A Study on Indoor Positioning System Using ID Modulated LED Tube Lights

CHANG LI

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CHANG LI

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Abstract

In recent years, stepping with the popularization of smart phone and the development of mobile communication infrastructure, the conditions for ubiquitous computing society become more and more complete. In the vision of ubiquitous computing society, LBS (Location Based Service) that provides an added value to an unprecedented user experience has been paid a great deal of attention by mobile operators all over the world. As the core technology for LBS, various positioning systems have been studied extensively. For the outdoor environment GPS is mature and common. However, the performance of GPS in indoor environment is bad. Moreover, currently there is no technique whose accuracy and cost are appropriate for deployment in huge areas.

This thesis presents a novel camera-based information transmission system for indoor positioning and navigation. This system, which avoids the use of any expensive equipment, is of particular benefit for infrastructure consumption and is completely portable using a hand-held terminal like smart phone. The high-intensity LED tube light, which is becoming the main illumination device due to its lower power cost and longer lifetime, is employed as optical beacon in this system. LED tubes are modulated to transmit ID information, which can be received by the camera equipped on smart phone. With the captured images of LED tubes which include the ID information, the smart phone can query a database to obtain the current position and orientation via mobile communication. The ID information embedded in LED tube lights has no harm at the illumination function o. The proposed system, which is with fairly low cost and high accuracy both about orientation and position, can be expected to be feasible for deployment in large indoor environment.

In Chapter 3, the basic structure of proposed system is studied. The contents include the method of producing information from modulation LED tubes and the processing of ID recognition and positioning. Experiments are conducted to investigate the recognition rate, positioning accuracy and the performance of employing Kalman filter.

In Chapter 4, we try to expend this system to the cameras with different kinds of exposure time. The recognition method in Chapter 3 has a limit that the exposure time should be set very short (~2ms). We present a method to overcome this limit by using motion blur. Specifically, the user shakes the camera at a proper direction while the exposure time, so that the position of LED tubes changes on the captured image to express a streaked pattern which looks like the bar-code. The streaked pattern can be exploited for ID recognition. Results of experiment showed that this method is easy to

operate for untrained users and can yield a good recognition rate.

In Chapter 5, the method how to ensure correct ID correspondences between physical spaces and virtual maps is studied. The correct correspondences are the precondition of providing correct position information. We proposed a pedestrian model which uses the constraint of walking speed to evaluate the possibility that the ID correspondence is correct or not. By using the proposed model, the incorrect ID correspondences could be fined out from the usage records of users and modified. Simulation experiments show that the incorrect correspondences can be modified when there are enough records.

Besides, Chapter 1 gives a belief introduction of the background and motivation; Chapter 2 is the overview of current positioning techniques for indoor environment; Chapter 6 is the conclusion of this thesis.

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➢ Chapter 1

Instruction

1.1 Background of this research

Over the long history, human beings have invented various tools to extend self-ability coping with work that is dangerous, boring and burdensome, and these inventions have greatly pushed the history of mankind forward. Computer, the imitation of partial function of human brain, undoubtedly is one of the revolutionary inventions and nothing epitomizes modern life better than it.

Though today it has infiltrated every aspect of our society, more than half a century ago it is raised for military affairs. John Atanaso built the first special purpose analog computer ABC (Atanaso Berry Computer) in 1939. This was improved in 1944 by using switching devices called electromechanical relays. In 1946, the ENIAC (Electronic Numerical Integrator And Computer) computer was developed. Instead of electromechanical relays, it used 18000 electric valves. This computer weighed more then 27 metric tons, occupied more then 140 square meters of floor space and used 150 kilowatts of power during operation. It was able to do 5000 addition and 1000 multiplications per second. The only problem was that it took very long to program the computer to do the calculations as it could not store the information. From this for a long time, computer is small in quantity and only can be operated by specifically scientific workers. Each computer was shared by lots of people and this period is called the era of mainframe.

The Intel 4004 chip, developed in 1971, took the integrated circuit one step further by locating all the components of a computer (central processing unit, memory, and input and output controls) on a minuscule chip due to the development of large scale integration (LSI). By the mid-1970's, computer manufacturers sought to bring computers to general consumers. In 1981, IBM introduced its personal computer (PC) for use in the home, office and schools. Ten years later, 65 million PCs were being used. In November 1985, Windows, OS (operating system) with graphical interface, was introduced by Microsoft. It notably eased the task for operating computer and PC was accepted by more and more ordinary people. Computer and people communicate with each other across desktop and this period is named the era of personal computer.

Nowadays, we will enter into the era of ubiquitous computer. The word "ubiquitous" means "whenever", "wherever" and "whoever". With the development of information infrastructure (internet etc.), communication technology (wireless, Bluetooth etc.) and miniaturized computing terminal (PDA, cell phone etc.), the concept "ubiquitous computing" was put forward. Ubiquitous computing is a model human-computer interaction in which the technology will recede into the background of our life. The purpose of this technology is to provide user appropriate information, help and services in the real world with the network of small, inexpensive, durable and computational devices distributed at all scales of surrounding ambience (Figure

1.1). This model is described as pervasive computing, ambient intelligence, or more recently, everyware [1-1][1-2]. The research of ubiquitous computing is interrelated with the technology of distributed computing, human–computer interaction, embedded system, artificial intelligence, Information integration and so on.

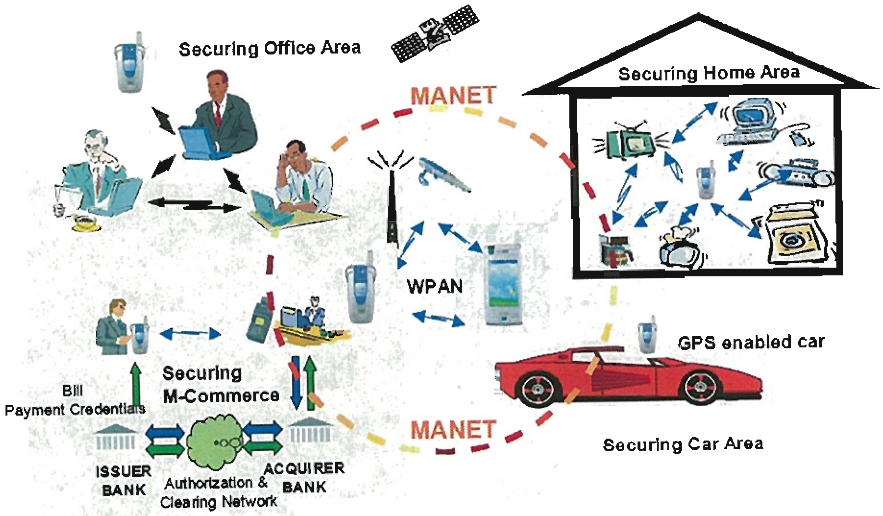


Fig 1.1 The smart living with ubiquitous computing [1-3]

As the key point of the next generation of information evolution, "ubiquitous computing" attracted a great deal of concern from governments and companies. IBM corporation presented the concept "Smarter Planet" [1-4]. From the perspective of national industrial development, South Korea propounded "u-Korea" strategy project [1-5]. The Japanese government also has adopted the term "ubiquitous network society" to describe a vision that in many respects is being transformed into concrete action plans. They have put in place an initiative under the label "u-Japan Strategy" [1-6] to replace the previous "e-Japan" policy framework [1-7].

