Personalized Location-sensing for Context-aware Applications

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Abstract

A context-aware computing system can detect its surroundings such as time, location and temperature, and changes its behaviour accordingly. Context-aware devices to provide personalized functionality to the users are designed to take advantage of nearby computing and communication resources. Location-sensing systems are used to determine the position of objects in the environment. They represent a practical subset of the context-aware computing paradigm.

Several systems of this nature have already been demonstrated. Most of them are design for outdoor environment using Global Position System (GPS) technology. Existing systems used by context-aware applications require dedicated hardware such as Active Badge and Radio Frequency transmitters. It is inconvenient and often limits the application domains they could support. Moreover, existing systems use centralized approaches which do not provide users' privacy protection.

This thesis proposes a location-sensing system which can overcome these shortcomings. The system can use a Personal Digital Assistant (PDA) device as the receiver and Bluetooth or IrDA as sensor. It is design for indoor environments such as offices and homes. This is well suited to the demands of location information in daily life, e.g. in a shopping mall. Two implementation media using Bluetooth and IrDA sensor are proposed. The performance of these two implementations for location sensing is evaluated. This thesis concludes by presenting a set of novel location-aware applications using the proposed location-sensing system.

論文摘要

環境導向的應用程式是一種能探測周圍環境因素的應用程式。例如它能探測使用時的時間，地點，當時的溫度等，並根據這些環境因素而改變程式的應用模式。環境導向的儀器則能利用其周圍豐富的電腦及通訊設備，從而提供個人化的使用功能。位置感應系統是用於探測某些物件在一環境中的位置。它是環境導向系統中的一部分。

某些有這種特性的系統已經被實現，其中大部分都是使用全球衛星定位系統（GPS）作戶外的應用。但是，現有應用於環境導向系統的位置感應系統必須配合特定的硬件才能使用，例如“Active Badge”及無線電（Radio Frequency）訊號發射器。這些特殊需求令這種系統變得很不方便，同時也限制了它的應用範圍。另外，現有的系統使用中央系統以集中處理用戶的資料，例如用戶所處的位置等。這樣的設計讓用戶私人資料受不到必要的保障，從而引起各種私隱問題。這些現存的問題爲位置感應系統的推廣構成不必要的障礙。所以，祇有這些問題得到解決，位置感應系統才能得到廣泛的應用。

爲了改善這些缺點，這篇論文提出了一種新的位置感應系統設計方案。這方案能利用個人數位助理（PDA）作爲接收器，同時使用各種無線電感

應器作爲訊號發射器。它主要是針對室內使用環境的應用，例如辦公室或家居。這篇論文還介紹了使用紅外線及藍芽以分別實現這系統的方法，並對它們表現作出了全面的評估。最後，這篇論文以介紹各種能應用於該系統的環境導向應用程式作爲論文總結。

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Chapter 1

Introduction

Many indoor environments, such as offices and homes, are rich in computing and communication resources. Such resources will become increasingly abundant in the future as research and development in electronic and wireless technologies make devices smaller, cheaper and more convenient to use. Concurrently, the number of people using mobile devices ranging from laptop computers to hand-held personal digital assistants (PDA) is also increasing. Following these trends, it is not hard to envisage that computing resources will be available anytime and anywhere in the near future.

"Ubiquitous computing" [30] is becoming more and more popular. Users will be able to interact freely with computing resources forming a seamless integrated information system. The configuration of such systems currently requires significant human effort. It will get worse as the complexity of computing and communications increase in the future. Thus, it is important to make system configuration as transparent as possible. One way to do so is to transfer some of the configuration burden to the mobile devices. In this way, devices will no longer be dedicated to particular tasks, and instead they will be adaptive and will change their behaviour depending on how and where they are used.

1.1 Background: Context-Aware Applications

Recently, active worldwide research in investigating adaptive computers that can autonomously change their behaviour based on their observation of the surrounding is underway. For example in personalized computing, applications are tuned to specific user's needs by detecting situational information such as user's location and identity. This section surveys the existing context-aware applications.

1.1.1 Definitions of Context

The general definition of context in a dictionary is "the interrelated condition in which something exists or occurs". However, some researches argue that dictionary definition does not offer much understanding about how context is related to computing environment. Thus, a more precise definition of context is developed.

Schilit et al. characterize context as a collection of information that describe the users in a context-aware system. Schilit describes context as the following [25]:

Definition 1: *In a mobile distributed computing system, context are the location of the user, the identity of people and physical objects that are nearby the user, and the devices the user interact with.*

More recently, Dey gives a different definition of context [8]:

Definition 2: *Context is any information that can be used to characterize the situation of an entity. An entity is a person, or object that is considered relevant to the information between a user and an application, including the user and application themselves.*

Definition 2 is more general in comparing to Definition 1. While it does not bind to a specific list of information, Definition 2 extends the notion of context to include any information that describes physical objects and computing application in addition to users. Besides Schilit's and Dey's definition of context, few other researchers also have attempted to describe context from a computing perspective [5]. All of which are closely in spirit of the formers.

1.1.2 Existing Applications

Context-aware computing applications [5] are designed to be aware of the context in which they are run. Such applications adapt to their environment, e.g. the location of use, the collection of people and hosts nearby, and types of accessible devices. They are sensitive and will change their behavior over time based on the surroundings. They are designed to deliver personalized services to a person, at the right time, in the right place and in the right way. This is very complex in mobile computing where the operating environment can change frequently and rapidly.

Recently, a number of context-aware applications have been developed [1, 2, 6, 19, 25]. For example, Sunday, one of the Hong Kong telecommunication companies, launched an intelligent network (IN) system where a customer in a shopping-mall could obtain the shopping information related to the vicinity of his/her current location [34]. Other examples of context-aware application include:

1.1.2.1 Office and Meeting Tools:

The Active Badge system [28] from AT&T Library is generally considered to be one of the first context-aware applications. With the system, a person could be located in an office, and telephone calls could be forward to the closest telephone set.

The ParcTab System [29] from Xerox Palo Alto Research Center works as a mobile personal digital office assistant. It can continuously monitor where each ParcTab is, e.g. which ones are in the same room, and notify the application concern of any location changes.

In/Out board [26] from Georgia Institute of Technology is a Java application showing if a user is at the office or not. It gathers information about the participants who enter and leave the building at the only entry point in the building.

1.1.2.2 Tourist Guides

Cyberguide [17] from Georgia Institute of Technology was designed to guide the visitors in their tour around the Graphics, Visualization and Usability Center. It is used in their monthly open house session.

Guide [7] from University of Lancaster is a tourist guide for Lancaster city visitors. Based on their location and preferences, visitors can obtain information related to their current location.

Smart Sight [35] from Carnegie Mellon University adopts wearable computing technology. It is intended to translate location language, handle queries spoken language, and be a navigational aid based on users' current location.

1.1.2.3 Memory Aid

Forget-Me-Not [16] from Rank Xerox Research Center is used to record where a user is, whom he/she is with, whom he/she phones, and other autobiographical information. It also stores such information in a database for later retrieval.

Name of the System	**Location**	**Time**	**Identity**	**Other device**	**User preferences**
Active Badge System	Yes				
The ParcTab System	Yes	Yes		Yes	
In/Out board	Yes	Yes	Yes		
Conference Assistant	Yes	Yes			Yes
Cyberguide	Yes				
Guide	Yes				
Smart Sight	Yes				
Forget-Me-Not	Yes	Yes	Yes		
Remembrance Agent	Yes	Yes	Yes		

Table 1.1: Context value in existing context-aware applications.

Remembrance Agent from MIT Media Lab is a wearable remembrance agent. It displays on-line summaries of note-files, emails, papers and other text information that might be relevant to the users' current context.

1.1.3 Review

Table 1.1 shows the context that existing context-aware applications are designed for. Most existing applications use location, identity and time to provide context-aware services. The reason for this probably lies in the difficulty for computer systems to obtain and process other kinds of context information.

1.2 Research Motivation

Over the past few years, we have seen a proliferation of computing devices with varying degree of computation power, ranging from powerful server systems to embedded net-enabled devices. A natural progression of this trend is leading toward an era when computing will be widely available and embedded in our environments, where it will be "ubiquitous" or "pervasive". The number of users of mobile computing devices has also been growing dramatically spanning the entire spectrum from laptop computers to hand-held personal digital assistants, to more specialized devices such as cellular phones or portable music players.

For applications running on mobile devices to truly benefit from the large number of services available in the environment, there need to be a mechanism for the application to determine its spatial location and the resources in its vicinity, and it behavior adapts to them accordingly. This in turn calls for a system to determine the physical location of both the fixed and mobile devices. In addition to discovering services in its vicinity, a mobile application can change its behavior depending on the location information. For example, a cellular phone does not ring loudly inside a conference room.

Applications that adapt to their physical location in outdoor environments using Global Positioning System (GPS) is now available, such as navigation utilities for cars. Since a large number of users and important applications are located indoor, a wireless application that can determine the user's location inside a building is important step towards context-aware computing.

1.3 Research Contributions

While there are several location-sensing systems in existence with a resource discovery system to support context-aware applications, our integrated system provides an indoor solution, which is cost-effective, scalable, and distributed. Furthermore, it protects user's privacy. This system provides a position-sensing algorithm, which does not require any information from the user. We have implemented two prototypes to demonstrate the advantages and to evaluate the performance of the design.

1.4 Thesis Outline

Chapter 2 examines the current development in outdoor and indoor location-sensing technologies. It concentrates on the characteristics of current technologies and evaluates their applications. Chapter 3 describes the overall system architecture and details the position-sensing algorithms of the proposed indoor position-sensing platform. Chapter 4 and Chapter 5 describe its implementation and evaluation results respectively. Chapter 6 presents potential context-aware applications based on the proposed solution. Finally Chapter 7 concludes this thesis and suggests possible future works for this project.

Chapter 2

Location-sensing Technologies

There are a number of location-sensing systems available today that support location sensing in both indoor and outdoor environments. Some of them are mature technologies used by many users while others are still confined to research laboratories. This Chapter presents a survey of these systems. Section 2.1 introduces the Global Positioning System (GPS), which is commonly used in outdoor environment. Section 2.2 surveys existing indoor location-sensing technologies. Section 2.3 summaries the survey and points out the risks of existing technologies. Section 2.4 focuses on the goals of our design.

2.1 Global Positioning System (GPS)

A commonly used wide area location-sensing technology is the Global Positioning System (GPS) [10]. GPS infrastructure consists of 24 satellites orbiting the earth of an altitude of about 20,000km every 12 hours, see Figure 2.1. These satellites periodically broadcast the positioning signals over orthogonal

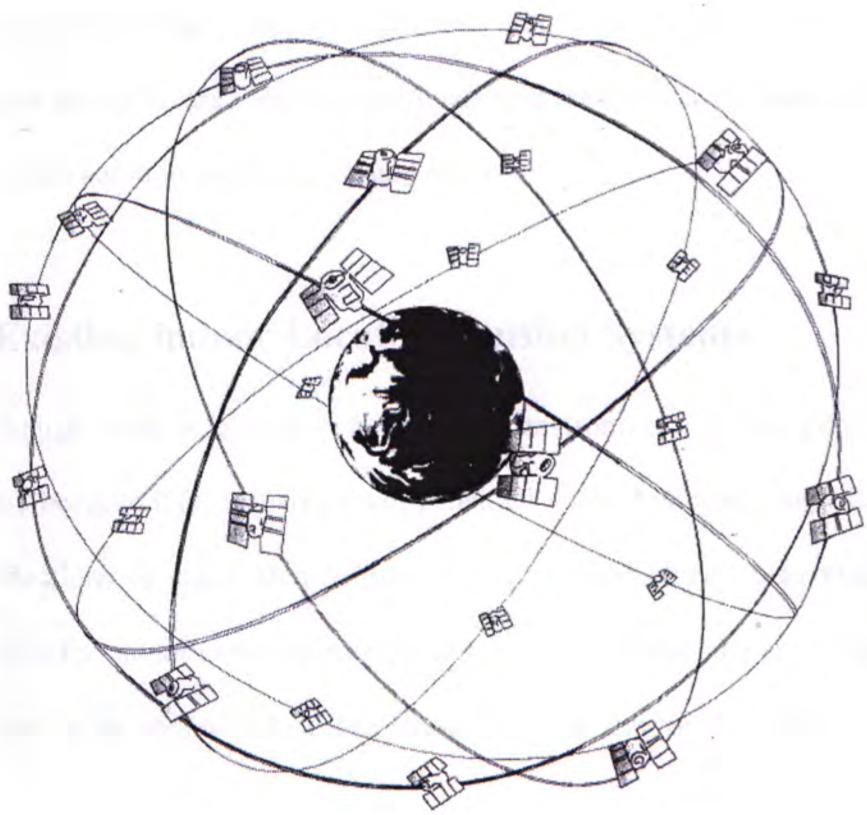

Figure 2.1: The 24 satellites of the Global Positioning System.

radio frequency (RF) channel. The positioning signals are coded such that the receiver can infer the offset time. Since the GPS satellites are not geo-stationary, the receiver contains a map of all GPS satellites, which allows it to determine the location of individual satellite at any given time. Based on the positions of the satellites, a mobile GPS receiver can calculate its current position by receiving four RF signals. The accuracy of the inferred location information improves if the receiver can receive signals from more than four satellites. GPS provides a precision of 5-10 meters for outdoor environments using low-cost receivers. At the same time, it is possible to achieve sub-centimeter accuracy by using very sophisticated receivers in outdoor environment. In addition, accessing the GPS signals is free of charge. Although GPS receiver costs more than $100 US dollars, no further infrastructure tools and administration tasks are need. Therefore, GPS is a low cost solution and used in many areas.

2.2 Existing indoor Location-sensing Systems

Although GPS is effective for outdoor environment, it has poor indoor accuracy because GPS signals cannot penetrate walls. Moreover, high RF noise and reflections of signal due to presence of metallic objects also make GPS unsuitable for indoor environments. Therefore, considerable amount of work has been done in the area of indoor location sensing over the past few years.

2.2.1 Active Badge

The Active Badge system developed at Olivetti libraries was one of the earliest indoor location-sensing systems [28]. In this system, objects are tracked by attaching a tag which periodically emits its unique code over the infrared channel. Infrared receivers placed around the host building pick up this information and relay it over a wired network to the central master station. The master station polls all the signal information from the receivers, processes them to find out the location of the tags, and finally it pushes the location information to the central display board, which shows current locations of all the tags. The walls inside a room act as natural boundaries for infrared transmission. Thus a receiver can safely assume that any tag is associated with the room in which the corresponding fixed receiver is located. This design is simple and cheap. However, the centralized tracking approach of this system raises several thorny privacy issues [22].

2.2.2 The Bat System

The Bat system developed at AT&T Research Labs provides more accurate indoor location information than Active Badge in three dimensions [11, 12]. In this system, users and objects within a region are required to wear a wireless tag, known as the Bat. A centralized location database storing the latest positions of these Bats is maintained by periodic tracking.

The Bat system infrastructure consists of a carefully laid out matrix of ultrasonic and RF receivers. They are typically mounted on the ceiling of a room, and are interconnected using a serial wired network. This wired network also connects to a RF base station and to a central location database. A wireless tag typically consists of a RF and an ultrasonic transmitter, and is assigned with a globally unique identifier. Each Bat is queried periodically, one at a time, by broadcasting message addressed to it from the central controller.

A base station periodically transmits a RF message containing a single Bat identifier. The corresponding Bat, upon hearing a message addressed to it, responds with an ultrasonic pulse to a grid of receivers, which are mounted on the ceiling. At the same time, the base station sends the RF reset signal to the ceiling receivers. Each receiver measures the time interval from reset to ultrasonic pulse arrival and computes its distance from the Bat. It forwards the distance measurements to the base station, which performs the lateration location computation.

With one base station and five receivers per $10m^2$, the Bat system achieves an accuracy of 9cm for 95% of the measurements. However, the tightly controlled and centralized architecture, and the accurately laid out receivers grid incur high cost for system deployment and maintenance.

2.2.3 RADAR

The RADAR system developed at Microsoft Research Center implements location-sensing system by leveraging on IEEE 802.11 WaveLAN wireless networking technology [4]. In this system, the signal strength and the signal-to-noise ratio are used to compute the 2D absolute position value within a building. The following two schemes, one using scene analysis and the other using lateration, are used to determine the position information.

In the first scheme, users indicate their current location at various positions by clicking on a map of the floor and their WaveLAN device sends a signal to the fixed base stations. The base stations measure the signal strength and record them in a database. After a signal strength map of the whole space is generated, the signal strength due to a transmitter is measured at base stations during normal operations. The transmitter's position is estimated by matching the signal strength measured in real-time to the empirically collected signal strength map.

