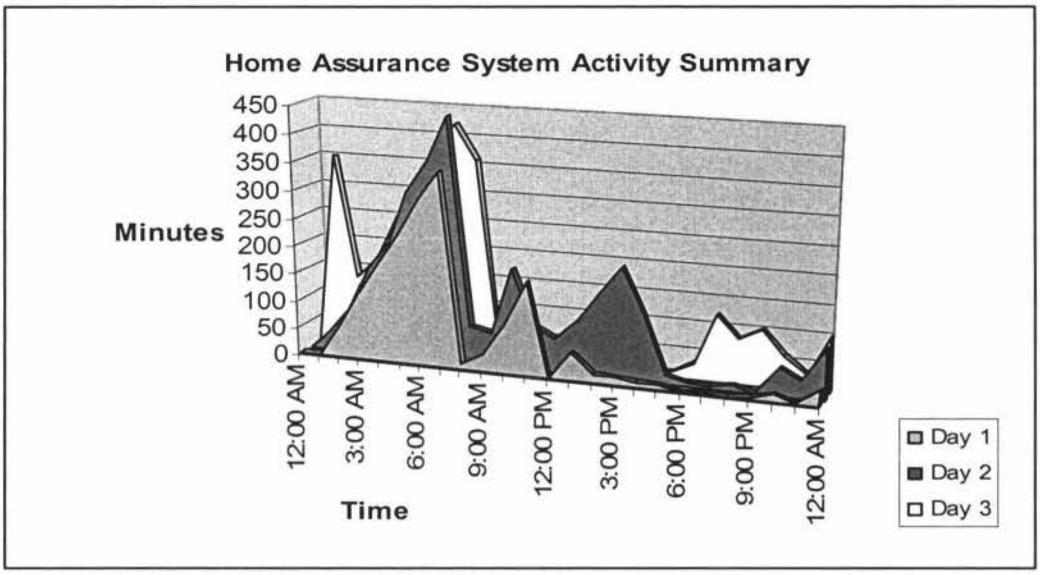


Figure 1.5 Activity summary from the Home Assurance System (P. Cuddihy et al., 2004)

Most smart houses for the disabled and elderly concentrate more on the wearable sensors and environmental sensors. Wearable sensors tend to focus on a specific area of study (cardiology, assessment of Activity of Daily Living (ADL), etc), and the environmental sensors focus on the safety and health of the user (such as temperature and fall sensors). Not much emphasis has been given in assisting the user with daily living activities (such as dishwashing and laundry) or convenience.

The focus with activity monitoring was to establish that the user was mobile and not stationary for too long (which might suggest that they have fallen somewhere and are unable to get up). The intelligent management system will attempt to integrate both the convenience found in the non-disabled smart environments and health sensors (both wearable and environmental) to get the best of both worlds and provide both assistance and comfort in the home. The Intelligent Management System will provide a means though which wearable devices and assisting the resident of the smart home with their daily activities may be merged

Georgia Tech's Aware Home (Kidd et al., 1999) is able to do just that. However, it uses the gesture pendant (Mynatt, Melenhorst, Fisk, & Rogers, 2004) to read hand movements as commands. It uses infrared illumination and a charge-coupled device (CCD) camera to recognise different gestures to dim lights, lock the doors or open the front door. It can receive commands as well as monitor the user's physical activity and request for help in the event of an emergency. They also have an application called the Digital Family Portrait (Mynatt et al., 2004) informs family members out of the house about its state (such as indoor and outdoor temperature) and the user's movement within the house.

1.3 The Massey University Smart House

In October 2002, Massey University began the Smart House Project. This venture involves the creation of a house that possesses a human-like intelligence to manage and perform daily tasks to help its occupant. It is the first New Zealand attempt in creating a home that will introduce intelligent technology into the home.

The Smart House Project is aimed primarily at the physically handicapped and the elderly. Statistics (Stewart, 2002) suggest that one in five New Zealanders will benefit from such research – those who are in need of extra help to live life comfortably, those in need of assistance to allow them to enjoy a higher degree of comfort and independence. The Smart House will allow them to improve their quality of life, deal with their physical limitations and a chance to enhance their independence and remain in their own homes for longer. It will result in a home that is safer and more enjoyable for them to live in.

The Smart House will be the test bed for all the different research projects intelligent technologies being developed. One of the technologies already developed at Massey University is the Internet controllable robotic lawnmower (see Figure 1.6). This lawnmower may also behave as a vacuum cleaner for indoors. The Smart House will integrate all these different elements together to create a functional smart home to increase its user's quality of life.