1.2 Positioning technologies for ubiquitous computing

In order to combine the context of an entity (things or people) with other relevant parameters (such as social and physical environment, and technical and communication infrastructure [1-8]), the system of ubiquitous computing need to learn about the relation between the two. Location data is an important dimension for describing the physical appearance of the objects [1-9]. It means positioning technology is one of the key elements of ubiquitous computing [1-10].

Nowadays, the rapid development of signal communication technology has provided a great prospect for the applications of human position guidance and navigation [1-11]. Global Positioning System (GPS) has been widely used for outdoor position measurement [1-12][1-13]. This system works out the current position based on distance from the satellites, by measuring how much time radio wave takes to transmit. The amount of satellites is 24 and the orbital radius is about 26,600 km (Figure1.2). The service of GPS can cover 98% of surface of the earth. GPS receivers determine their position by tracking at least 4 satellites simultaneously. GPS receivers have benefited greatly from miniaturization. The original mobile units tested by the US Army in the 1970s weighed 25 lbs and filled a backpack. In contrast, modern GPS receivers are typically around the size of a cell phone, and new single chip GPS implementations have made form factors as small as a wristwatch as possible (Figure 1.3).

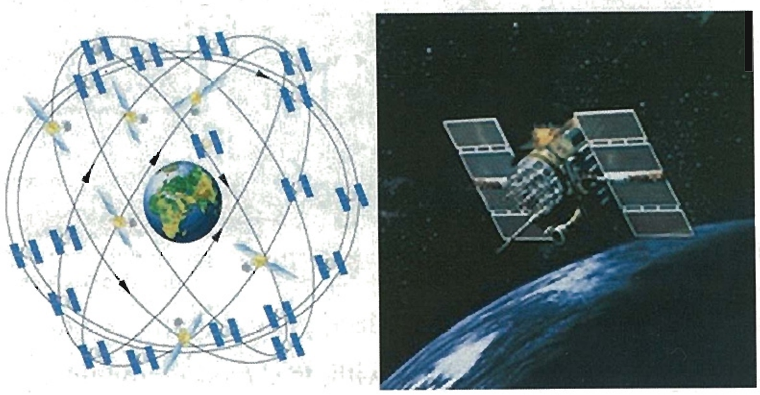
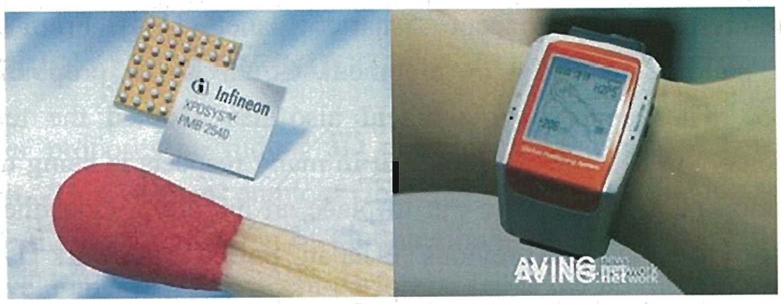


Fig 1.2 Global Positioning System [1-14]



(a) (b)

Fig 1.3 Modern GPS receivers

(a) Epson GPS chip [1-15] (b) a wristwatch with GPS function

Although the technology of GPS is quite mature, it is limited by two problems:

1) As GPS uses radio wave, it could not provide information indoors or in crowded urban areas since the signals from the satellite would be shielded by the concrete structure of the building [1-16]. Moreover, there are some places where signals from certain part of the electromagnetic spectrum are forbidden e.g. hospitals.

2) Even in outdoor situation, the error of GPS can reach dozens meters. This accuracy could not be applied to some application.

Therefore, other approaches are raised. For example, a feature landmark database is used to estimate camera position [1-17]. This method provides higher accuracy than GPS. However, it needs a pre-constructed database (Figure 1.4) which limits its deployment.

Fig 1.4 Omni-directional multi-camera system for positioning [1-17]

Especially for indoor environment, positioning has many tasks for study because of the complicate indoor structure and high requirement for accuracy. A lot of researchers presented kinds of technologies and these technologies usually need a deployment of reference objects such as Wi-Fi access points, infrared beacons, and visual markers. It will be an overview of such technologies in Chapter 2.

1.3 Objective of this research

This paper proposes an indoor 3D positioning system based on visual light communication. This system employs the high-intensity LED tubes, which are predicted to be the next generation of illumination system in the near future because of its rapid development and excellent performance, as the referenced markers in real world. The sensor used in experiment is also ordinary camera rather than high-speed camera. Without additional artificial markers and any especial equipment, this system will be low of initial fixture and operating cost, both for money and labor.

Fig 1.5 The goal of proposed system

Theoretically, if there are at least 4 position-known points in the screen, the 3D location of the camera could be determined, so our system consists of pairs of LED tubes, one camera and a personal computer. The goal of this system is to implement this system on a mobile phone (the type with camera) in future (Figure1.5).

The researches with proposed system can be divided into three parts, whose titles are list as follows:

A. Indoor Navigation System using ID Modulated LED Tube Lights

B. Recognizing ID of Modulated LED Tube Lights by Using Motion Blur

C. ID Mapping Using Pedestrian Model for Camera-based Indoor Positioning System

The detail of these parts will be introduced in following chapters.

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➢ Chapter 2

Overview of indoor positioning

2.1 Key issues of indoor positioning

Position means a place where someone or something is located or has been put. In a more precise definition one can distinguish three types of a position:

-An absolute position means that the position is unique for a certain location independent of the hardware used to determine the location. The best example for this is the use of GPS coordinates. Result of measurement is described in a coordinate system which can define every single position on earth

-A relative position is a position relative to an absolute position or a known object. The known position is the starting location and from there a relative position can be given. Usually it is possible to recalculate an absolute position from a relative position if all data to make this calculation is available and accurate. The approach of research is computing the location relative to LED markers and finally obtaining the absolute position from the absolute location of markers.

-Proximity based positioning is the coarsest form of positioning. If no absolute or relative position can be given, sometimes it is possible to estimate a position or a range by saying that it is in proximity of an object with a known position. The result is only described by "near" or "far away"

Positioning has been around for centuries, but recent technological developments have enabled very accurate determination of positions. With this increased accuracy, more precise navigation has been made possible as well. Positioning is distinguished from navigation by restricting positioning to: "determining an adequately accurate position" and navigation to: "support traveling from one position to another". This implicitly means that navigation requires continuous positioning. To get navigation to work one first has to create an adequate, more or less continuous positioning system. Using this obtained positioning information one can develop a navigation system.