In the second scheme, the system uses a mathematical radio propagation model to build the signal strength map. The theoretically computed signal strength data take into account factors such as number of walls between a base station and the transmitters. This information is then used to obtain the best fit for a given transmitter's position. The position calculation can be done either at a central controller or at the receiver. If the latter approach is used, the system preserves user privacy.

With 3 bases per floor, the first scheme has 3 meters position accuracy with 50% probability, while the second scheme has 4.3 meters position accuracy at the same probability level. RADAR depends on the signal strength map to determine the distance to base stations. But the highly unpredictable nature of the radio propagation within buildings, coupled with the dynamic nature of the environment itself affect the accuracy of distance measurement [4]. Furthermore, in the first scheme, the generation of the off-line signal strength map is a cumbersome procedure.

2.2.4 PinPoint 3D-iD

3D-iD from PinPoint [21], a commercial company which sells asset-tracking packages, is similar to RADAR. PinPoint's 3D-iD performs indoor position tracking using a proprietary base station and RFID tags to measure signal strength. A region such as a business organization is divided into cells. Each cell has a base station to which several RF antennas are attached. And RFID tags are attached to the devices being tracked. The base station generates a spread spectrum radio signal that is broadcast via antennas. Each tag, after receiving a signal, responds with a message containing its unique ID. The signals received by different antennas are sent to the base station. The base station uses the time of flight of the RF signals to identify the location of the tag. PinPoint based systems achieve an accuracy of one to three meters. The 3D-iD system offers easy deployment and administration infrastructure. However, it suffers from the disadvantage that each antenna has a narrow cone of influence. This can make ubiquitous deployment prohibitively expensive. And it has difficulty interoperating with the 802.11 wireless networking infrastructure.

2.2.5 Easy Living

The Easy Living project developed at Microsoft Research Center adopts computer vision technologies to figure out where objects are [14]. It uses two sets of Digiclops real-time 3D color cameras to provide stereo-vision positioning capability in a home environment. One set of stereo cameras with three heads is mounted around the walls of the room. Each stereo camera is attached to its own dedicated PCs, which calculates a depth image. The depth image is subtracted from a background image of the empty room to quickly detect moving objects including people. The outputs from all the person-detectors are fed into a person-tracker which matches the people seen by different cameras from different angles. Another camera looks down from overhead and tracks a wireless keyboard as it is picked up, put down, and handed from person to person.

The information about people's locations and the keyboard locations is sent to a central database called the World Model. The World Model is implemented using a commercial SQL database program. It has been augmented with the ability to perform geometric reasoning about point and polygon intersections. The world model also stores information about devices and their regions of service. The lights serve the entire room. Therefore, when a person enters the room, his/her location in the world model intersects the light service region, and the lights are turned on.

Although Easy Living can provide significantly accurate location information, it heavily depends on infrastructural processing power. Furthermore, the public distrust of ubiquitous cameras can limit the scalability or suitability in many context-aware environments.

2.3 System Properties and Risks

Location-sensing systems typically tradeoff positional accuracy, uncertainty and latency in proving location information for ease of configuration, lower hardware costs, scalability and user privacy.

Table 2.1 summarizes the properties of the location-sensing systems we discussed in Section 2.2. In the following section, we investigate how these properties affect location-sensing system design and discuss their impact to context-aware applications.

System Name	Technique	Accuracy	Cost	User Privacy	Decentralized	Limitations
GPS	Radio time-of-flight lateration	5-10 m (95%)	Expensive infrastructure and receivers	Yes	Yes	Not indoor
Active Badge	Diffuse infrared cellular proximity	Room size	Expensive administration cost, cheap tags & base	No	No	Not fine-grained
The Bat	Ultrasound time-of-flight lateration	9cm (95%)	Expensive administration cost, cheap tags & sensors	No	No	Required ceiling sensor grids
RADAR	802.11 RF scene analysis & triangulation	3-4.3m (50%)	802.11network installation, Expensive wireless NICs	Possible, with user comput-ation	Centralized radio frequency signal database	Require Wireless NICs
PinPoint	RF lateration	1-3m	Expensive infrastructure & installation	No	No	Proprietary, 802.11 interference
Easy Living	Vision, triangulation	Variable	Need cameras & high processing power	No	No	Ubiquitous public cameras

Table 2.1: Comparison of different location-sensing systems.

2.3.1 Accuracy

From location-sensing system perspective, positional accuracy is often the most fundamental concern. It determines it suitability for a particular context-aware application. The Bat system described in Section 2.2.2 supports centimeter-level precise location resolution. However, providing such accurate precise location information requires dedicated hardware, extensive pre-configuration and an elaborate centralized server. Typical context-aware applications however do not require this level of accuracy. For example, personal location-sensing system for home and office applications would be used to answer queries like "Which room am I in?" and "What devices are near me?", rather then "Where, to the nearest centimeter, is my computer placed?"

2.3.2 Cost

The cost of location-sensing system includes several factors, such as installation and administration needs, infrastructure and hardware required, and price of mobile devices carried by the users. The current location-sensing systems always require a major capital investment to build and launch the infrastructure. At the same time, they require users to carry dedicated mobile devices in order to send signals to the central controller. For example, the Active Bats in the Bat System described in Section 2.2.2 are used to send radio frequency signals. In these cases, both the infrastructure and the mobile device contribute to the incremental cost and hence affect system scalability.

2.3.3 User Privacy

A key design issue in location-sensing systems is preserving privacy. People have always been concerned about privacy issues in computing system. Especially, people are worried about how computer systems collect and use their personal information.

Current location-sensing systems are mostly centralized, real time based and operated with unrestricted access. These designs make it easy to collect and use location information about individuals at any particular point in time. Given the information about a person's past and present locations, an observer could deduce the behavior and intention of the person. This seriously intrudes one's privacy and in most cases this is very annoying. Privacy intrusion often leads to inter-personal distrust. This in term could affect the acceptance of context-aware applications.

Privacy is intrinsically bound up with control – who controls what information as well as the applications that construct and disseminate that information [31]. In the existing location-sensing systems, users often do not have control over how personal information is being acquired. As tracking sensors are built to be hidden in the physical space, personal information is collected without the explicit consent of the users. This is a serious privacy problem.

2.3.4 Location Representation

Location value can be specified in two ways: absolute and relative. Almost all of the existing location-sensing systems adopt absolute location representation. An absolute location system uses a shared reference grid for all located objects. GPS provides absolute location value. For example, our engineering building is situated at 22°43'57''N by 114°25'39''E. And two GPS receivers placed at the same position will report equivalent location reading. Therefore a system providing absolute location value can usually be used in map systems. In contrast, each object in a relative location system can have its own frame of reference. For example, a mountain rescue team searching for avalanche victims can use hand-held computers to locate victims' avalanche transceivers. Each rescuer's device reports the victims' position relative to itself.

An absolute lactation value can be transformed into a relative location value. In reverse, an absolute location can be determined from multiple relative readings if the absolute location of the reference points are known. But if the reference points themselves are mobile, it is impossible to determine the absolute position.

2.3.5 Other Limitations

Some location-sensing systems do not work in certain environment. For example, GPS cannot detect satellite transmission indoors. For another example, vision systems like Easy Living only work well with up to three people in a room. With more than three people moving around, poor clustering would occur. In addition, people wearing similar colored outfits will lead to tracking misalignment. These limitations restrict the scope of existing context-aware applications.

2.4 Design Goals

Based on the previous survey, we have observed that there is currently no design standard in indoor position sensing. Although, Global Positioning System (GPS) works well outdoor and is almost universally used, its signals are not strong enough to penetrate building walls, and thus unsuitable for indoor applications. There are many context-aware applications, which could benefit from indoor positioning, e.g. indoor robots inventory tracking, security, and location-funding, etc. Some methods have been design for indoor positioning. However, their design does not fit the needs of indoor context-aware applications. They are mostly based on centralized control and cost-ineffective.

We proposed a location-sensing system, which facilitates indoor context-aware applications in a pervasive computing environment. It overcomes the above shortcoming by balancing between privacy, cost, and accuracy issues. A set of design goals is laid down for this purpose:

2.4.1 Operate Inside Buildings

Most context-aware environments are expected to be indoors. This implies that the proposed location-sensing system should work well inside buildings.

2.4.2 Preserve User Privacy

Users generally detest exposing their locations. Presence of location tracking often causes tension in workplace. Some research such as [22] pointed out similar findings. And it is believed that the location-sensing system will be widely adopted only if it is accepted to their potential users. The proposed system should facilitate users to learn their locations rather than by tracking them.

Listening device carried by users should be passive, they should only be able to infer and provide information to applications running on the same devices. Effectively, the central system should know nothing about the users' locations.

2.4.3 Low Cost

The cost of deploying a location-sensing system should be small. Due to the nature of context-aware application, the total system cost would depend primarily on the number of transmitters used, and the mobile receivers in place. Any kind of mobile devices, such as notebook computer, Personal Digital Assistants (PDA), or mobile phone, embedded with IrDA and Bluetooth port should be supported. The proposed system should be built by using off-the-shelf components, and avoid using custom hardware.

2.4.4 Fast Response

As users of context-aware applications always move around inside a building, the location information should be updated as often as possible. However, the computational power in most mobile devices is limit. Complicated location estimation algorithms like scene analysis are unsuitable to achieve this goal. The proposed system should incorporate a simple location estimation algorithm to reduce response time.

2.4.5 Spatial Recognition

Location information that describes a space, such as a room is very meaningful in real life applications. This should be supported. But the conventional spatial representation format based on point coordinates should not be neglected. Also, the system should be able to detect natural boundaries such as walls between spaces accurately.

2.4.6 Easy Administration and Deployment

Easy administration and deployment are important aspects of any system. The proposed system should adopt a decentralized architecture, and should be scalable and support incremental deployment.

2.5 Summary

A survey in location-sensing technologies was given in this chapter. Existing location-sensing systems were presented. The properties of these systems, and the possible risks in using them were outlined.

Context-aware applications, which track physical locations in outdoor environments using Global Positioning System (GPS) are popular, e.g. car navigation utilities. Since many user activities take place indoors, indoor position sensing is very important in context-aware applications. However, current location-sensing technologies are impractical for indoor operations. This is because they are costly and lack of good privacy protection mechanisms. For this reason, an indoor position-sensing system, which is low cost, scalable, and decentralized, is required for indoor context-aware applications. In the next chapter, the design of the proposed indoor location-sensing system with the said features is give.

Chapter 3

System Design

The design and deployment of a system for obtaining location and spatial information in an indoor environment is a challenging task for many reasons, including preservation of users' privacy, reduction of administration and management overheads, facilitation of system scalability, and efficient operation under the harsh nature of indoor wireless channels. This chapter proposes a new indoor position-sensing system, which is suitable for different kinds of indoor context-aware applications. Section 3.1 gives the overall system architecture. Section 3.2 introduces the mathematical algorithms for location and position sensing.

3.1 System Architecture

The architecture of our system is divided into three sections: the location-sensing platform, the resource information base, and the context-aware applications. Figure 3.1 shows the overall architecture, and Figure 3.2 illustrates the underline communication between basic components of the system.

Context-aware applications			
Position-sensing platform		Resource information base	
Bluetooth	IrDA	XML database	WWW search

Figure 3.1: The overall system architecture.

The position-sensing platform provides abstraction from the positioning devices. It is responsible for sensing all remote transmitters, calculating its current position by using the data collected, and reporting the position to the context-aware applications wherever it is required. The description of the position-sensing platform is given in Section 3.2.

The resource information base provides methods for remote devices to obtain the published resources for the location where the users are currently in by searching a local database or the Internet. The resource descriptions are represented as XML documents, where the location is represented as fields in the XML document. The location is also associated with a URL, which links to the corresponding XML document. Users can download and store the resource descriptions in their remote device such as PDAs before they enter an unfamiliar building. Alternatively, such data could be downloaded automatically by the context-aware application when the users enter the building. Our idea is similar to [13], which uses the Resource Description Framework (RDF) [15] as a basis for service description.

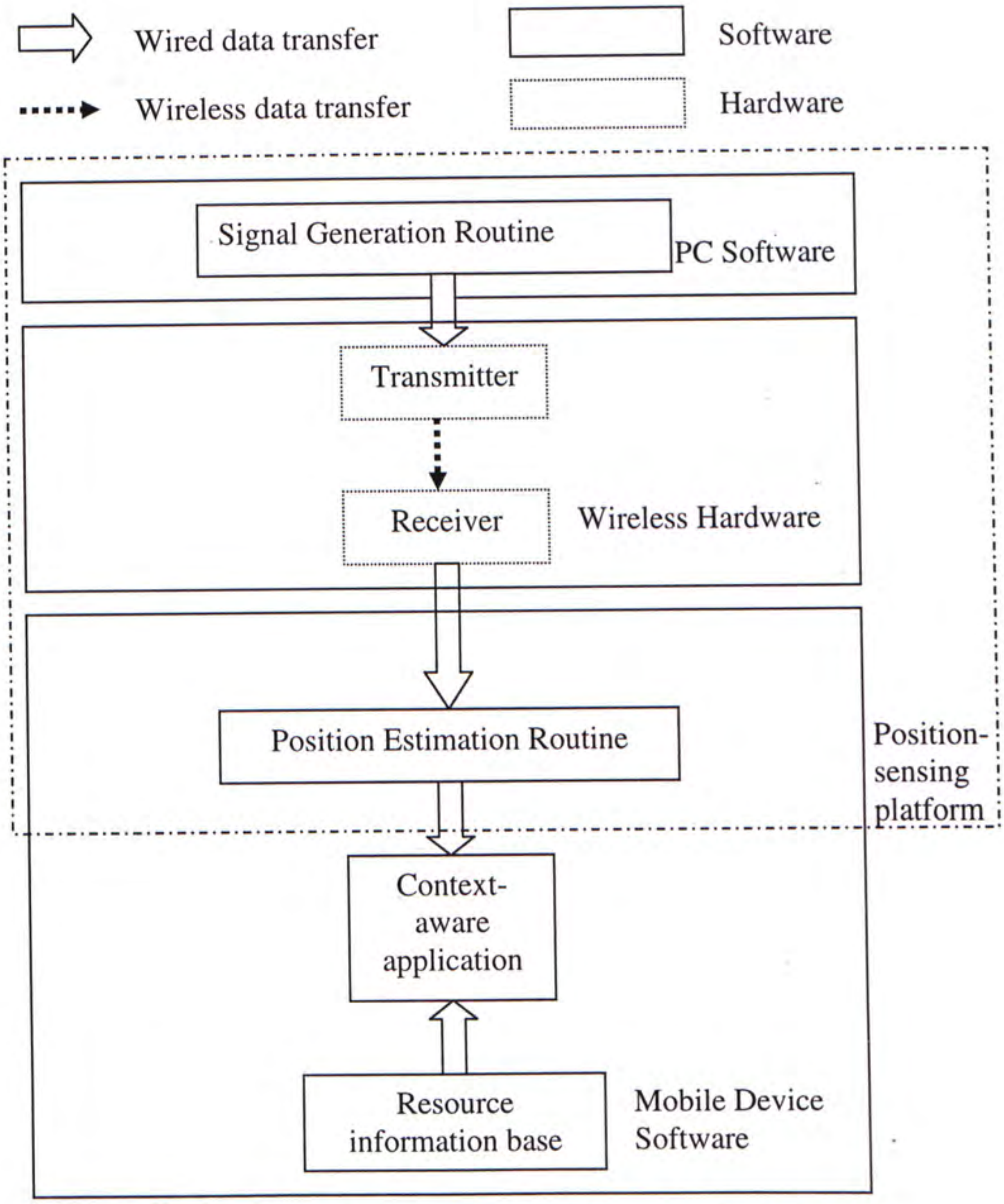

Figure 3.2: Block diagram of the indoor positioning system.

The context-aware application provides methods and user-interface for remote users to access position-sensing platform and resource information base. It is responsible for collecting position information, e.g. coordinates from the location-sensing platform. With the position information, it contacts the resource

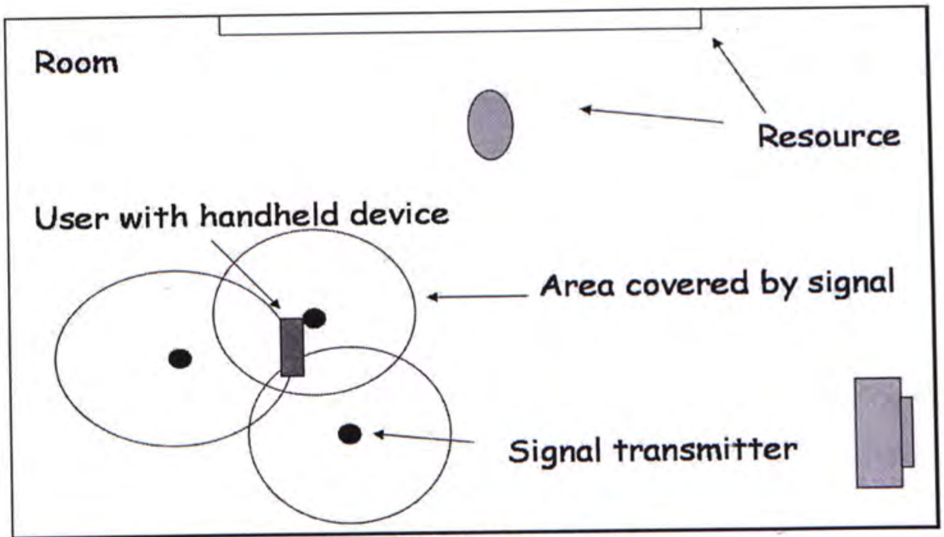

Figure 3.3: Platform design.

information base for resource descriptions if necessary. It then combines the information it collected and displays the final results through a Web browser.