Figure 1.6 The (silent) robotic lawnmower (Restall, 2002)

1.4 Smart Technologies, the Disabled and the Elderly

An important factor of creating smart environments is the attitude of the end users toward the technology that is created for their benefit. It is all well and good to design and produce technology that will assist those who are disabled and elderly, but it would be pointless if they were uncomfortable with the technology. It is commonly believed that the elderly in particular are not open to technology. If they are not receptive, then they are less likely to use it, and consequently, cannot benefit from it. This section will give a brief overview of the social implications of smart environments for the disabled and elderly.

The elderly are not entirely hostile towards technology. In fact, they are quite adept at their use of electronic devices within the home (most dwellings nowadays are equipped with microwave ovens, television sets and security alarm systems). Wearable devices such as hearing aids and the Lifelink Medical Alarms provided by St John have been welcomed in the community. Older persons now also enjoy the Internet – they are able to perform online tasks, including online chatting and email access within the comfort of their own home (Adler, 2002; "Elderly surfers click onto net," 2004). These technologies have a positive effect in the lives of these people as they allow them to communicate and interact with others more fully.

It has been found that the potential users will welcome smart technology more if it is absolutely necessary (Carrelli, 2003; Mynatt et al., 2004). Most of the time, they prefer to forego the use of assisting devices, as they do not want to be discriminated against. This is true in the cases of both the disabled and the elderly. In New Zealand, 22 percent of disabled children aged 5-14 find it difficult to make friends and are limited from actively participating at school (Maskill, Hodges, Burns, & Carroll, 2004). Adults refuse assistive devices within the home such as raised toilets that could save them from a fall because they do not want the stigma that comes with it. This fear is very real – this discrimination and prejudice towards the elderly is called ageism (Butler, 1969). Research at York (Monk & Baxter, 2002) found that the worry "I don't want to be stereotyped or stigmatised in any way" was second only to "I want to keep my independence."

One more common cause of the elderly negativity towards assistive equipment within the home is their lack of understanding and distrust about the technology. In a case study performed (Reed, 2002), it was discovered that the education of the user during pre-installation period of the technology within the home is essential to the user's understanding of what the system does and how it works. In Sweden, the users were testing technologies after it had been developed, with no thought given to the end-user; causing irritation and distrust of new systems, delaying public acceptance of the new technology (Mekibes, Mekibes, & Thiberg, 1994).

An additional issue that was raised is the denial of privacy. Being monitored by a camera everyday in a "Big Brother" manner would be considered an intrusion of their privacy. For example, the Home Care Technologies System (Tran, 2002) does this to some degree, where cameras are activated by motion sensors and once activated, the images are automatically "pushed" to a web server and can be accessed remotely over the internet via a URL. The input is not continuous, however, and is only refreshed periodically. The person may not mind the Activity Summary (Figure 1.4) but might regard video monitoring as crossing the line.

A fear also expressed is isolation and loneliness (Mekibes et al., 1994; Monk & Baxter, 2002; Tiikkainen, Heikkinen, & Leskinen, 2004). Having a smart system and provision of comfort in the home could lead to isolation and lack of variety and contact with other human beings. Technology cannot replace personal care and social needs. A possible scenario could be the installation of an excellent alarm system that might mean that caregivers no longer call in to see if you are well. An extreme instance mentioned by Mekibes et al (1994) is a case where a woman lay dead in her apartment for a period of months. All her bill payments were taken care of by automatic banking, and her landlord was not concerned because her rent was paid on time.

The opposite side of the coin is over-reliance on the technology. The development of smart technologies for the home is aimed mainly for assistance. It is to retain the person's independence and autonomy. It is not designed to totally replace the housekeeping chores of the home. Not using your capability can negatively affect your physical condition (Dunkle, Roberts, & Haug, 2001; Tirrito, 2003). Participation in regular exercise (such as walking) and physical activity helps to prevent the physical decline of the body and retain autonomy and independence (Carlson et al., 1999; *Healthy Ageing and Physical Activity*, 1999).

1.5 Organisation of this Thesis

This thesis documents the approach I have taken in creating the Smart House Intelligent Management System. I begin by describing smart environments and linking it to the home, as well as several past and current applications of smart devices and environments. In the next chapter I discuss the Intelligent Management System problem – including the design principles and assumptions I have made in the system. The third chapter will give an overview of the Intelligent Management System. The fourth chapter will deal with some thoughts on future work for the system. Finally, I conclude with a discussion of the contributions of this thesis.