Comparing with outdoor environment, indoor environment is much more complex. The conditions of interior architecture, building material and decoration are possible to affect the result of indoor positioning. Without purely technical considerations, many human constraints, such as security and privacy, also concerns the indoor positioning strategy. Proceeding from various applications and requirements, many techniques which can be used for indoor positioning have been presented, such as the use of infrared, ultrasonic, RF wave. These methods generally have a strong application background and the objects of services are also different. We investigated some of the current indoor positioning technologies and summarized the following key issues:

1. **Coordinate system configuration and location information expression**

The establishment of the coordinate system is a precondition for positioning. GPS gives a position result of the global latitude and longitude. In general, the indoor positioning system has an independent coordinate system corresponding the whole building. Of course, it is possible to achieve the integration of indoor and outdoor coordinate system by converting the independent coordinate to global coordinate. When calculating the location of the target, some position systems establish a fixed coordinate system, which need a fixed reference object; some of the other systems do not dependent on the fixed reference object, and the pointing result is expressed as the relative position to a dynamic reference object. In other words, the system does not really establish a coordinate system, and does conversion when it is needed. In the indoor environment, people usually do not need or care an absolute coordinates of the location of positioning objects. People hope that the system can provide the information like "somebody is in lobby, and the printer is in Room 204", which is actually called address. The address is a kind of proximate information and cannot be directly displayed on the map. With the purpose to solve this problem, geographic information system (GIS) uses "geocoding" technology (Figure 2.1) to match the address and the location on the map. For indoor environment, it is common that people are concerned about the address, so geocoding is playing an important role.

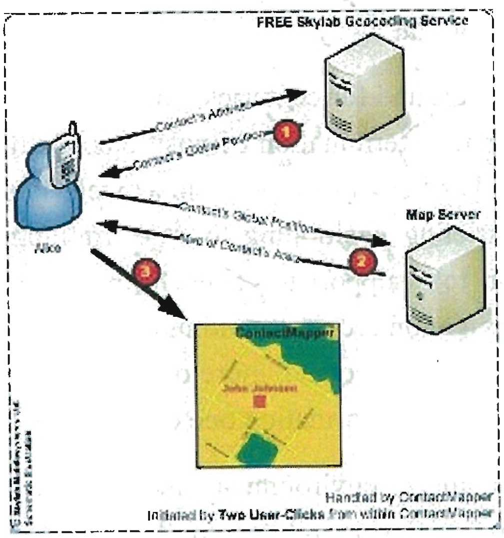

Fig 2.1 Geocoding service[2-22]

2. Security about location information estimation and sharing

The indoor position of people is a sensitive issue. People do not want to disclose his location to other persons unless under certain circumstances. This is where the problems about location security arise. The problems lay on two aspects: one is the calculation method, the other one is the information transmission. Currently there are two kinds of calculation method for positioning: the first one is that the position is estimated on the terminal of user (local), and the user decides whether publish his location or not; the second one is that the central server processes the request from the user (centralized) and replies with the location information. Generally it is believed that local computation is the safer way. The information transmission is the field of communication security which hardly falls within the scoped of this article.

3. Positioning accuracy

Different applications have different requirements for positioning accuracy. Indoor environment is relatively small, so in general a high accuracy is needed. However, at most cases the positioning system only need to answer this question "which room is the certain people in?" Usually we do not care the exact position in room, so the accuracy reaching the level of room meets many actual needs. Positioning accuracy can be enhanced by improving the device and the algorithm, but we need to weigh the gains and losses between accuracy and cost.

4. Tracking and orientation discrimination

Orientation discrimination is a common problem in the positioning system. The direction of moving trend is very important information, such as the vehicle direction for vehicle navigation system. Besides tracking the moving object and determining the moving direction, indoor positioning system often need to determine distinguish the orientation of user when keeping still. The orientation when keeping still is a key problem in indoor positioning, which is discussed in [2-1].

5. Identification ability

Practical applications often require the positioning system a certain degree of identification capability. This capability can integrate the positioning system with the personal identification system, such as RFID card or barcode. We also could combine the positioning system with image and voice recognition systems, so that a higher level of recognition rate can be achieved.

6. Device dependence

Indoor positioning system is proposed long ago, but it has not been able to get more widely used. One reason is that the current systems often need to install particular devices, which means a high cost. This problem greatly limits the widespread of indoor positioning system. In recent years, with the rise of wireless LAN, researchers began trying to use WiFi signal for positioning [2-2]. Because the wireless has been the popular infrastructure in buildings, indoor positioning is possible to get rid of the dependence of the specific devices and be widely deployed.

7. System stability

Indoor positioning systems need a certain degree of stability, simplicity for maintenance and repair, and the ability adapting to the change of indoor environment.

If the indoor arrangement gets change, or some of the positioning devices break down, the system is expected to work normally. For current systems the stability problem exists universally, and it is one of the important issues to be solved.

2.2 The major indoor positioning techniques and systems

The main current technologies can be used for indoor positioning are showed as follows.

1. Infrared
2. Wireless LAN
3. Bluetooth
4. Ultrasonic
5. Computer vision
6. Magnetic field

Some of these techniques have been maturely developed, and there are already systematic location-based service solutions or commercial products. The others are still in the stage of research and study. Computer vision methods are discussed in [2-1], and [2-2] introduces the experiment for a smart floor which uses magnetic and pressure sensors for positioning.

2.2.1 The general architecture of the positioning system

In general, we can divide the component parts of the positioning system into two categories: mobile units and fixed units. Normally, the fixed units are the infrastructure of positioning system, which is equivalent to the base stations in the mobile communication system. The fixed units are used as the references of known locations and their locations are not easily changed. The mobile units are the devices carried by the person or objects which are needs to be located. In most cases, they are light signal transmitters and receivers. The mobile units determine their relative locations to the fixed units by communicating with the fixed units, and further determine the absolute positions in the world. Some of the positioning systems do not require the mobile units, for example the system using surveillance cameras to locate the person or objects directly. However, this kind of positioning technologies often can only be applied in very limited environment.

Positioning systems using infrared, WLAN and ultrasonic technologies usually involve the signal transmitters and receivers. Both of the mobile units and the fixed units can be transmitter or receiver, depending on the operating mode of the system. General, the positioning systems have these following operating modes:

1. Single transmitter, multiple time synchronous receivers

The signal is transmitted from a mobile unit and it will be received by several fixed, time synchronous receivers, which have known locations and are linked together with physical networks. This kind of operating mode can easily get the time differences among the timings the signal reaches each receiver. With the time differences, the coordinates of the mobile unit in the world can be solved out by using mathematical models.

2. Single receivers, multiple time synchronous transmitters

Signal pulses are transmitted by several fixed, time synchronous transmitters, whose locations are known. And the mobile unit receives the signal pulses, and estimates the location of itself. This operating model is suitable for realizing the local computing, which means the mobile unit decides the position calculation and position information publishment independently. These two kinds of operating mode are shown as Figure 2.2.