In this thesis, we mainly focus on the design of the position-sensing platform (see dotted box in Figure 3.2).

3.2 Position-sensing Platform

Figure 3.3 shows the design of our position-sensing platform. In this platform, we use signal transmitters to disseminate information about a geographic space to the mobile device, i.e. a signal receiver held by the user. The receiver will then determine its location from the signals received.

It is assumed that a user inside the room holds a mobile device, e.g. a PDA, this device constantly listen to messages sent by the transmitters. The mobile device then uses these messages to infer the space it is currently in. And then it can use this information to appropriately advertise its location to the context-aware application. The devices learn their location information using the signals they received. This approach avoids the needs for any per-node configuration. The only configuration required is setting the URL string for a space, which is disseminated by the transmitters.

3.2.1 Platform Architecture

The position-sensing platform is comprised of two hardware and two software entities as shown in Figure 3.2:

Hardware entities:

- A set of transmitters are placed at several known points in the room. Each transmitter has a unique ID and a transducer capable of emitting position signals generated by the signal generation routine.

- One or more signal receivers are carried by the users entering the room. The receivers detect their own position by receiving signals from the transmitters and then it forwards the signal to the position estimation routine.

Software entities:

- A signal generation routine is used to generate position signals periodically and transmits the signal across a transmitter interface.

BOF	UID	TIME	POSITION	LOCATION	DATA	EOF

Figure 3.4: Frame layout of transmission signal.

Packet section	**Size / Bytes**	**Description**
BOF	1	Start of frame indicator
UID	1	Unique identifier for each transmitter
TIME	5	Signal send time
POSITION	8	Two dimensional position value for each transmitter
LOCATION	8	Space value for each transmitter
DATA	16	URL link to resource map or server
EOF	1	End of frame indicator

Table 3.1: Packet description.

- A position estimation routine is run on a signal receiver. It calculates the transmitter-receiver distance using time-of-flight, and based on that, it determines the receiver's position information.

3.2.2 Transmission Format

The purpose of each transmitter is to transmit a unique identifier code to the mobile receiver. In this way, the receiver can determine its own location using the received message. The transmission signal frame layout is shown in Figure 3.4. And a more detailed description of each field of the signal frame is shown in Table 3.1.

The UID field contains the unique identifier code of the transmitter. The TIME, POSITION and LOCATION fields provide the necessary information for the receiver to determine its current location. Description of the position inference protocol is outlined in Section 3.2.4. The DATA field contains a URL to the resource information base. The upper context-aware applications will use this URL to discover related resources in the space that the corresponding receiver is currently in. In total, each transmission frame is 40 bytes long.

3.2.3 Distance Measurement

To determine the position of a receiver, the receiver must first calculate the transmitter-receiver distance from the measured transmission signal, and then find the 2D position based on those distances [33]. This section details the calculation steps.

We use time-of-flight to calculate the distance between the signal transmitter and receiver. For each receiver, the measured transmission t between sending a signal and receiving a signal is the sum of several individual periods:

t_t, the signal transmit time from transmitter to receiver.

t_e, the signal encode time in transmitter.

t_d, the signal decode time in receiver.

N, the noisy factor for fixed delays.

t is given in equation 1:

$$t = t_t + t_e + t_d + N \tag{1}$$

Given:

$$l = c \times t_t \tag{2}$$

Where

l - the distance between transmitter and receiver

c - the speed of light in air

We can rearrange equation 1 and get:

$$l = c \times (t - t_e - t_d - N) \tag{3}$$

By empirically determining the delays (t_e and t_d) and the noisy factor (N), we can use the above equation to calculate the transmitter-receiver distance.

The accuracy in this calculation depends on the maximum range of the transmitter signals. The longer is the range, the higher the error can be. It would be possible to make some accuracy improvement if the knowledge of the physical limitations such as angle and range limitations are known in advance. However, this would require more calculations on the mobile device. It is impractical for a mobile device to run heavy calculations as most of the mobile devices only have limited processing power.

3.2.4 Position Estimation

The signal receiver takes the following procedure to estimate its current location. It first looks for all possible signals in the room within a time period and makes an estimation if it receives enough information; otherwise it would time out.

If a receiver only receives one signal, its position is believed to be inside a circle around the transmitter with the radius equals to the calculated distance, see Section 3.2.3. The estimated receiver's position is then set by taking the transmitter position (see Figure 3.5).

If the receiver receives two signals, two circles will be used for the calculation (see Figure 3.6). And the final position of the receiver is set by taking the mean value of the intersection point.

If the receiver receives three or more position signals, these signals can be combined to calculate a more accurate position (see Figure 3.7). We consider a set of transmitters placed at points on a horizontal ceiling, with orthogonal coordinate axes x and y. Suppose a receiver is at coordinate (u, v) and its distance from a transmitter at the coordinate (x, y) is d, equation 4 will be applied.

$$d = \sqrt{(x^2 + y^2) + (u - 2xu) + (v - 2yv)} \tag{4}$$

We define that all distances shown in Figure 3.7 (i.e, d_1, d_2, d_3) belong to a set D. Every pair of distances from the set $\{d_i, d_j, d_k\}$, where d_1, d_2 and d_3 belong to D, are analyzed to find the intersection point.

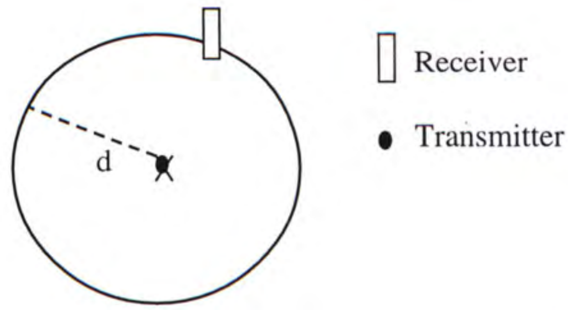

Figure 3.5: One source of position signal. The receiver is somewhere in the circle.

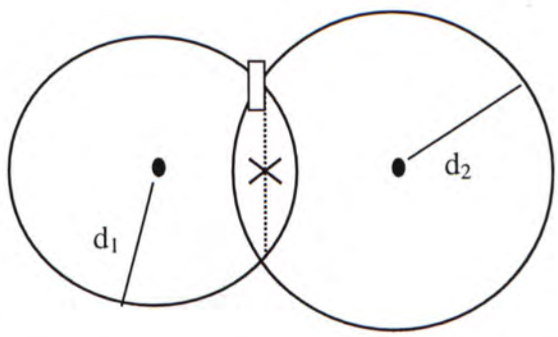

Figure 3.6: Two sources of position. The receiver is on the intersection points of two circles.

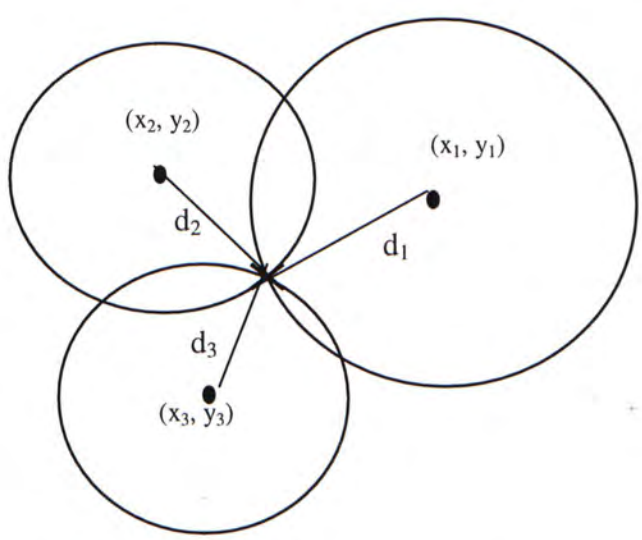

Figure 3.7: Three position sources. The receiver is on the intersection point of the three circles.

When every pair of distances has been analyzed, we calculate the final position (i.e. u, v) of the receiver by taking the mean value of all intersection points.

3.2.5 Noise Cancellation

Noisy Factor (N) is mainly due to the time gap between the signal transmitter and signal receiver. However it is a difficult task to synchronize these two clocks. Two-way signal based on a centralized system could solve this problem. But it would create the privacy problem, which we aim to solve in the first place.

In our design, all signal transmitters are linked to a network. Therefore, the clocks in the signal transmitters are synchronized. When the receiver receives three signals from three different transmitters, it will calculate the distances (d_1, d_2, d_3) by using the equations shown in Section 3.2.3 with N assumed zero. And it will also get the location values of the transmitters (c_1, c_2, c_3) from the signals received. The difference between the detected distance and the actual distance is ζ (Figure 3.8). Mathematically, we can show that the intersection point of three circles (c_1, $d_2+\zeta$) (c_2, $d_2+\zeta$) and (c_3, $d_3+\zeta$) is independent of ζ if all c_s and d_s are known. And the circles will only intersect when ζ equals to a particular value. Based on this observation, we can calculate the signal receiver's location value, i.e. the intersection point, without synchronizing the transmitters' and receivers' clock.

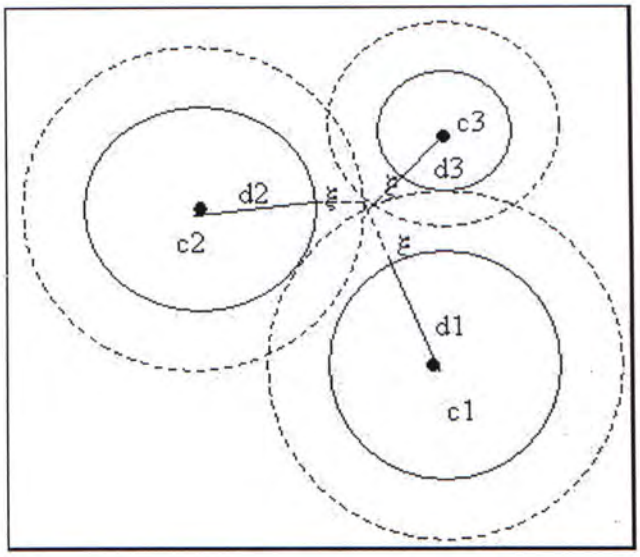

Figure 3.8: Noisy factor ζ.

3.2.6 Location Inference

The location information of a mobile receiver is simply set to the nearest transmitter. For transmission signal, which cannot pass through walls, like infrared, this algorithm is good enough because the walls act as natural boundaries of the enclosure, e.g., the room. The receiver can safely assume that all transmitters it discovered is within the enclosure where it is located.

For other transmission signals which can pass through walls, such as Bluetooth, Our algorithm no longer works. Figure 3.9 shows this situation. Although the receiver is in room B, it finds that the transmitter in room A is closer than transmitter B. Error occurs if the receiver sets its location as the same as transmitter A.

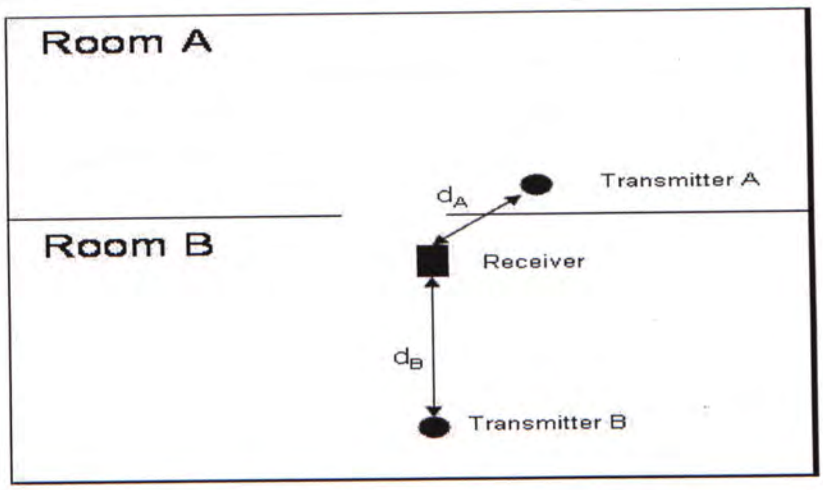

Figure 3.9: The nearest transmitter is not at room A.

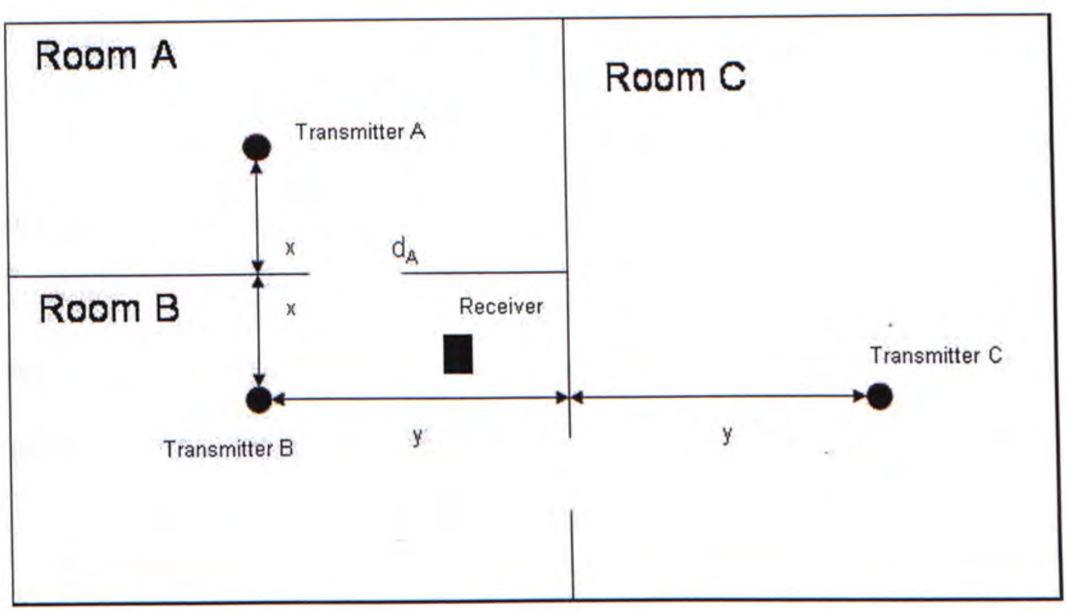

Figure 3.10: Bluetooth transmitter positioning.

To overcome this limitation, maintaining a centralized database of physical boundaries and providing such information to the receiver is a possible solution. Other centralized systems, like the Bat system, use this approach. However, this approach raises privacy issues and contradicts our design goal.

In this thesis, we provide a simple engineering solution to this problem, we propose a decentralized architecture. This preserves user privacy. Figure 3.10 shows an example of this setting. The two transmitters corresponding to two different spaces separated by boundaries must be placed at equal distance from the boundary. In this setting, the receiver can correctly detect the nearest transmitter no matter where it is.

3.3 Summary

A new decentralized indoor position-sensing platform for context-aware applications was introduced in this chapter. This system protects user privacy by enabling users to learn their own locations rather than by tracking. Signal receivers in this system are passive devices. They only determine and provide position information to the context-aware applications running on the devices.

Algorithm that can determine mobile receiver positions was described. It can determine transmitter-receiver distance from time-of-flight information. It can then use these distances to estimate the 2D receiver positions. A method for canceling the noisy factor was also presented.

Chapter 4

System Implementation

This Chapter outlines the implementation of two position-sensing platforms: an Infrared-based platform and a Bluetooth-based platform. Section 4.1 reviews four communication technologies, which are suitable for the position-sensing platform. The advantages and disadvantages of these technologies are outlined in Section 4.2. Section 4.3 describes the hardware used by the prototype and the software routines therein for position sensing are presented in Section 4.4.

4.1 Communication Technologies

We have looked at four different short-range communication technologies which are suitable for indoor position-sensing. They are Ultrasound, RFID, Bluetooth and IrDA. We found that Bluetooth and IrDA are best for our position-sensing platform. This section presents a review of these technologies.

4.1.1 Ultrasound

Ultrasonic devices vary depending on the applications they are designed for. There is no standard for the communication between ultrasonic readers and transducers. Thus, the devices from different manufacturers adopt different designs and support different transmission ranges.