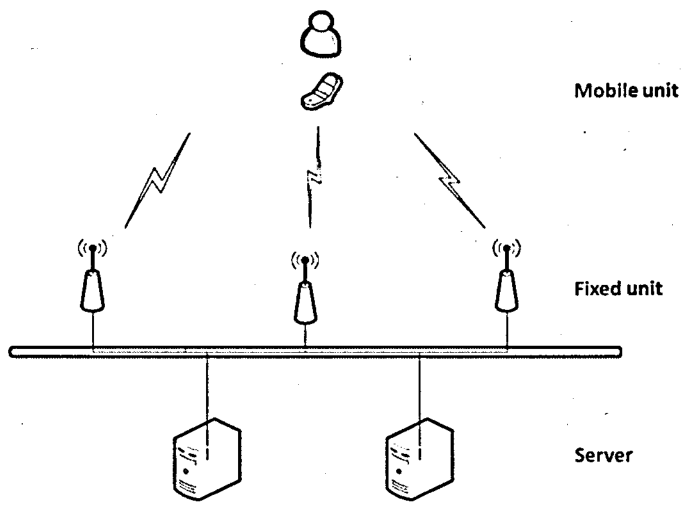

Fig 2.2 The architecture of indoor positioning system

3. Transmitter of multiple synchronous signal

Two or more types of signal are transmitted from one unit whose position is known. These types of signal propagation in space are quite different, such as electromagnetic waves and ultrasonic, so that there are time differences among the timings when the receiver gets certain type of signal. The mobile unit is able to receive these types of signal and calculate the location according the time differences. This kind of operating mode is shown as Figure 2.3.

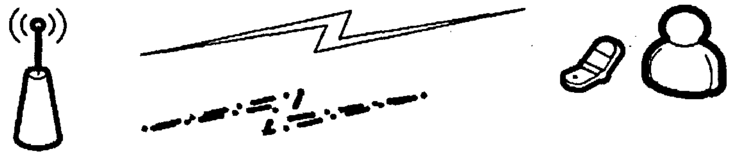

Fig 2.3 Multiple types of signal

2.2.2 The position calculation method

The positioning technology is expected to provide position information with high-precision and real-time response. It mainly involves three kinds of methods: ① measure the distances between several reference points, or measure the directions to the reference points, and decide the position according the triangular principle of edges or angles. ② measure the degrees that the target is close to the reference points or not to estimate the position. ③ analyze the environment and decide the location. In specific applications, the poisoning usually adopts one or more of the above methods. The first method involves a variety of location-aware algorithms, such as the algorithms based on signal strength, time or angle. Next we will analyze the features of these algorithms respectively.

(1) The algorithm based on signal strength

This algorithm measures the received signal strength and calculates the signal propagation loss according to the known signal transmission power and RSSI (Received Signal Strength Indicator). Then the distances are obtained by using the result about the propagation loss. The target mobile unit can be located if there is three or more values of distance. This algorithm usually is mainly used for the methods of RF signal and IEEE 802.11 wireless LAN.

The algorithm using signal strength is relative simple but with a poor accuracy. The causes are mainly the multipath effect during the wireless signal transmission and the shadow effect while passing the obstacles. Therefore, this algorithm is not suitable for indoor high-precision positioning.

(2) The algorithm based on time

This algorithm can be divided into two types: TOA (Time of Arrival) and TDOA (Time Difference of Arrival). According to the known signal propagation speed and the measuring result of the signal propagation time, the target position can be decided. It can be used for a variety of different signals, such as RF signal, ultrasonic, infrared and UWB.

The principle of TOA algorithm is that if the signal propagation time between the mobile unit and the base station is t, the distance between these two should be R=ct, where c the speed of signal transmission. The mobile unit should be located on the circle whose center is base station and radius is distance R. TOA algorithm requires the base stations which are the participants of measurement must be strictly synchronized in time.

The principle of TDOA algorithm is using the time differences, which is between the timings the base stations received the signal from the same mobile unit, to calculate the distance differences between base stations and this mobile unit. If the difference of the distances from this mobile unit to two different base stations is a fixed value, the mobile unit must be located on the hyperbola with two focus on the two base stations. If there are three or more base stations, the intersection of the two curve of hyperbola is the location of the mobile unit (Figure 2.4).

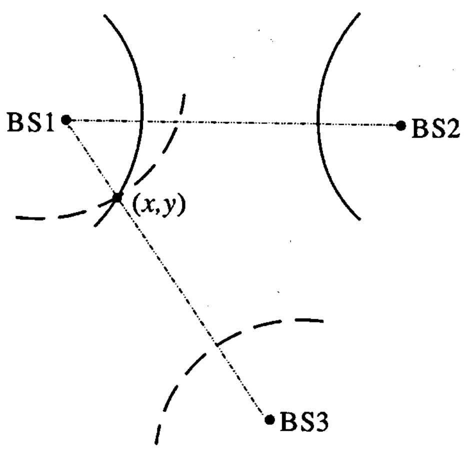

Fig 2.4 TDOA algorithm

For time-based positioning method, the propagation delay due to multipath propagation effect and NLOS (Non Line Of Sight) effect is the main cause for a location-aware error.

In indoor positioning environment, different types of signal should be considered separately:

Infrared: Infrared has short transmission range, and is easily blocked by obstructions in the transmission path, so its applicability is not enough.

RF, ultrasonic: The main problems are the interference of the reflected signal in the room and the error due to multipath propagation effect and NLOS effect. The solution could be increasing the number of base stations and employing high-precision estimation algorithm.

UWB: UWB is a kind of non-line-of-sight signal which can penetrate obstacles and it is robust to multipath propagation interference. Therefore, UWB can solve two problems in indoor positioning [2-3]: (1) the signal occlusion, which makes a system using line of sight signal need some special devices. (2) the multipath propagation interference, which resulting in pulse synchronous difficulties and low estimation accuracy. In addition, if the estimation error distribution field is calculated in advance according to high-precision prediction algorithm, the error can be reduced by optimizing the number of base stations and distribution.

TOA algorithm requires the base stations must be strictly synchronized for the timings of signal receiving. In the indoor environment, due to the high radio wave propagation rate, the time delay is generally at the level of nanosecond. Even employing the ultrasonic, a large error could not be avoided. Hence, for TOA, the requirement on equipment and environment is quite harsh and it is difficult for practical applications. For TDOA algorithm, only the time differences between the timings of receiving the same signal and the strict synchronization is not required, so there is a high feasibility. However, if only TDOA positioning is employed, the accuracy still needs be further enhanced.

(3) The algorithm based on angle of incidence

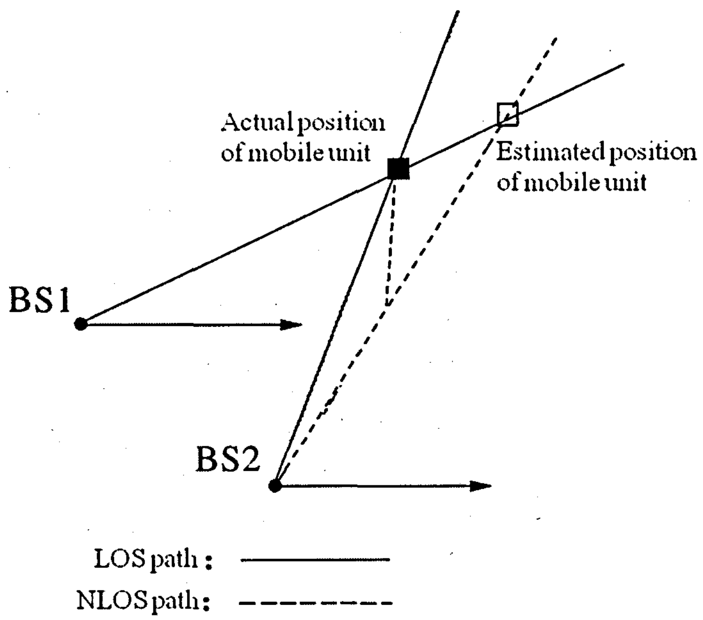

Fig 2.5 AOA algorithm and estimated error

AOA (Angles of Arrival) algorithm located the mobile unit by using the incident angles. A line from the base station to mobile station is formed, and with two lines from two base stations, the location of mobile unit can be decided as the crosspoint. Therefore, AOA algorithm only needs two base stations to determine the location of mobile unit, and there is no phenomenon of multiple crosspoints.

Though this algorithm is very simple principle, there are still some drawbacks.

First, non-line-of-sight propagation brings unpredictable errors to the positioning result (Figure 2.5). Even when line-of-sight is primary, the multi-path propagation effects will still affect the result of AOA measurement. Second, due to the limitation on the angular resolution of antenna, the longer the distance from the base station to mobile unit is, the lower the result accuracy is. Therefore, there is a high requirement on the antenna of receiver.

(4) Hybrid positioning algorithm

Hybrid positioning algorithm uses two or more of the above positioning algorithms to achieve higher positioning accuracy. A typical example is the hybrid positioning system using both of AOA and TDOA algorithm. This system is able to reduce part of the error derived from the multipath effect and achieve a higher accuracy. For indoor positioning, this algorithm has great prospect for development and application.

In summary, for indoor positioning, these algorithms have the following issues to be considered:

First, we need to consider the characteristics of the transmission medium (UWB, ultrasonic, Bluetooth, infrared), and choose the most appropriate technology. Because currently UWB gets advantages on the functions both of super short-range communication and positioning [2-4], it has good prospects expected by researches.

Second, each object in the system has a unique identification code and related property value which connects to other parts of the ubiquitous computing system closely. A simple model is as follows: in indoor environment, when the user moves to a new location, the system must be capable to work out the position in real-time and gain the set of information related to this specific location. The system can actively select and broadcast the information to the user and the user can effectively obtain the information which is needed.

2.2.3 Introduction of commercial and experimental indoor positioning systems

By now, a variety of positioning systems with different information medium and architectures have been proposed. They have different accuracies, configurations, and reliabilities. The following presents a short list of current indoor positioning systems which are classified by types of information medium.

►Infrared

The most famous method using infrared is ActiveBadge developed by AT&T

Cambridge [2-5], which is the first and arguably archetypal indoor badge sensing system. Each person using the system can locate wears a small infrared badge like that shown in Figure 2.6. The badge emits a globally unique identifier every 10 seconds or on demand. A central server collects this data from fixed infrared sensors around the building, aggregates it, and provides an application programming interface for using the data.

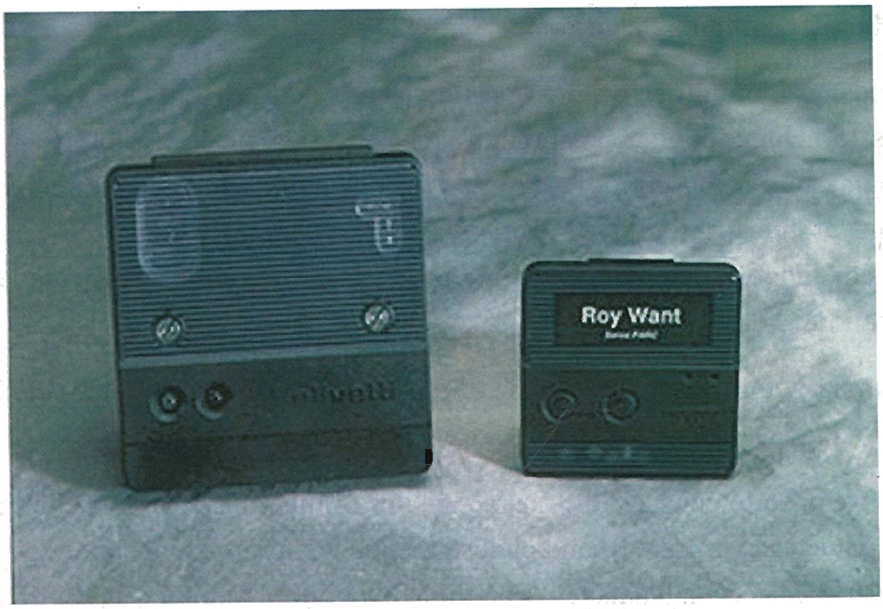

Fig 2.6 Olivetti Active Badge (right) and a base station (left)

►Bluetooth

Bluetooth is another technology which has a gained a stable foundation [2-6][2-7]. The most important problem when using Bluetooth for positioning is the time uncertainty of response of a Bluetooth device. To discover other Bluetooth adapters and then use their discovery for cell of origin (or even RSSI) it is necessary to quickly detect other Bluetooth devices that are in the neighborhood. Various design choices of the Bluetooth specification limit the discovery of devices that are near to the user from a few to about 11 seconds. In a mobile environment this can have severe consequences on the position accuracy. One can for example pass a Bluetooth beacon without detecting it at all because its radio range is limited.

►RFID

Radio Frequency IDentification (RFID) is an automatic identification method, relying on storing and remotely retrieving data, using devices called RFID tags or transponders, which can be attached to or incorporated into a product, animal or person [2-8] for the purpose of identification using radio waves. Passive tags require no internal power source and therefore have a detectable range of only a few centimeters, whereas active tags require a power source and can be detected over several meters.

When passive RFID tags are used it is possible to deploy a very dense and cheap grid of tags, but the range of a passive tag needs a RFID reader to be very close to the tags [2-9]. A positioning system based on active RFID tags [2-10][2-11] can support both Center of Origin as well as RSSI as most active RFID tag systems support to read out a RSSI value of the received signal. Using active RFID tags can be used to provide a relative positioning system.

►UWB

Location estimating based on transmitting time of electric wave is difficult because of multipath propagation. In recent years methods employing new wireless communication technology Ultra-Wideband (UWB) with capability overcoming this hurdle are of wide concern. The accuracy of positioning system based on UWB-IR is about dozens of centimeter [2-12].