General ultrasound characteristics include:

- Operates in frequency greater than 20 KHz.
- Reflects when it strikes a reflecting surface.
- Does not travel through brick walls.
- The transmission speed depends on transmission media.

4.1.2 Radio Frequency Identification (RFID)

RFID is designed for a wireless identification system [23]. This technology has much in common with barcodes. A basic RFID System consists of three parts: the antenna, a reader with decoder and a transponder, also called RF tag.

The range of RFID systems depends on the applications they are designed for. Range varies between contacts and is up to 20m. The difference is due to power usage and frequency. Low-frequency systems, 30KHz to 500KHz, have short reading ranges and lower system costs. They are most commonly used in security access and asset tracking applications. High-frequency systems, 850MHz to 950

MHz and 2.4GHz to 2.5GHz, have long reading ranges (greater than 20m). They are widely used in railroad car tracking and automated toll collection applications.

Many of the standards, which have been developed for barcodes are also applicable to RFID. But today there are no standards for the communication between readers and transponders. This makes devices from difference manufacturers incompatible with each other.

General RFID characteristics include:

- Transmits data between a reader and a transponder.
- Provides identification data for objects.
- Supports non line-of-sight transmission through walls and briefcases.

4.1.3 Infrared Data Association (IrDA)

In general, IrDA is used to provide wireless connectivity technologies for devices that would normally use cables for connectivity. IrDA is a point-to-point, narrow angle, ad-hoc data transmission standard designed to operate over a distance of 0 to 3 meter and at speeds of 9600 bps to 16 Mbps.

General IrDA characteristics include:

- Proven worldwide universal cordless connection.
- Wide range of supported hardware and software platforms.
- Designed for point-to-point cable replacement.
- Backward compatibility between successive standards.

- Narrow angle cone, point-and-shoot style applications. (Non-interference with other electronics and low-level security for stationary devices.)
- High data rates; 4 Mbps currently, 16 Mbps under development.

IrDA is widely available on personal computers, peripherals, embedded systems and devices of all types. In addition, the wide use and acceptance of IrDA standards and robust solutions have accelerated adoption of the IrDA specifications by other standards organizations. The universal adoption and world-wide implementation of IrDA specifications guarantees a universal hardware port, and rapidly emerging software interoperability.

4.1.4 Bluetooth

Bluetooth is a Radio Frequency (RF) specification proposed to replace interconnect cables between different personal devices, such as mobile phones, headset, PDA's and portable computers. Its nominal link range is from 10 cm to 10 m. But it can be extended to 100 m by increasing the transmission power. Bluetooth used the unlicensed ISM band. ISM Band is available and has same frequency range in countries all over the world except France.

General Bluetooth characteristics include:

- Operates in the 2.4 GHz Industrial-Scientific-Medical (ISM) band.
- Provides built-in security.
- Support non line-of-sight transmission through walls and briefcases.

- Uses Frequency Hop (FH) spread spectrum, which divides the frequency band into a number of hop channels. During a connection, radio transceivers hop from one channel to another in a pseudo-random fashion.
- Supports up to 8 devices in a piconet.
- Supports both isochronous and asynchronous services and easy integration with TCP/IP.

Even Bluetooth is not as common as IrDA nowadays, but the Bluetooth market has made solid progress in spite of the economic ups and downs. Final 2002 worldwide chipset shipments were 35.8 million units, resulting in 245% growth over 2001. And it is believed that Bluetooth chipset units will swell from 35.8 million to 575 million from 2002 to 2007, for a five-year Compound Annual Growth Rate (CAGR) of 74% [36].

4.2 Technologies Overview

Bluetooth and IrDA are similar [9]. They support two-way communication protocols, and high-speed network connection. Communication using IrDA requires line of sight. This limits its practicality. Bluetooth on the other hand, can communicate in all directions. Many existing PDAs, notebook computers and some mobile phones have built-in infrared ports. Thus, infrared devices are ready for our adoption; and they are cheap to maintain. On the other hand, Bluetooth is not as common as Infrared. Bluetooth devices are more expensive. Table 4.1 shows a summary of the above four technologies.

	Ultrasound	RFID	Bluetooth	IrDA
Network	N/A	N/A	1Mbps	4Mbps
Communication	One way	One way	Two ways	Two ways
Security	Poor	Poor	Very Good	Good
Range	Varied	0-20m	10-100m	0-3m
Angle dependency	No	No	No	Yes
Reliability	Good	Good	Very Good	Very Good
Cost	Low	Low	High	Low
Standard	No	No	Yes	Yes
Handheld devices	Not supported	Not supported	Few Devices	Supported
Application	Active Bat	RADAR	Alipes [32]	Active Badges

Table 4.1: Summary of four communication technologies.

4.2.1 Positioning

The technology must be able to locate mobile device. Mobile devices using any technologies can store a position signal and transmit it to other mobile devices freely.

4.2.2 Networking

It is important that the technology provides efficient network access. In context-aware system, a network may be open for many services such as map and information retrieval about the surrounding facilities spaces. In this way, the technology could be used to provide different network services. Bluetooth and IrDA are both designed for networking. Bluetooth delivers a maximum speed of 1Mbps while IrDA delivers a maximum speed of 4Mbps. RFID and Ultrasound on the other hand do not support networking.

4.2.3 Communication Protocol

Obtaining position information, e.g. coordinates, manually is clumsy. Thus automatic device discovery and service discovery are desirable. All technologies support automatic device discovery, which can locate any new devices within a certain range. However, only IrDA and Bluetooth support automatic service discovery. The automatic service discovery mechanism checks whether if the positioning service is present in the discovered device. If there is no such service, no position information would be sent.

4.2.4 Range

IrDA has a range of typically one meter to three meters. Bluetooth has a typical range from 10m to 100m depending on the power class of the device. Class 3 Bluetooth, with a typical range of 10m, is most common in mobile devices at present. Since there is no industrial standard, RFID and Ultrasound vary quite a lot in range.

4.2.5 Angle Dependency

Radio devices based on RFID, Bluetooth, and ultrasonic, are independent of angles and line of sight. However, due to optical angle limitation of IrDA, line of sight is required.

4.2.6 Hardware supports

Although most mobile devices, such as PDAs, notebook computers, and mobile phones, support IrDA, Bluetooth technology is becoming more popular. As such, Bluetooth communication ports can be found in many new mobile device models. On the other hand, RFID and Ultrasound are uncommon in such devices. If they were adopted for position sensing, user would require to carry add-on hardware modules. This would be very inconvenient as well as costly.

4.3 Hardware

We use off-the-shelf hardware components to implement our position-sensing platform. Lack of customized hardware significantly reduces cost. This section gives detailed descriptions about hardware design.

4.3.1 Mobile Receiver

For mobile receiver, we use two Palm hand-held devices, Palm M130 and Palm TUNGSTEN T from 3Com which runs PalmOS 4.1 and PalmOS 5.0 respectively [20]. They support:

- IrDA data transfer for transmitter detection.
- Program storage for application and site database storage.
- Direct access buttons and touch screen display for user input.

Palm TUNGSTEN T, has build-in Bluetooth communication port. But a Bluetooth expansion card is required by Palm M130 for Bluetooth communication.

4.3.2 Transmitter

For IrDA transmitter, we use ACT-IR 220L+ from ACTiSYS. The ACT-IR 220L+ is attached to the RS232 serial port of a personal computer to give the user wireless IrDA data transfer directly from infrared-capable mobile devices like notebook computers and PDAs. It is fully compliant with IrDA transmission standard and supports operation range up to three meters.

For Bluetooth transmitter, we use Bluetooth USB Dongle BT3030 from TECOM. BT3030 attaches to the USB port of a personal computer to give the user wireless Bluetooth data transfer directly from Bluetooth-capable mobile devices. It is fully compliant with Bluetooth specification version 1.1 standards [3], class1 operation, and supports operation range up to 100 meters.

4.4 Software

We follow the existing communication standards to implement our transmitter and receiver software. This makes our implementation suitable for devices which are compliant with the same standards. In this section, we will discuss the design of our software components for both the transmitters and receivers.

4.4.1 Communication Protocol

For Infrared, we implement IrCOMM protocol, and for Bluetooth we implement RFCOMM protocol. The descriptions of these protocols are given in Appendix A and Appendix B.

4.4.2 Programming Environment

We initially planned to develop our position-sensing platform in Java. This is because Java from JavaSoft is a machine independent programming language, which can be integrated with different operating systems and platforms easily. However Java does not support IrDA and Bluetooth communication protocols currently. Alternatively, we developed the transmitter and receivers program in C. And also by using Java Native Interface, a set of libraries was developed to facilitate integration with context-aware applications, which were developed in Java.

4.4.3 Signal Generation Routine

The signal generation routine in the transmitter is shown in Figure 4.1. This routine searches for all possible remote devices within the range at every 250ms, which is the minimum refresh time for a TECOM Bluetooth device. If the remote device is found, it will make a connection and send the request through the

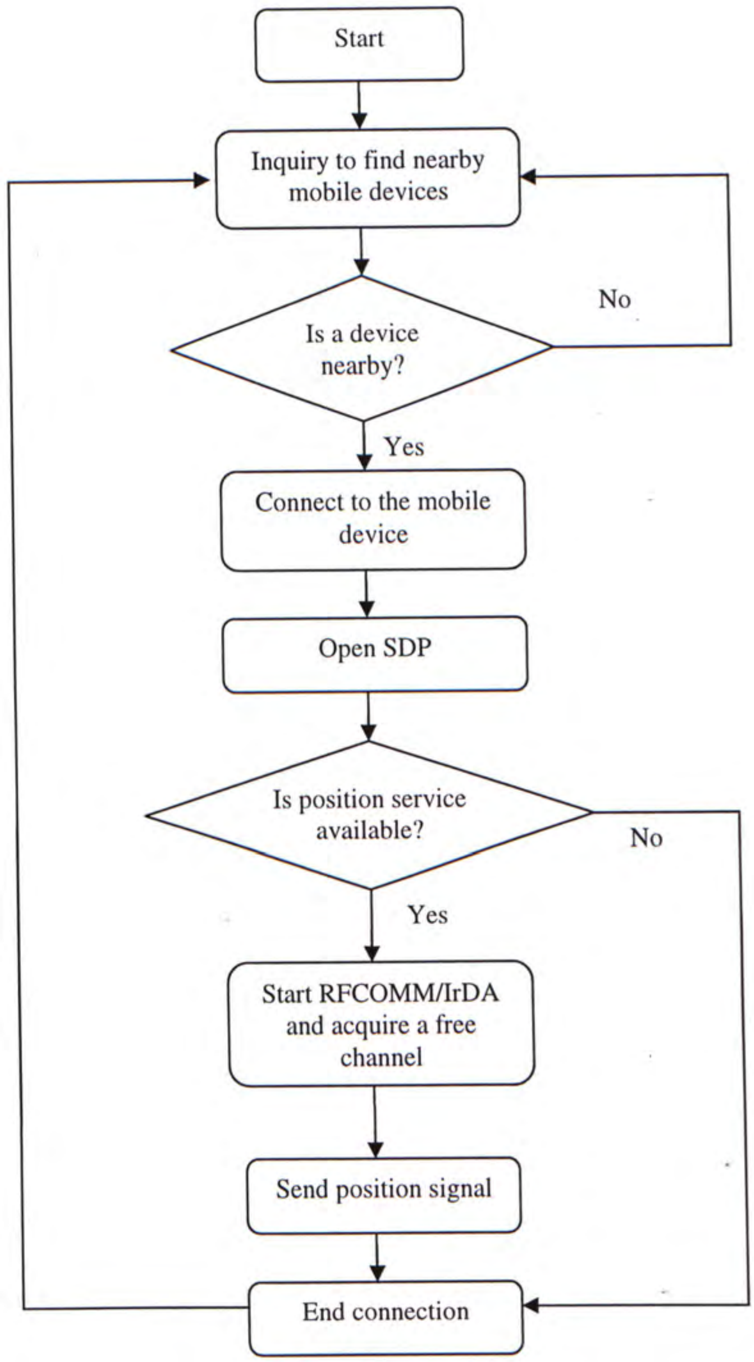

Figure 4.1: Flow diagram showing the signal generation routine in the transmitter.

Service Discovery Protocol (SDP) to figure out the services provided by the remote device. If the remote device provides the position estimation routine (see section 0), it will send its position signals to the remote device. Otherwise, it will terminate the connection and look for other devices.

4.4.4 Position Estimation Routine

All palmOS applications are event-driven and have a similar event loop structure, see Figure 4.2. The event loop passes events, which are posted to an event queue by hardware, by the operating system, or by other applications, to the appropriate event handlers.

Our palm receiver program also has an event loop. The hardware infrared or Bluetooth port passes an incoming connection request to the applications by posting an event to the event queue. When there is an event indicating that a transmitter signal has been received, the signal receiving routine, shown in Figure 4.3 will be invoked. The routine retrieves the signals from the transmitter. If the time out event is received, the position estimation routine calculates will be called and calculate the position value by the algorithm shown in Figure 4.4, and finally it reports the result to the context-aware application.

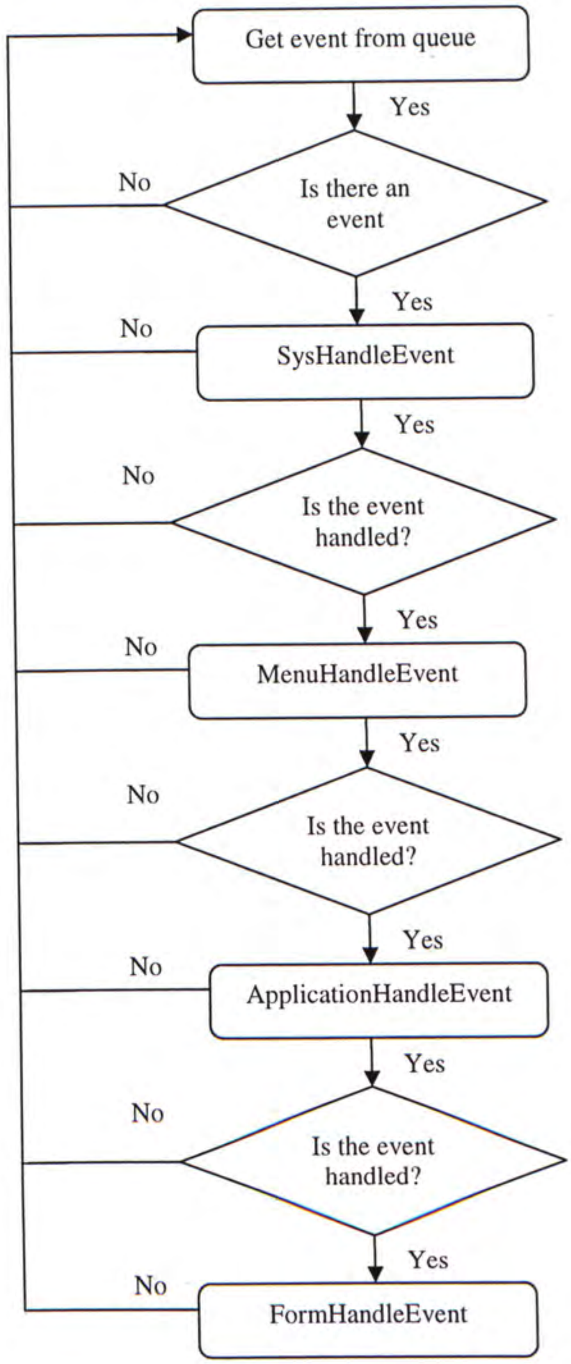

Figure 4.2: PalmOS event loop.