►Ultrasound

Systems using ultrasound are of a high accuracy and the most representative one is ActiveBat [2-13]. Users and objects carry ActiveBat tags shown in Figure 2.7. In response to a request the controller sends via short-range radio, a Bat emits an ultrasonic pulse to a grid of ceiling-mounted receivers. At the same time the controller sends the radio frequency request packet, it also sends a synchronized reset signal to the ceiling sensors using a wired serial network. Each ceiling sensor measures the time interval from reset to ultrasonic pulse arrival and computes its distance from the Bat. The problems of using this ultrasonic technique are the requirement of large number of receivers across the ceilings and their placements across the ceiling which needed quite sensitive alignments.

There are two other ultrasonic positioning systems whose name are Cricket and Dolphin respectively. Cricket is developed by the MIT Laboratories [2-14]. A Cricket unit which is a transmitter/receiver application board is shown in Figure 2.8. The architecture of Dolphin (Distributed Object Locating system for PHysical space Inter Networking) is explained in [2-15] and [2-16]. The Dolphin system consists of distributed wireless sensor nodes as Figure 2.9 shows.

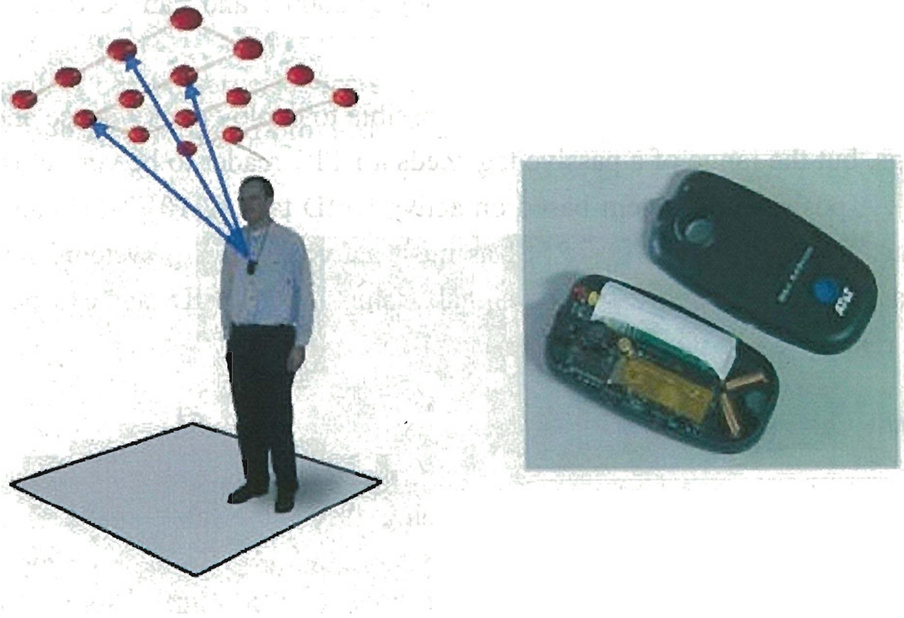

Fig 2.7 ActiveBat system

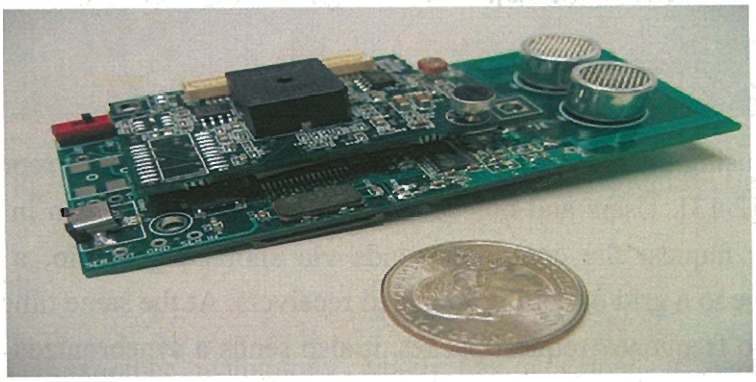

Fig 2.8 Cricket unit with sensorboard

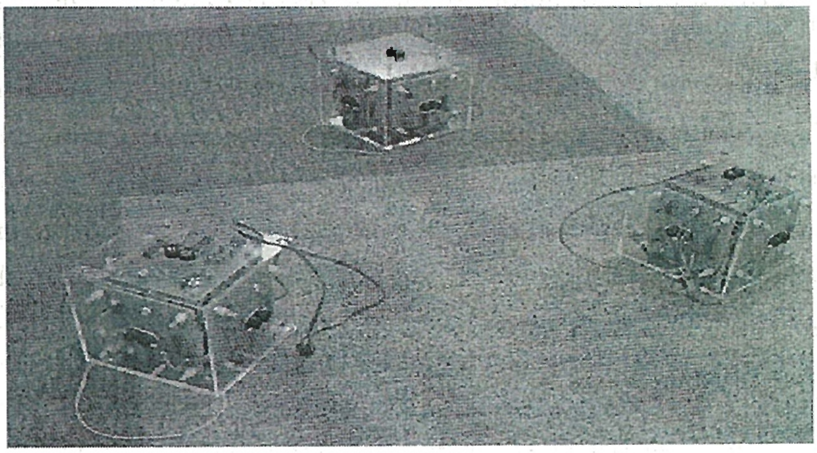

Fig 2.9 Dolphin ultrasonic system

►Wireless LAN

Wireless LAN (WLAN) offers an interesting basis for positioning. The technology supports RSSI readings from broadcasting access points [2-17]. This method is remarkable for employing the existing infrastructure throughout inhabited environment and the error of positioning is still a problem.

►Computer vision

According to the use of artificial markers, positioning system based on computer vision can be divided into two categories. The character of the technique which tracks the nature features is estimating position with physical principle in the environment where the arrangement of the artificial material is impossible. Mainly natural feature points such as corner and edge are detected and tracked from scene captured by camera [2-18]. There is a problem the computational complexity is so huge that real-time capability is low. Moreover, natural feature point detecting could not work effectively if the objects in environment occur to move. On the other hand, with the purpose of obtaining 3D position and posture of camera and high expansibility of workspace, a mass of paper markers at a low price are adopted by many systems in the last few years. Signpost system of Kalkusch [2-19] (Figure 2.10) uses ARToolKit [2-20] for detecting the markers and measuring the relative position from the markers. ARToolKit employs foursquare paper markers with thick black borders and estimates the four corners of square by applying the PnP problem.

Fig 2.10 System of Kalkusch etc.

Variety of currently used indoor positioning systems have been introduced and their advantages and disadvantages are compared as Table 2.1.

Table 2.1 Overview of comparisons between various positioning systems

system	outdoor	indoor	realtime	accuracy	range	signal	date rate	cost
GPS	+		+	5-100m	global	RF	20Hz	high
Cellphone	+		+	50m	outdoors	RF	20Hz	moderate
Active Badge		+	+	7cm	5m	Infrared	0.1Hz	moderate
Active Bat		+	+	9cm	50m	Ultrasonic	75Hz	moderate
Cricket		+	+	2cm	10m	Ultrasonic	1Hz	Low
Dolphin		+	+	2cm	room scale	Ultrasonic	20Hz	moderate
WLAN		+	+	3m	room scale	RF	4Hz	moderate
UWB		+	+	10cm	15m	RF	1Hz	moderate
RFID		+	+	1.7m	Indoors	RF	100Hz	moderate
Computer vision		+	+	10cm	room scale	Visual light	3.5Hz	high

2.3 Other relevant technologies for indoor positioning system

The technology of indoor positioning system can be divided into two parts logically: positioning technology and services based on position information. The features of positioning technology have been discussed with above. In practical applications, in addition to the requirement of a stable positioning function, indicating the positioning result on various mobile devices, communicating position information in security and providing services are also the important components of a positioning system. The implementation of these functions depends on the different architectures of hardware and software. It involves GIS, wireless communication and development of mobile devices, and their logical interdependences constitute the framework of the indoor positioning system. The combination of indoor positioning technology and various information technologies can not only provide services to people directly, but also help to solve the problems in other research fields. For example, the robot with the capability of indoor positioning can move in the indoor environment according to the instructions from the operator. The operator also could learn the indoor situation through the sensors equipped on robot. The provision of location-based services relates to hardware and software support, and requires the development of professional applications as well. Therefore, it involves a number of other related technologies, which will be introduced in detail as following.

(1) Wireless indoor positioning and LBS (Location Based Service)

Indoor positioning systems are very similar to outdoor positioning system (GPS) on architecture. In formal way, we can consider the indoor positioning system to be the extension of GPS or other outdoor positioning technologies, as shown in Figure 2.11.

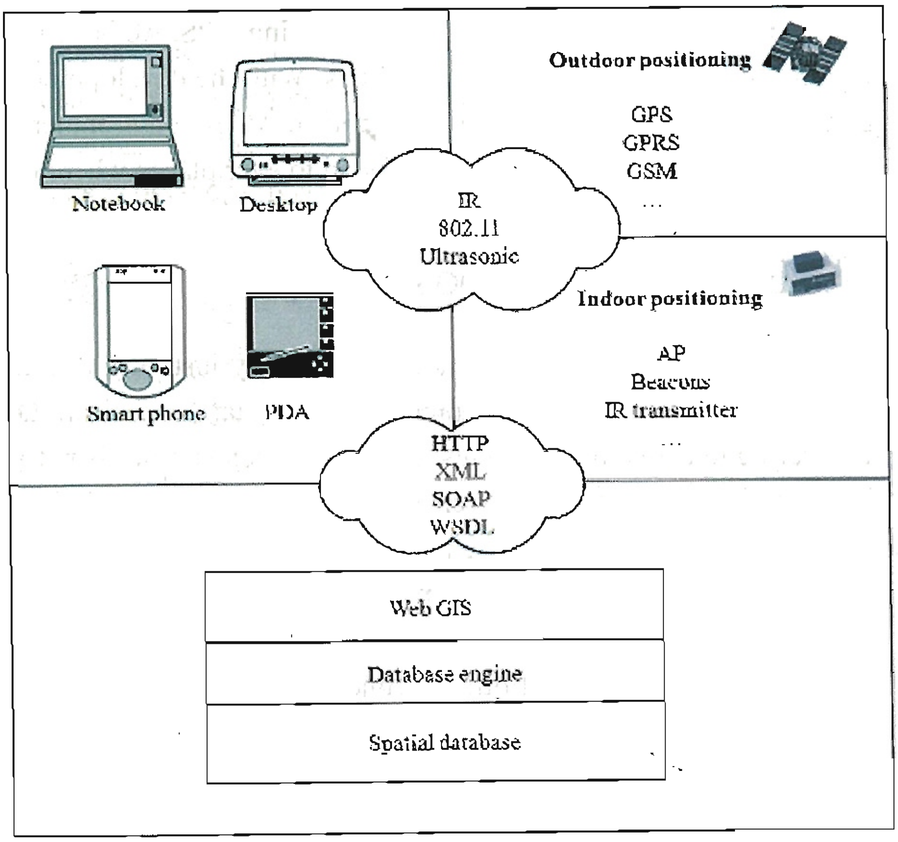

Fig 2.11 LBS with positioning function

The information we required in daily life is often related to the current location in a certain extent. LBS is kind of service depending on the location information of mobile devices. It locates the mobile devices with the help of positioning systems, and serves users with the services base on user's location by using GIS database and wireless communication [2-21]. From the viewpoint of mobile communication, LBS is a kind of value-added service the mobile communication operators provides to users by achieving users' location information.

Currently, LBS mainly depends on GPS and the mobile communication base stations to achieve positioning. Its typical application is providing emergency assistance and navigation. Indoor positioning technologies have greatly enriched the contents of LBS. In addition to emergency assistance and path selection, LBS would also be able to provide the information like "which room I am in", "which room the printer is in".

(2) Location oriented mobile communication

Since the 1990s, voice oriented mobile communication technology has been greatly developed. A huge market related to mobile phone has been formed. At the same time, multimedia communication started to be required. Location oriented mobile communication is the communication method centric to position information, and we can view it as an advanced form of LBS. By using GPS, we have been able to provide real-time navigation and other map services. With the development of indoor positioning technology, indoor environment and outdoor environment will be integrated seamlessly, and the LBS will be expended to ever places where the users. It will completely change our way of life.

2.4 Conclusion for indoor positioning technology

Indoor positioning causes a lot of concern from many institutes and companies. It has major significance in the development of information society. Objectively speaking, comparing to actual requirements, the current technologies is not yet mature to be called practical technology. However, with the development of communication infrastructure and technology, we believe that indoor positioning gets mature in near future. First, the positioning accuracy can be improved by employing multiple methods simultaneously, and the stability of system can be enhanced as well. Second, the combination with GIS, GPS and other technologies, would make the system be able to meet the requirement of various applications. Finally, the indication of indoor environment and the positioning result (the map for multi-floor buildings, 3D space etc.) is also the key issues for one promised indoor positioning system.

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➢ Chapter 3

ID recognition of embed code in LED tube

3.1 Overview of proposed system

Our work presents a novel method for indoor positioning by pointing a camera, available on a hand-held computing terminal, at LED tube lights fixed on the ceiling. This system provides an exact estimation of both 3D position and orientation. The concurrent use of LEDs for simultaneous illumination and communication makes this system very cheap for deployment in wide-scale areas.

Figure 3.1 is a schematic diagram of the proposed system and one of the possible applications. Assume you are in an academic conference which is large in size. You can use your mobile phone, which is equipped with at least one camera, to observe the LED tubes and the mobile phone would notice you the current presentation in nearby rooms with the schedule already installed in the phone.