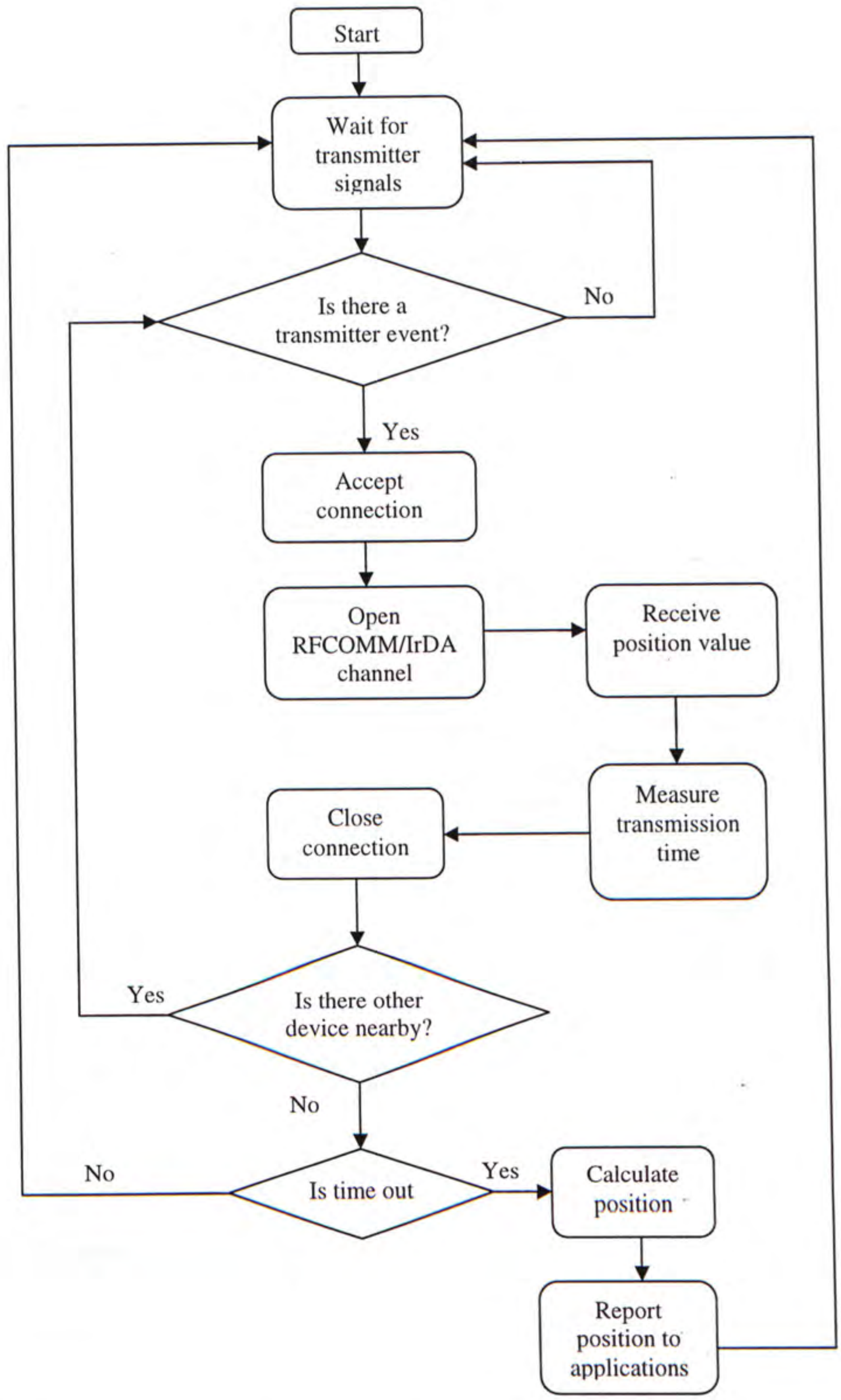

Figure 4.3: Flow diagram showing the position estimation routine on the remote device.

```
Procedure position estimation
begin
  foreach signals s
        get the transmitter id from the s
        if there exist signals with same id in set S then
              drop s
        else
              append s to the signal set, S = {s1, s2, ...}
        end if
  end for loop
  if number of element in S ≥ 3 then
        estimate the position for every pair of (si, sj, sk) where si, sj, sk ∋ S
        calculate the central point of all estimated positions
        return the central point as the final position
  else if number of element in S = 2 then
        find two intersection points
        return the mid-point of the intersection points as the final position
  else if number of element in S = 1 then
        return the position of the transmitter as the final position
  end if
end procedure
```

Figure 4.4: Position estimation algorithm.

4.5 Summary

The communication technologies, which are suitable for indoor position-sensing platform, were described in this chapter. A survey for these technologies was presented and the reasons for choosing IrDA and Bluetooth were giving. The hardware used by our IrDA and Bluetooth position-sensing platforms was described. The two software components we developed for both the transmitters and mobile receivers were also illustrated in this chapter. In the next chapter, evaluation of the prototypical platforms is outlined.

Chapter 5

Evaluation

In this chapter, several experiments were conducted to evaluate the performance of the prototypical indoor position-sensing systems. One set of experiments is based on a small field test. They are designed to evaluate the performance of distance measurement and location estimation. Another set is simulation based and uses the data collected from the field test. It is used to evaluate the performance of a large-scale application. This chapter presents and analysis the results of the experiments. Section 5.1 describes the measurements taken to filter outliers and to determine delay constants. Section 5.2 and 5.3 presents the experimental results over the IrDA and Bluetooth prototypes, respectively.

5.1 Platform Calibration

Before the position-sensing platform can be used for evaluation, the sum of constant terms in Equation 1 must be determined and the outliers of collected

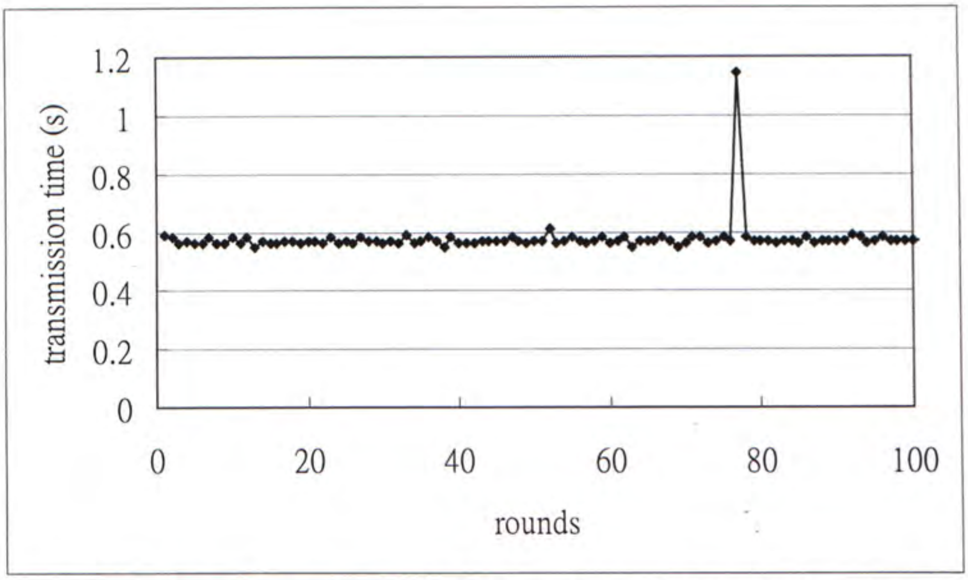

Figure 5.1: Infrared signal transmission time measured by a fix receiver and a fixed transmitter.

data must be filtered. This section describes the measurements taken to calibrate the receivers and to determine their fixed positions.

5.1.1 Outliers Elimination

Figure 5.1 shows the IrDA position signal transmission time measured by a receiver placed at a fixed position over 100 readings. The position signals were generated from a fixed transmitter, which was placed at a distance of 1.5 meters from the receiver. Figure 5.2 shows the result for Bluetooth signal with the same experiment setting.

Figure 5.1 and Figure 5.2 shows that the majority of the time-of-flight readings laid within small intervals. However some outliers, i.e., the 77th and 95th round of the figures respectively, are far away from the majority. These

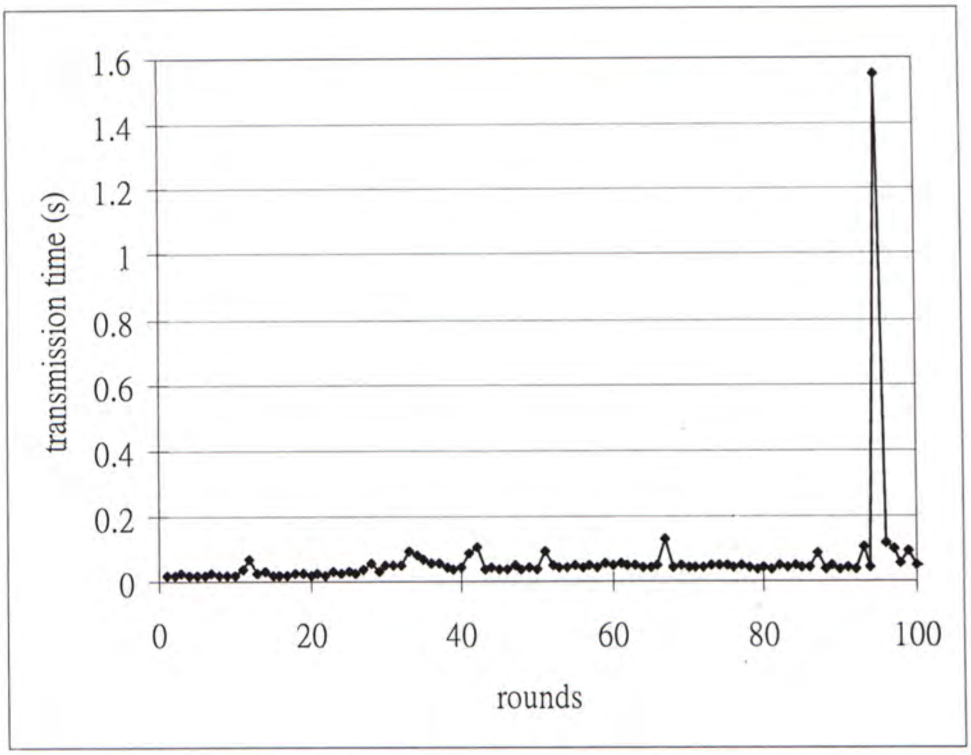

Figure 5.2: Bluetooth signal transmission time measured by a fix receiver and a fixed transmitter.

erroneous measurements are mainly due to the Operating System in the mobile receiver. The central processor of the mobile receiver is time-shared by the position-estimation routine and the Operating System. When an Operating System function is being processed, the received position signal will be placed in a buffer. Therefore the measured time-of-flight is larger then the normal cases.

To filter out these outliers, we make use of the fact that the distance measurement error is always positive [18]. A pairwise comparison of received signals was performed. Consider the setting shown in Figure 5.3. A receiver has detected two signals from two transmitters. The transmitters were placed at a distance l apart, and the distances from the transmitter to receiver have been estimated as d_1 and d_2. Simple geometry shows that the inequality (Equation 6):

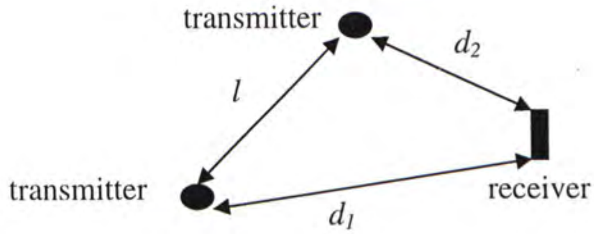

Figure 5.3: Distance estimation constrain.

$$l \geq |d_1 - d_2| - 2\rho \quad (6)$$

where $$l = |d_1 - d_2| + 2\sqrt{d_1 d_2}$$

must hold, where ρ is the maximum expected distance measurement error. If this inequality does not hold, the larger of d_1 and d_2 must be an erroneous estimation, and can be discarded from the data set. The values of ρ used for our experiments were 3 meters for IrDA and 10 meters for Bluetooth. As Palm Devices have a typical range of 3 meters for IrDA and10 meters for Bluetooth, it is reasonable to set the maximum expected distance measurement error to be the maximum signal range that Palm Devices supported.

5.1.2 Delay Determination

To determine the sum of the delay constants t_e, t_d and N, Equation 3 (see Section 3.2.3) is rearranged as:

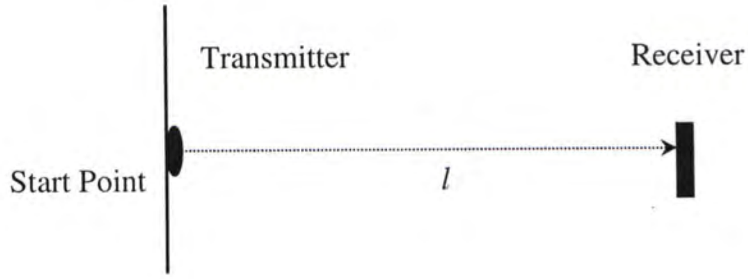

Figure 5.4: Experiment setup for delays determination.

$$D = t - \frac{l}{c} \tag{7}$$

Where $D = t_e + t_d + N$

In order to determine *D*, the relation between the transmission time *t* and the measured distance *l* must be derived. Figure 5.4 shows the setup for the experiment to determine *D*. A transmitter which sends its location string was placed on the ceiling. Distance samples were taken at 0.1m intervals along the *l* direction. And for each interval, 100 samples were collected. Equation 7 shows that D only depends on noisy factor N. If N is a constant, D must also be a constant.

The experimental results (see Figure 5.5) demonstrate both average sum of delays and the minimum sum of delays over 100 samples at varying distances by using an IrDA transmitter and receiver. The average sum of delay across all readings is 56.695±0.125ms. And the minimum sum of delays across all readings was 55.026±0.050ms. The significant large range in average sum of delays

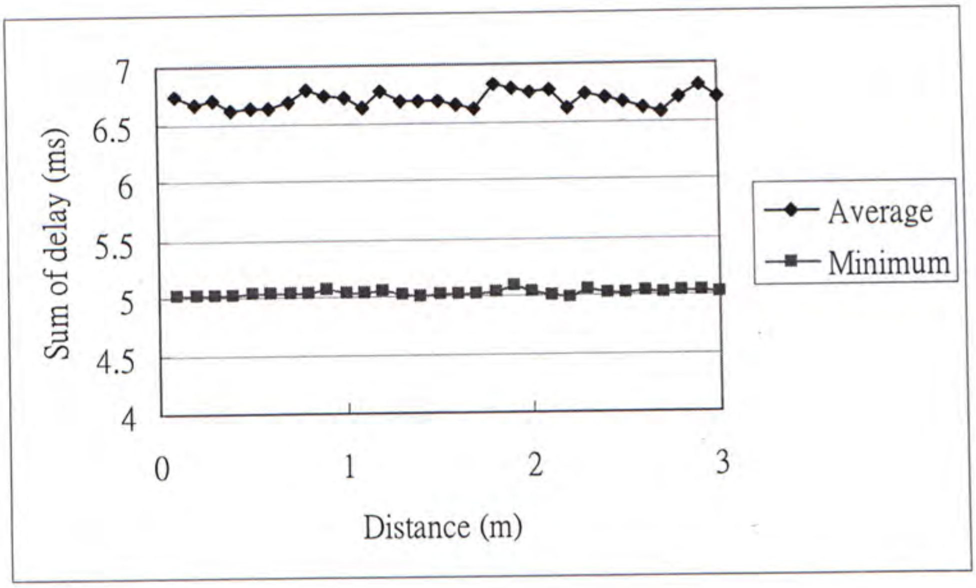

Figure 5.5: IrDA experimental results for delays determination. D is assumed to be a constant, where $D=t_e+t_d+N$.

indicates that N is not a constant. Therefore, the relationship between the transmission time and the transmitter-receiver distance is not fully modeled by Equation 3. Due to signal reflection and multipath effects, the distance measurements always show significant modal behavior. For this reason, the minimum sum was adopted for the IrDA experiments. (i.e. D = 55.026ms)

With the above observation, a statistical algorithm was used to further improve the accuracy of distance measurement method:

Statistical algorithm: For each transmitter, the receiver collects *n* distance samples and picks the minimum value among the sample window.

The advantage of this algorithm is that it can discard the erroneous distance measurements easily. Little computational resource is involved, as the new

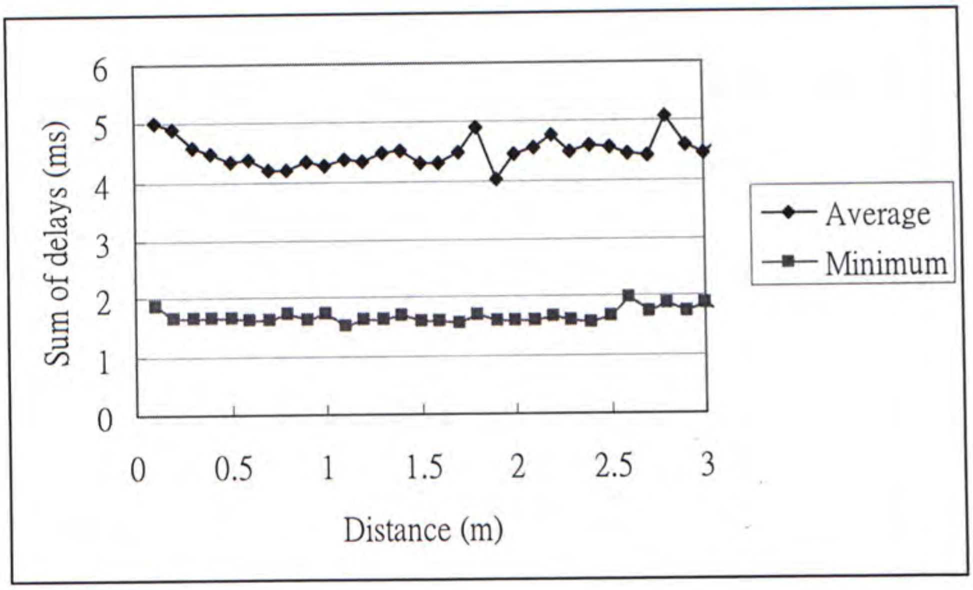

Figure 5.6: Bluetooth experimental results for delays determinations. D is assumed to be a constant, where $D=t_e+t_d+N$.

distance sample updates the minimum sum in a straightforward manner. Figure 5.6 shows the experimental results by using the Bluetooth transmitter and receiver under the same setting. The average sum of delay across all readings was 4.482±0.515ms. The average of minimum sum of delay across all readings was 1.675±0.224ms. The trend of the results of the Bluetooth experiment is similar to that of IrDA. Therefore the same statistical algorithm was adopted to improve distance measurement. Thus the value of *D* was set to 1.675ms.

5.1.3 Window Size Determination

To determine the window size (*n*) described in the statistical algorithm in Section 5.1.2, similar experiment setting shown in Figure 5.4 was used. The only difference to the previous setting was that the receiver was placed at a fixed point,

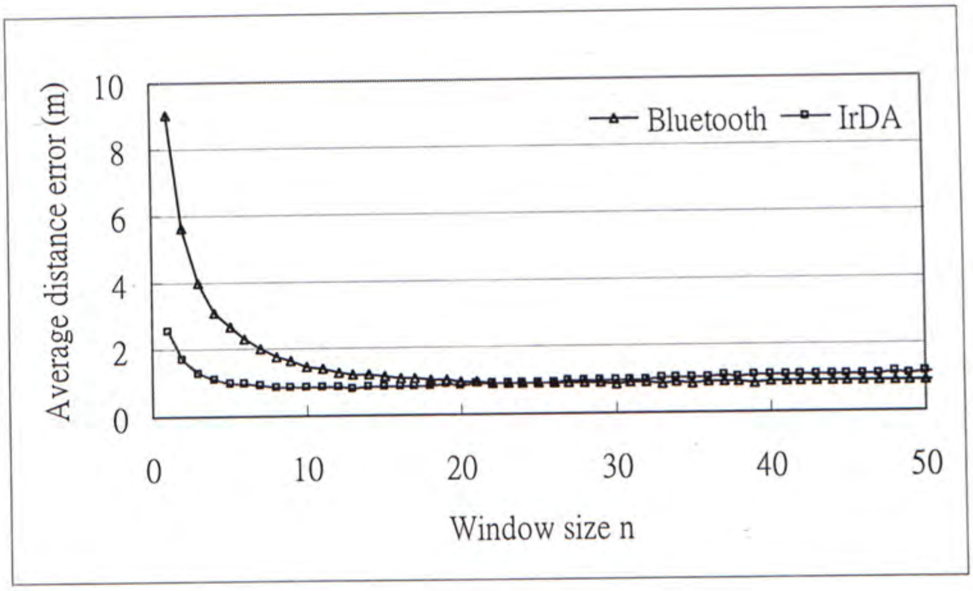

Figure 5.7: Average absolute distance error as a function of window size.

where the distance from the transmitter was 1.5m. Figure 5.7 shows the average absolute distance error over 1000 readings. Absolute distance error was used as accuracy measures in our experiments. An exponentially downward trend in average error with increasing window size is observed. This indicates that the statistic algorithm performs well in both IrDA and Bluetooth cases. Without the statistical algorithm (i.e. window size = 1), the average error is 2.526m for IrDA. It reaches the minimum average error, which is 0.807m, when window size equals 13. Similarly, without the statistical algorithm, the average error is 9.014m for Bluetooth, and it reaches the minimum average error, which is 0.870m, when window size equals 39. From the experiment, it indicates that the window size should be set as large as possible in order to achieve better distance measurement performance. However, large window size means more computational time to complete a distance measurement cycle. If the algorithm is

Window size	IrDA		Bluetooth	
	Average Computational Time (second)	Average distance error (meter)	Average Computational Time (second)	Average distance error(meter)
5	0.034	0.998	0.022	2.681
10	0.067	0.840	0.045	1.461
15	0.100	0.807	0.067	1.147
20	0.132	0.807	0.090	0.973
25	0.179	0.807	0.112	0.910

Table 5.1: Average computational time and average distance error with different windows size for both IrDA and Bluetooth distance measurement algorithms.

too slow, it would limit the number of practical context-aware applications, and also it would affect the distance measurement performance if the mobile receiver is moving too fast.

Table 5.1 indicates the relationship between computation time and window size, and also the relationship between distance measurement error and window size. To balance the computation time and distance error, the window size for IrDA is set to 10 and for Bluetooth is set to 15. The average computation time for these two settings are both 0.067s. It means they can handle at most 16 signals in one second. And the distance measurement errors for these two settings are still acceptable. They are 0.840m and 1.147m for IrDA and Bluetooth, respectively.

5.1.4 Revised Position Estimation Algorithm

In Figure 4.4, the original algorithm used to estimation algorithm basically has two operators: detect() and estimate().The first operator detects incoming transmitter signals and the second operator calculate the position. In the revised algorithm, two new operators: eliminate() and minimum(). eliminate() removes outliers and minimum() returns transmitter signal with minimum D. With these two operators, the revised algorithm to estimate position is shown in Figure 5.8

5.2 Platform Evaluation – IrDA

This section takes a look at how well the IrDA position-sensing platform performs in practice. Three different aspects of the platform have been tested: the performance of distance measurement algorithm; the performance of position estimation algorithm if the receiver is static; and the performance of position estimation algorithm if the receiver is mobile.

5.2.1 Distance Measurement

To characterize the distance measurements made by mobile receivers, a transmitter was placed at a fixed place, and the receiver was placed at varying positions along x direction. Figure 5. shows the experiment setting. 100 samples were collected at 0.1m distance intervals along x direction. Figure 5.10 presents the results of the experiment. From the experiment, 98.5% of the horizontal displacement measurement samples were found to be less than the expected displacement by more than one meter.

```
Procedure revised position estimation
begin
    foreach signals s
        if s is a outlier then
            eliminate s
        else
            get transmitter id (j) from s
            append s to the signal set for transmitter j: Tj = {s1, s2, ...}
        end if
    end for loop
    foreach signal set Tj
        if number of elements in Tj ≥ window size n then
            set m = {minimum of si in Tj}
            append m to the ready set R: R = {m1, m2, ...}
        end if
    end for loop
    if number of elements in R ≥ 3 then
        estimate the position for every pair of (mi, mj, mk) where mi, mj, mk ∍ R
        calculate the central point of all estimated position
        return the centre point as the final position
    if number of elements in R = 2 then
        calculate the two intersection points
        return the mid-point of the intersection points as the final position
    else if number of elements in R = 1 then
        return the position of the transmitter as the final position
    end if
end Procedure
```

Figure 5.8: The revised position estimation algorithm.

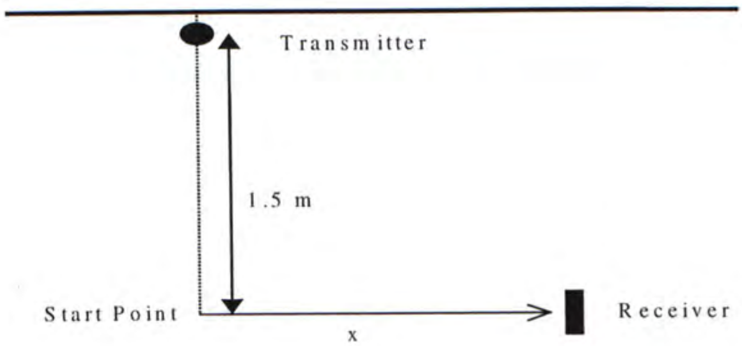

Figure 5.9: Experimental setup for distance performance evaluation.

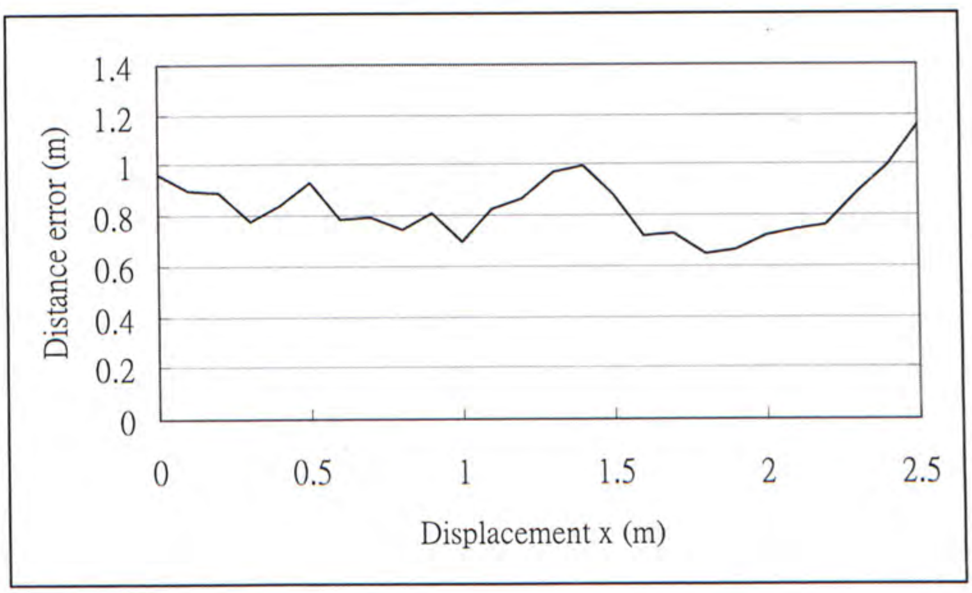

Figure 5.10: IrDA horizontal distance measurement experiment results.

5.2.2 Position Estimation – Static

To evaluate the performance of our position estimation method, a field test was conducted. Figure 5.11 shows the setup for this experiment. Six transmitters were placed at the positions around the receiver. The receiver was placed at position P1 and 1000 readings were collected. Figure 5.12 shows the cumulative

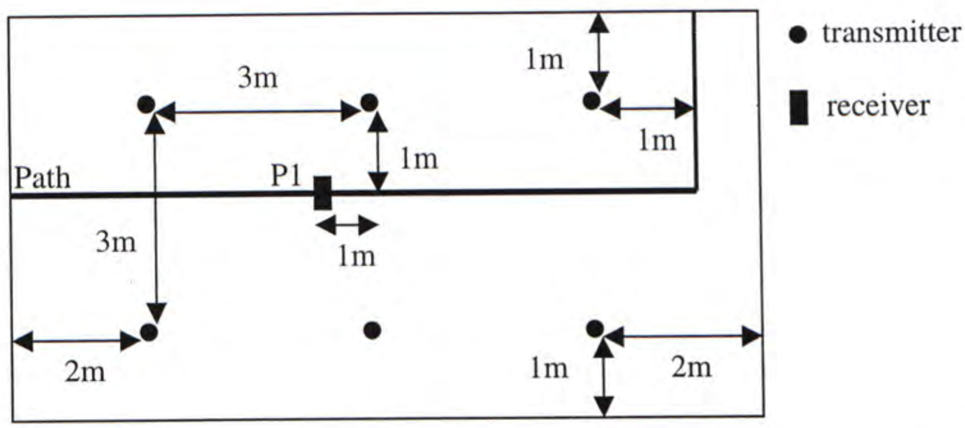

Figure 5.11: Experimental setup for positioning performance evaluation.

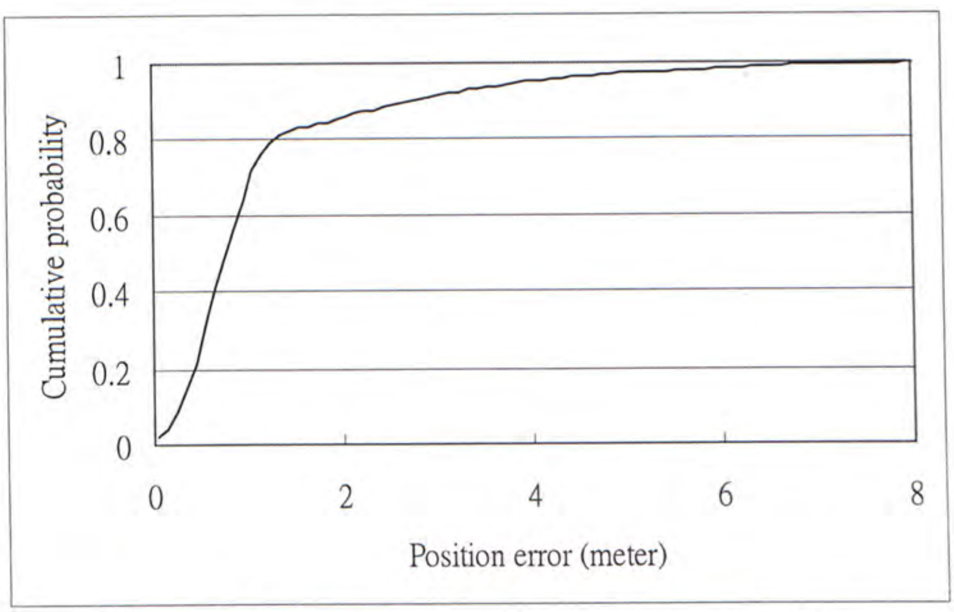

Figure 5.12: Accuracy of IrDA static position estimation.

error probability distribution for the static position estimation experiment. It indicates that 80% confidence level is just less than 1.25m.

The accuracy of the IrDA position estimation is strongly dependent on the transmitters' positions. They affect the number of distance signal that can be detected by the receivers. Also, an IrDA device can only detect signals from transmitters which are placed at certain angles. Therefore, the number of distance signals is limited and the accuracy of the overall position estimation is reduced.

5.2.3 Position Estimation – Mobile

This experiment examines the performance of IrDA position estimation algorithm against interference caused by nearby transmitters when the receiver is mobile. From a practical point of view it is important to obtain accurate location information of a mobile receiver within a short time (say, a few seconds). In this experiment, the setup of the transmitter was the same as the static position estimation experiment. However, the receiver was not placed at a fixed position. It was placed at varying positions following the path shown in Figure 5.. The receiver was moved at constant speed and collected readings at the same time. This setup resembled someone holding a hand-held device walking in a building. The receiver updates the location values in every time period. Figure 5.1 shows the position error for the experiment. The error-rate is calculated over the readings collected within the time period which the receiver moved around. From the results, it is evident that larger time intervals provide better results over smaller ones. This is not surprising since a large interval gives the algorithm more readings to work with.

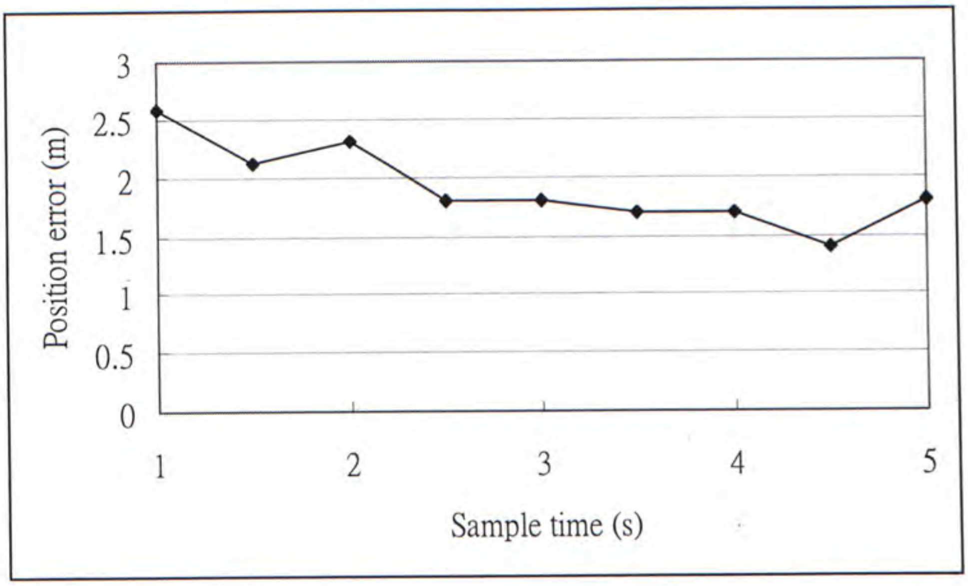

Figure 5.13: Position errors in mobile IrDA position estimation.

5.3 Platform Evaluation – Bluetooth

This section investigates how the Bluetooth position-sensing platform performs under realistic circumstances. Similar experimental settings were used to evaluate the performance of build in distance measurement and position estimation algorithms.

5.3.1 Distance Measurement

To characterize the distance measurements made by mobile receivers, a transmitter was placed at a fixed place, and the receiver was placed at varying position along x direction as shown in Figure 5.. 100 samples were collected at 0.1m distance intervals along x direction. Figure 5.1 presents the results of the experiment. The results indicate that performance decreases when the horizontal displacement increases. This trend is especially obvious when the horizontal displacement is larger than 4 meters.

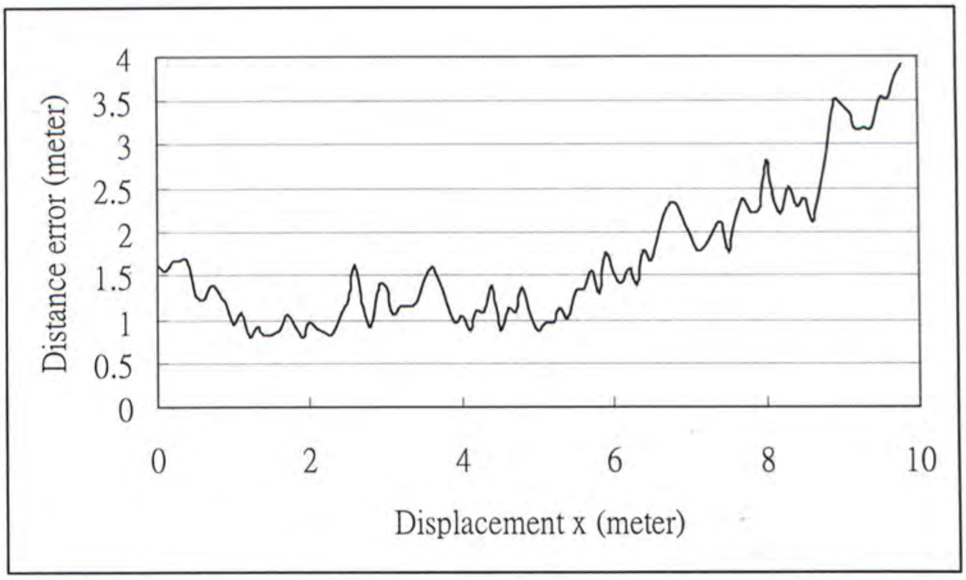

Figure 5.14: Bluetooth horizontal distance measurement experiment results.

Unlike IrDA, the line-of-sight signal detection would not be assumed in Bluetooth. Therefore, signal reflections and multipath effects always significantly impact distance measurements. Such effects can be filtered by the statistical algorithm presented in Section 5.1.2. However, the significantly large in position estimation error indicates that the window size determined in Section 5.1.3 are not large enough to filter out all enormous distance measurements.

5.3.2 Position Estimation – Static

A field test was conducted to evaluate the performance of the position estimation method. Figure 5.11 shows the setup for this experiment. Six transmitters were placed at the positions around the receiver. The receiver was place at the position P1 and 1000 readings were collected. Figure 5.1 shows the cumulative error probability distribution for the static position estimation experiment. It indicates that 80% confidence level is less than 2 meters.

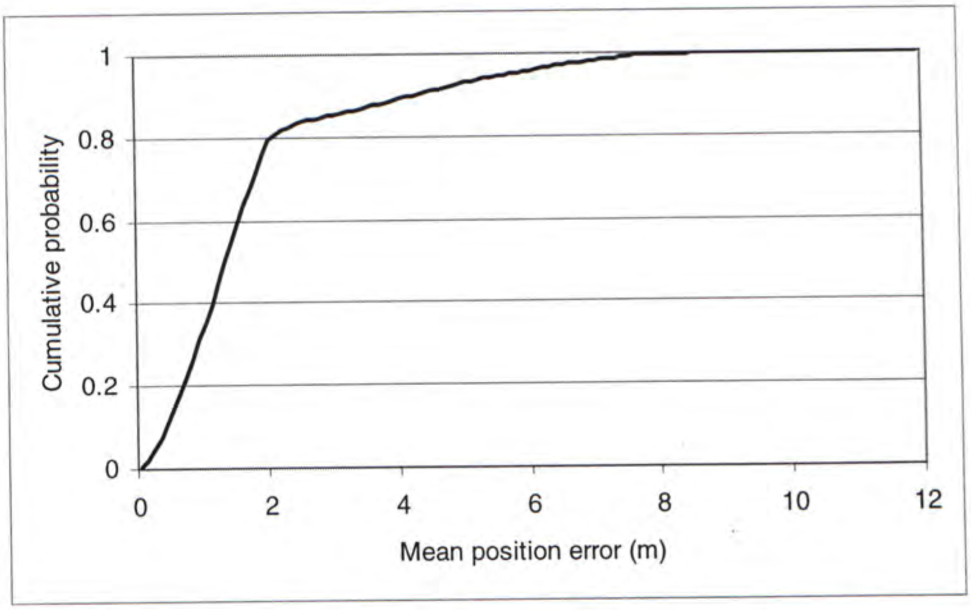

Figure 5.15: Accuracy of Bluetooth static position estimation.

Because of the larger measurement errors in horizontal distance measurement, the accuracy of the Bluetooth position estimation is not as good as that of IrDA. However the performance is not as bad as expected. The reason for this phenomenon is that the optical angle limitation does not exist in Bluetooth signal transmission. Hence the accuracy of the position estimation increases as more distance signals are detected.

5.3.3 Position Estimation – Mobile

This experiment examines the performance of Bluetooth position estimation algorithm against interference due to nearby transmitters when the receiver is mobile. Figure 5. shows the experimental setup. Six transmitters were placed at fixed positions and the receiver was placed at varying positions following a pre-defined path. The receiver was moved at constant speed and concurrently

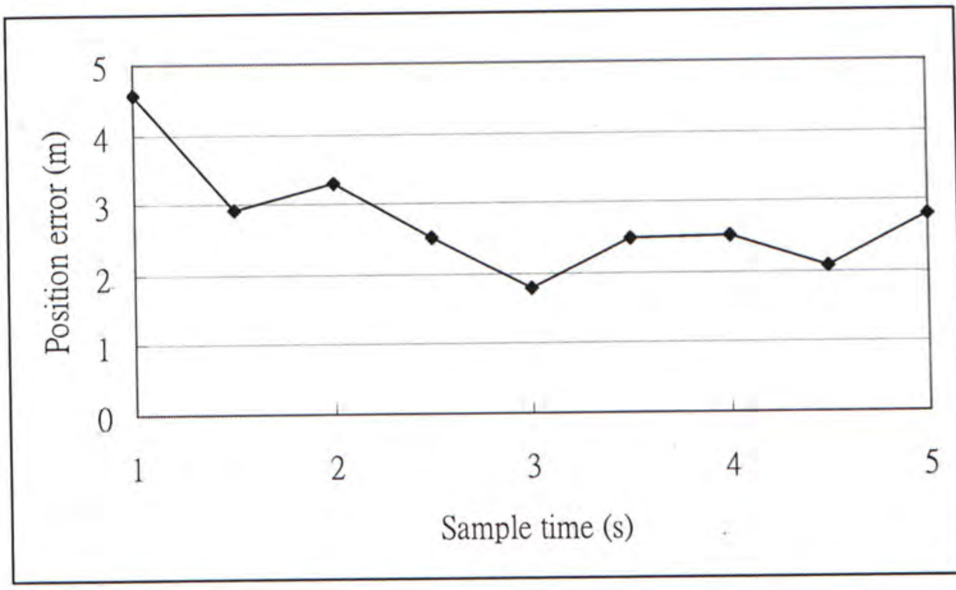

Figure 5.16: Position error in mobile Bluetooth position estimation.

readings were collected. The receiver updated the location values at the end of each time period. This emulated a typical user walking in the building. Figure 5.16 shows the results of this experiment. The error-rate was calculated over the readings collected within the time period which the receiver moved around.

The same downward trend in position error is also observed. But it is more significant than that in the IrDA experiment, see Figure 5.1. This is because the optical angle limitation does not exist in Bluetooth signal transmission. A large interval gives the algorithm more readings to work with and hence the position estimation algorithm is improved.

5.4 Summary

The performance of both IrDA and Bluetooth indoor position-sensing platforms were evaluated and the results of the experiments were then discussed in this chapter. In the next chapter, potential context-aware applications using IrDA and Bluetooth indoor position-sensing platforms will be presented.

Position estimation were found to be accurate to within 1.25m (80% confidence level) made by IrDA prototype, and 2.03m (80% confidence level) by Bluetooth prototype. Furthermore, it has been shown that the proposed platform can be used in real time position update when the user is mobile. Due to the limitations of the processing power of the hand-held devices, the results are not rigorous enough. However, it is believe that the advancement in hardware devices in the future would lead to more robust and rigorous results.

Besides IrDA and Bluetooth, ultrasound was also considered because of the low frequency. It was believe that the performance of the ultrasonic location system should be better than other electronic wave systems. However, the findings from surveys on wireless technologies point out that purely ultrasound-based system does not work well for indoor location system [33]. Indoor environment often contains substantial amount of reflective materials (e.g. physical wall) that affect propagation of ultrasound signals in non-trivial ways, causing severe multipath effects, dead-spots, noise, and interference. And at the same time, ultrasonic mobile devices are not as common as that of IrDA and Bluetooth. Therefore, only IrDA and Bluetooth are considered and evaluated.

Chapter 6

Applications

This chapter examines context-aware applications that could be implemented by using the proposed position-sensing platform. The dropping price of microelectronics, low-power IC design, and miniaturization of components facilitate the deployment of cheap, truly unobtrusive indoor position-sensing systems. It would not be long to see that a building-wide position-sensing systems being widely deployed.

6.1 Potential Applications

Scenario: *A job hunter is traveling for an interview with a company in an unfamiliar region. He arrives at an MTR station and uses his GPS-based platform to get directions to the company. He enters the building, which is about 30 floors high. His GPS device stops working because the GPS signal is too weak indoors. His device seamlessly shifts to Bluetooth-based technology, which is widely available in the building. The device uses Bluetooth to discover that the* *interview room is on the first floor, southeast wing. The platform then provides a map of the building, with clear directions to the interview room.*

After the interview is over, the job hunter walks out of the building. The Bluetooth system automatically stops functioning. The platform then seamlessly switches back to GPS mode, identifies his location, and provides him a road traffic assistance, which helps him get to the next destination on time.

The above scenario shows how the position-sensing technologies can be integrated with one's every day life. With an indoor position-sensing platform, many context-aware applications could be enhanced to achieve automatic personalized decisions. This section outlines how an indoor position-sensing platform could be used.

6.1.1 Resource Tracking Systems

A nearest-resource tracking system could be offered to users with portable computers. The system could detect the positions of electronic resources, e.g. printer, in a strange environment. The mobile devices carried by users, i.e. portable computers, could then be configured automatically to use the nearest available resources anywhere in the building.

Another example is a redirect system, which would allow a user to redirect their working Window System environment to the nearest computer. By pressing a button on his/her mobile device, the user's working Window System environment would be transfer to the computer nearest to his/her through the wired network. At the same time, the user's authorization information, such as user ID and password, would be sent from the mobile device. Once correctly authorized, the computer would then display the working environment. This application is useful in a large open-plan office with hundreds of displays.

For the above applications, an Infrared based position-sensing platform is better than Bluetooth based platform because of cost and location resolution consideration. Office is usually not large and their resources are usually densely located. Also IrDA has good isolation properties. Infrared signal cannot penetrate builThis is good for office environments.

6.1.2 Shopping Assistance System

A shopping assistance application could be offered to shoppers to display routes to selected destinations. Shoppers could receive an electronic directory and advertisement flyer on their wireless PDA after entering the shopping mall. The device would display a map of the facility that identifies the person's exact position on the map. When the shopper clicks on a store, restroom, and ATM machine in the directory, the map would automatically show the directions.

To take further advantage of this, shoppers could retrieve sales information about the shops located within the vicinity of their current positions. If a shopper selects one of the advertisements, his/her PDA could lead him/her to the specific merchandise. However, this would result in electronic competition. For example, when a shopper was shopping for tools in one store, a competing store could pop up an advertisement for a better deal in an attempt to steal the business. Effectively, above applications combine the advantages of traditional and on-line shopping.

Both IrDA and Bluetooth based position-sensing platforms are suitable. For this application, the choice between the two technologies would depend on the size of the shopping mall. If the mall is small, IrDA would work better.

6.1.3 Doctor Tracking System

A doctor tracking system could be used in hospitals to locate doctors promptly in an emergency. The mobile device carried by doctors would receive an emergence signal when they are inside the same region as the patients requiring attention. The device would check the doctors' schedule. If they are free, it would report to the central controller. The doctors who are free and nearest to the patients would be prompted by an emergence call message from the central controller.

It is important to locate doctors in an efficient and fast way during an emergency. Currently pagers and wireless phones are widely used. A problem with the existing search systems is that it can only search for the doctors but not their exact location in the building. This could lead to long delay and hence endanger the patient's life.

As indicated in [27], Infrared signals do not interfere with medical equipments as long as the signal codes are not the same. On the other hand, RF signals, such as signals from cellular phone, could affect normal operation of equipments in the same room. As a result, Bluetooth based system is not suitable and should be avoided in hospital applications.

6.1.4 Tourist Guide Application

An airport service system could give a passenger the directions to the right check-in counter, present the flight actual timetables, provide booking and reservation possibilities and also give personal gate information. In addition, this system could also provide shopping assistance service (see Section 6.1.2), which based on the passenger's profile, points at special offers in the tax-free shops.

At present, such information could only be obtained manually form tourist help desk at the airport. However, tourists would find difficulties in finding the help desk as most airports are very large in size, such as the Hong Kong International Airport. It is in general not easy to find a help desk in an unfamiliar airport.

An IrDA based position-sensing platform is not suitable for a large-open area, such as an airport. The maximum sensing range for IrDA is only 3m. Huge mount of infrared transmitters would be required in an airport in order to cover all regions. This is very cost ineffective. On the other hand, Bluetooth based system should be used as the maximum sensing range is 100m.

6.1.5 Other Applications

Indoor position-sensing platforms have wide applications in entertainment. For example, the location aware virtual pets of the future would need to be taken to the kitchen for feeding. For another example, using indoor position information could enhance the learning application described in [24]. This application would help educators to make more personalized decisions.

6.2 System Limitations

Due to the limitation of PDA hardware and the nature of IrDA and Bluetooth protocols, the proposed position-sensing platform was not robust enough. The proposed position-sensing platform does not meet the rigorous position demands of virtual reality applications and is therefore unsuitable for these tasks. In addition, this platform does not provide the orientation information about the user. The queries, such as "What devices are in front of the users?", cannot be answered.

6.3 Summary

In summary, position-sensing technology allows applications to provide people with information that is relevant for them in the specific context in which they find themselves. In this chapter, some potential applications which are suitable for the proposed position-sensing platform were suggested.

Chapter 7

Conclusion

7.1 Summary

This thesis describes the theoretical and practical considerations of an indoor position-sensing platform suitable for implementation of a context-aware system. On the theoretical side, a position-sensing platform was proposed and the mathematic algorithm was detailed. On the practical side, two experimental prototypes platform were developed and evaluated using IrDA and Bluetooth.

Previous position-sensing technologies have mostly made use of centralized control system, which seriously intrudes user's privacy. And also they always have made use of dedicated devices such as the Bat, which reduce the system scalability and is cost-ineffective. Unlike the existing location aware systems, the proposed platform reduces the cost and increases the scalability by adopting off-the-shelf hardware and standardized protocol. Therefore, all kinds of existing hand-held devices with build-in IrDA or Bluetooth communication port can be used in this platform. Users are not required to buy any special devices.

Furthermore, the proposed platform uses standard IrDA and Bluetooth communication protocol to implement the software routines. This makes devices from different manufacturers compatible with each other, and hence increases the system scalability. Most importantly, the proposed platform preserves user privacy by adopting decentralized design. Users in this platform learn their locations by detecting signals from transmitter. The central system knows nothing about the user location as no centralized tracking is performed. This is an important user requirement as users detest being tracked.

Indoor position-sensing is an unsolved problem, mainly because GPS does not work indoors. Through our research, we found that IrDA and Bluetooth sensor system can provide cheap, flexible, and relatively accurate (on the order of a meter) position-sensing solutions. By using the proposed position-sensing platform, a user can locate nearby resources or services automatically. Further based on these resources, users can make personalized decisions. As we have discussed in Chapter 6, many context-aware application would take the advantages of the proposed platform. Thus it will advance the use of mobile devices in context-aware applications.

7.2 Future Work

The indoor position-sensing platform described in this thesis is an operational prototype, and further work will need to be undertaken before it could be deployed as part of the infrastructure of a context-aware system.

Currently, we have only studied IrDA and Bluetooth based prototype systems and tested them in a small room with few transmitters. It was impossible to test the prototype system in a large open area. Although, the price of Bluetooth devices is dropping, the current price is not affordable for us to buy large number of devices for evaluation in a true building-wide setting. To make the proposed system practical, such experiment would be useful for us to understand more about the platform performance and to determine the usefulness of context-aware applications.

Due to the nature of IrDA and Bluetooth protocol, and the limitations of the processing power of mobile devices, the prototypical platform is not rigorous enough in its current state. However, the results are quite encouraging. The advancement in software protocols and hardware devices in the future would lead to more robust and rigorous systems. Possible improvement would be to give the signal strength information for a particular link. This feature is mentioned in the Bluetooth specification but not implemented in any of the recent Bluetooth products. If this information is made available, it could facilitate accurate location sensing.

Currently, it is impossible to build a context-aware application prototype using Bluetooth based position-sensing platform. As the Bluetooth programming APIs for PalmOS are still under testing and is not open to public. The API test version we got from Palm Source only supports low layer communication protocols like RFCOMM. They are not suitable to build complicated context-aware applications which may require other TCP/IP communications. For example, if a complete set of open APIs are available, the applications described in Chapter 6 would be feasible.

It would be interesting to provide a 2-level position calculate algorithm. Currently, we only consider decentralized design and let the client device performs all the calculations. However, this design is impossible to provide very rigorous position values because of the limitation of the processing power and the problems of time synchronization. In our current design, we assume that all the clocks in transmitters are perfectly synchronized. However, the most accurate synchronization protocol available in the market would only provide microsecond level accuracy. A combination of centralized and decentralized design could be considered to provide more accurate position estimation. In such design, the users' position could be calculated in client device in order to protect user privacy. It could also be calculated in central server if a user requires more accurate position value. This approach would take advantage of both privacy protection and position accuracy.

It would be interesting to look at other wireless technologies in conjunction with IrDA and Bluetooth. For example, setting up a platform by using Ultrasound and Bluetooth or Ultrasound and IrDA may lead to better performance. Some existing systems, like the Bat system [12], adopt this design. The Bat system combines ultrasound and Radio Frequency technologies. It can locate Bats to within 9cm of their position for 95% of the measurements

However, such design requires a large fixed-transmitters infrastructure throughout the ceiling. Two sets of transmitters, one for ultrasound and one for radio frequency are needed. And it is rather sensitive to the precise placement of these transmitters. This design tends to be expensive and mechanically complex. Thus, lack of scalability, hard to use, and costliness are disadvantages of this approach.

One of the positive sides of Bluetooth is its ability to create small networks with nearby Bluetooth devices. The master device is able to communicate with several slave devices simultaneously. This could be used for Bluetooth devices to exchange position information over wireless ad-hoc networks leading to more accurate position estimation.

Placement of transmitters is an open issue. It would be interesting to try different transmitter configurations to see which one gives the best accuracy. Figure 7.1 shows an example of transmitter configuration. The central transmitter has long sensing range thus allowing it to scan a large area. Several transmitters with short sensing range are placed along the circumference range of this central transmitter. The advantage of using this approach is that the region is divided into several smaller regions that can be uniquely identified. A receiver that receives signals from the one of the transmitter along the circumference and the central transmitter is in the intersection of the central reader and the outer circle. A receiver that only receives one signal from an outer transmitter is located outside the bigger circle but within the outer circle and so on.

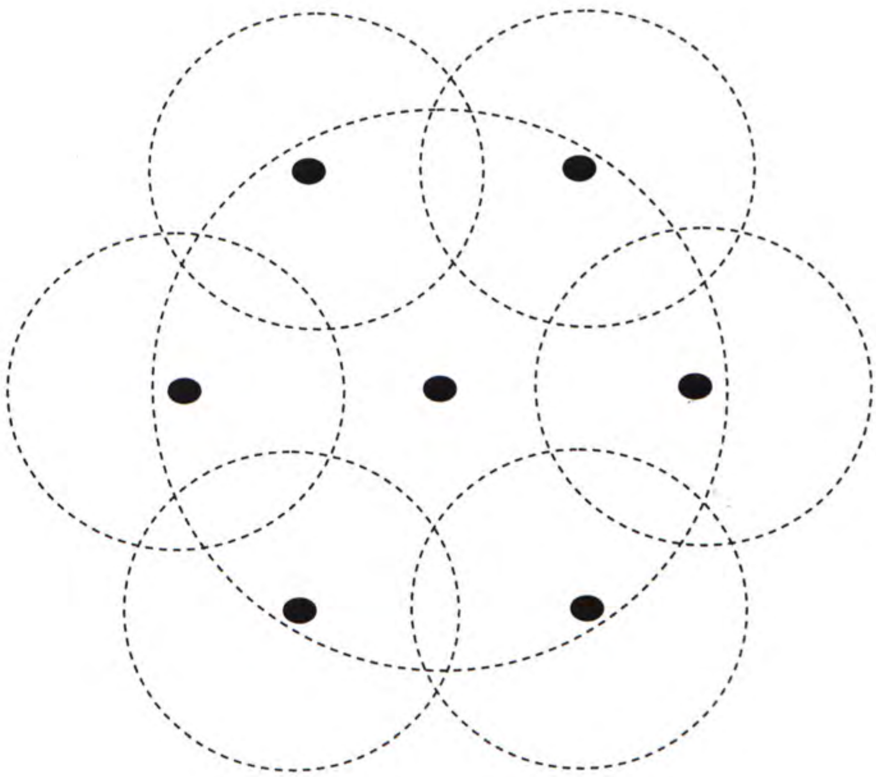

Figure 7.1: Transmitters placed to form a ring structure.

Appendix A: IrDA

IrDA (Infrared Data Association) is a communication system based on infrared light. It is commonly used in mobile devices for cheap point-to-point communication. Digital cameras, mobile phones and laptops are just a few examples of devices that often use IrDA for wireless communication.

A.1 IrDA Physical Layer

IrDA protocol consists of a mandatory set of protocols and a set of optional protocols. Figure A.1 shows how the IrDA protocol stack is layered. The most important protocols are of course the mandatory protocols: PHY (Physical Signaling Layer), IrLAP (Link Access Protocol) and IrLMP (Link Management Protocol). Among the optional protocols Tiny TP, IrTran-P, IrOBEX, IrLAN, IrCOMM and IrMC can be found.

<table>
<tr><td>IrTran-P</td><td>IrOBEX</td><td>IrLAN</td><td>IrCOMM</td><td>IrMC</td></tr>
<tr><td>LM-IAS</td><td colspan="4">Tiny Transport Protocol – Tiny TP</td></tr>
<tr><td colspan="5">Ir Link Mangement – MU – IrLMP</td></tr>
<tr><td colspan="5">Ir Link Access Protocol – IrLAP</td></tr>
<tr><td colspan="2">Asynchronous Serial Ir
9600bps – 115.2kbps</td><td colspan="2">Synchronous Serial Ir
1.152Mbps</td><td>Synchronous 4PPM
4Mbps</td></tr>
</table>

Figure A.1: The IrDA protocol.

The Physical layer contains the actual Ir transducer module. The physical layer is responsible for transmitting and receiving Ir signals and also encode/decode these signals for the IrLAP layer.

Figure A.2 shows an IR transducer module. The electrical signal showed in the figure goes from a serial bit stream in stage 1 to an optical signal in stage 3. The electrical signals in stage 2 correspond to the optical signals at 3.

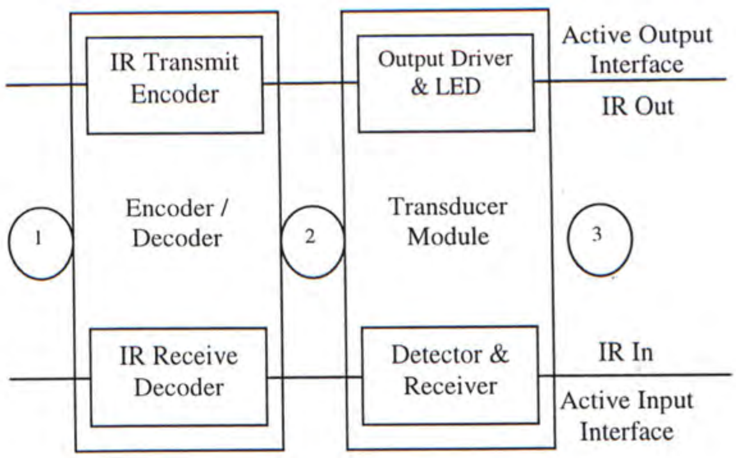

Figure A.2: Ir Transducer Module.

A.2 Physical Aspects of IrDA Physical Layer

As IR is light being transmitted there are several limitations in range and angle. These limitations consist of limited range, line of sight and limited viewing angles.

A.2.1 Range

The range is at least one meter and in some cases even up to three meters. There is also a low power version and the range for that is typically 20-30 cm. As of now the range is fairly short but ranges up to ten meters are under development, though this will still be limited to line of sight as well as limited transmitting and receiving angles.

A.2.2 Optical Angle Limitations

The transmitter has a typical limitation of 15° to 30° from the optical axis, also called half angle. The receiver is limited to 15° half angle or just above.

A.2.3 Power Consumption

IrDA has low power consumption and there are several procedures for saving power such as sniffing which will be described later. There is also a low power version with less range as mentioned earlier. This version consumes 10 times less power compared to the standard version.

A.2.4 The Capacity and Formats of IrDA Physical Layer

The IrDA physical layer is split into three distinct data rate ranges: 2400bps to 115200bps, 1.152Mbps, and 4Mbps. Initial protocol negotiations takes place at 9600bps, making this data rate compulsory. All other rates are optional and can be added if a device requires a higher data rate.

Infrared receiver contains a long-pass filter to remove background daylight. This long-pass filter forces the use of encoding on the link to ensure that long strings of zeros or ones are not lost in transmission.

A.3 Discovering Other IrDA Devices

There are three discovering services request, indication and confirm. The "request" is used to find out what, if any, devices are within communication range and if they are available for connection. “Confirm” returns a list with all available devices. Finally, the “indication” is used to send information about the device that sends a request, to other devices.

A.4 Connection of IrDA Devices

A device, which wants to broadcast its desire to connect, may do so by using a procedure called sniffing, which is a power conservative procedure. A device that wants to connect and approaches a network of Ir devices is called a hidden node. This device needs to listen and wait until spoken to, before it can connect to the network. This procedure is also a part of the sniffing procedure.

The basic procedure of the sniffing device:

A sniffing device wakes up and listens for a short period of time. If it hears traffic it goes back to sleep.

If it does not hear traffic it transmits an exchange identification (XID) response frame with a special value unique to the sniffing procedure. This XID indicates that the device desires to be connected as a slave.

The device then waits a short period for a message directed to it. If such a message arrives the device can connect.

If no frames are sent to it, the sniffing device goes to sleep (usually 2 – 3 seconds) and starts the procedures again. If it hears traffic not directed to it, it is assumed to be connection traffic and the device cannot connect.

A.4.1 Modes for Connection

IrLAP is build around two modes of operation, corresponding to whether or not a connection exists. The two modes are: Normal Disconnect Mode (CDM) and Normal Response Mode (NRM).

NDM is also known as the contention state, and is the default state of disconnected devices. In order to connect from this state the device must first listen for a time greater than 500 milliseconds. If no traffic is detected during this time then the media is considered to be available for establishment of a connection.

NRM is the mode of operation for connected devices. Once both sides are talking using the best possible communication parameters (established during NDM), higher stack layers use normal command and response frames to exchange information.

A.4.2 Address Confliction

The address conflict services are used to resolve device address conflicts. If the discovery log contains entries for more than one device with the same device address, the address conflicts service may be invoked in non-conflicting device addresses. The IrLAP addresses are 32-bit randomly selected address. On an address collision a new random address is selected.

Appendix B: Bluetooth

Bluetooth is an open standard specification for radio frequency (RF)-based, short-range connectivity technology, which promises to change the face of computing and wireless communication. It is designed for all classes of portable devices, such as laptops, PDAs and mobile phones.

B.1 Bluetooth Stack

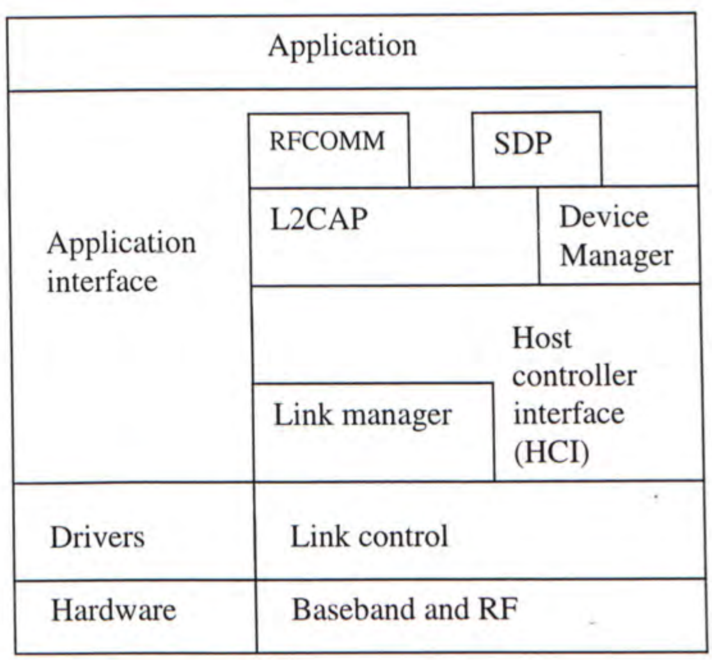

Figure B.1: Overview of the Bluetooth stack.

The building block of Bluetooth module is the Bluetooth stack, which includes the hardware and software portions of the system. Figure B.1 shows a graphic representation of the stack.

B.2 Radio

Bluetooth uses the unlicensed ISM (Industrial, Scientific and Medical) band. The ISM band is available in countries all over the world.

B.3 Frequency Hopping

The ISM band is a rather crowded frequency band and therefore Bluetooth implements frequency hopping to avoid collision with radio waves from other sources. The ISM bandwidth is divided into 79 channels. The Bluetooth devices will jump between these channels 1,600 times per second in a pseudo random order. This makes it unlikely that interference in one channel will disturb the communication between two devices for a longer period.

B.4 Package Structure

The structure of the difference packages in Bluetooth is very similar. Figure B.2 shows the structure of Bluetooth package.

Access Code	Header	Payload

Figure B.2: Structure of a Bluetooth package.

Access code: A package starts with an access code. It has the information about where the package belongs.

Header: The header contains an address of the slave in the piconet and a type tag to identify the packages type and slot length. It also contains acknowledgement of the package that is received by the sender.

Payload: Payload contains the data to be sent. Two different package types are used. ACL payload is used to send data containing up to 2,712 bits of data. SCO payload has a fixed size of 30 bytes.

B.5 The Link Controller

The link controller is responsible for the different states of the Bluetooth devices. Some link controller states are: standby, inquiry, sniff and active.

In some circumstance, the device that initiated the connection may not want to continue the master role, or a slave might want to take over the role as the master. In order to facilitate this, the Bluetooth specification contains a method for a master and a slave to exchange roles. The master is always the one that initiates the exchange, but a slave can request an exchange through the master.

B.6 The Link Manager

The link manager establishes and manages a link. It puts a link in a different mode depending on what commands it receives from the user or from the link manager on the other side of the link

B.7 Logical Link Control and Adaptation Protocol

The Logical Link Control and Adaptation Protocol (L2CAP) is used to pass data and messages between the upper and lower layer protocols. All applications must use L2CAP, either directly or through some other protocol that uses L2CAP to communicate over Bluetooth.

Channels: The L2CAP uses channel ID to distinguish between different connections. Some of these are reserved for the most import upper layers such as RFCOMM and SDP.

RFCOMM: RFCOMM emulates the serial cable line settings and status of a RS-232 serial port. It is based on the GSM TS 0.710 standard, which is an asymmetric protocol used by GSM cellular phones to multiplex several streams of data onto a physical serial cable. RFCOMM is used by almost all applications that send data over Bluetooth.

B.8 The Service Discovery Protocol

The Bluetooth specification is designed for devices, which are in constant motion. That means it will have to discover new devices and new services while this are being carried around a premises. The Bluetooth specification includes a protocol to discover what services exist on a connected device.

The SDP database: The SDP database is simply set of records describing all the services that a Bluetooth device can offer to another Bluetooth device.

Browsing: To make the process of finding a service easier, services are arranged in a hierarchy structure. Clients begin to examine the root of the hierarchical and follow the tree until the desired service is reached.

Universally Unique Identifiers (UUID): Every service has an unique identifier. UUID represented in a special format, which is 128 bit long.

B.9 Encryption and Security

Encryption in Bluetooth is based on a variant of the SAFER+ cipher. Cylink Corporation designed it as a candidate for the U.S. Advanced Encryption Standard (AES).

Bluetooth support 3 modes of security:

Security Mode 1: Devices will not initiate any security procedure.

Security Mode 2: The channel or service using an L2CAP connection decides if the link should be secure or not.

Security Mode 3: A device in security mode 3 will initiate security procedures while the link managers are connecting.

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