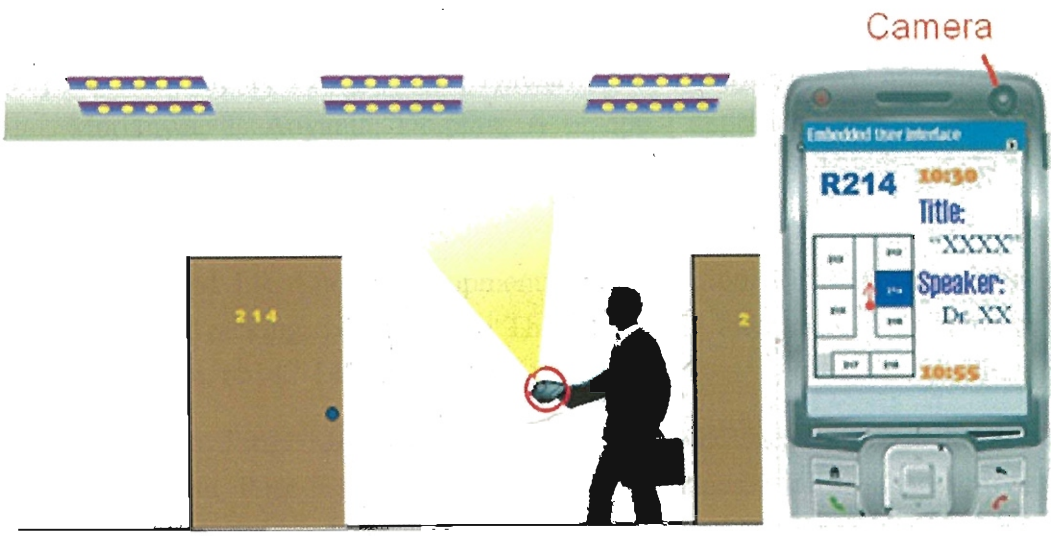


Fig 3.1 The structure of proposed system

The proposed system uses units of LED tubes (one unit contains a pair of tubes), which are modulated with different ID, as the markers in real world, and the position of tubes is stored in database according to the index of ID information. Figure 3.2 shows the simple process flow of location estimation.

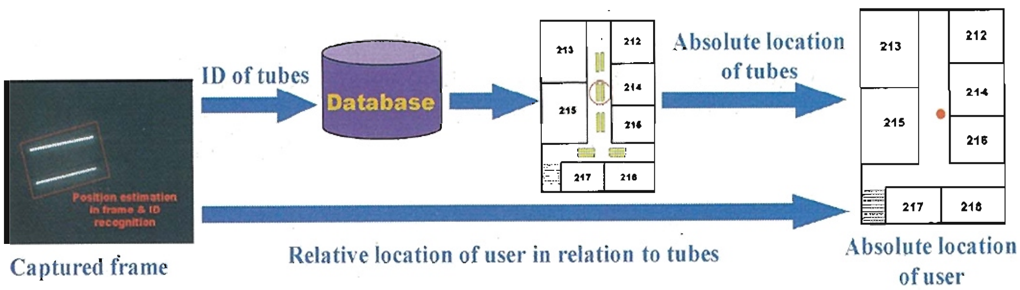


Fig 3.2 Process flow of location estimation

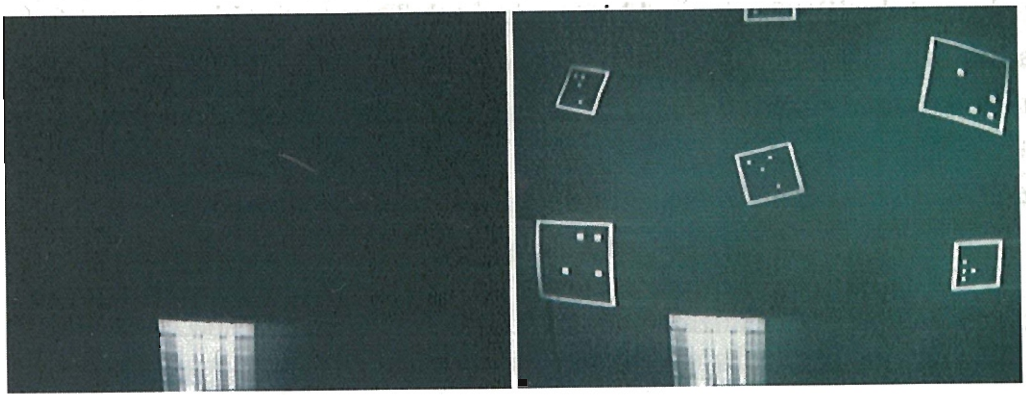
At first, relative location of camera in relation to tubes could be estimated directly, and the ID of unit would be recognized. Then a query is operated from the database with the ID to get the absolute location of tubes. Finally, we elicit the absolutc location of camera.

3.2 Related works

As mentioned in Session 2.2.3, employing visual markers is an implemental and practical method for realizing indoor positioning. This method, which has low requirement on the devices, can achieve a high accuracy and reasonable experience. Mulloni et al. evaluated subjective experiences about ease of use and awareness of location for various mobile navigation applications that use marker-based localization, no localization, and seamless localization [3-1] (Figure 3.3). Their work shows that marker-based localization is a good solution for navigation in indoor environment when no GPS positioning is available.

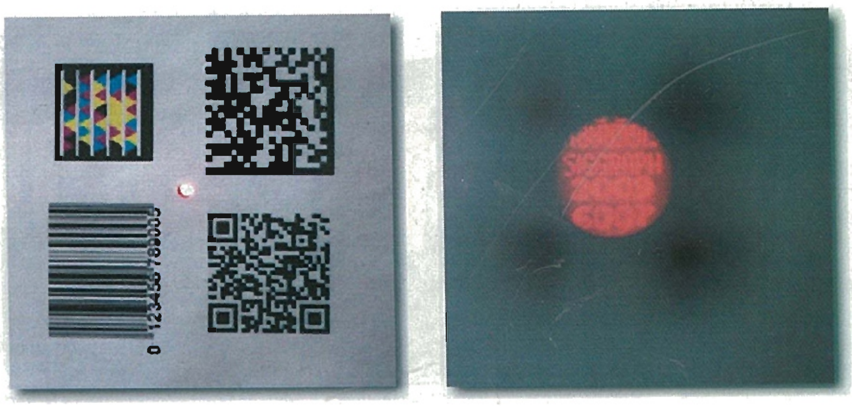
Fig 3.3 Marker-based positioning and continuous positioning

However, marker-based systems usually involve the problem of visual obstruction in interior environment. Nakazato et al. [3-2] introduced a kind of invisible marker made of translucent retro-reflectors. An infrared flasher attached to a wearable device is used to illuminate the makers for capture by an IR camera (Figure 3.4). The compact visual barcode called Bokode [3-3] invented by Mohan et al. has much potential to be used as an imperceptible marker for indoor positioning (Figure 3.5).



(a) (b)

Fig 3.4 The markers made of translucent retro-reflectors
(a) Captured image when infrared LEDs are switch-off
(b) Captured image when infrared LEDs are switch-on



(a) (b)

Fig 3.5 Bokode: a kind of compact visual barcode
(a) in focus photograph (b) out of focus photograph

Another method involves taking advantage of an illumination instrument that has already been deployed in the building as part of the infrastructure. Without the need for additional artificial markers, this type of system would be economical and feasible for application on a large scale. Makino et al. [3-4][3-5] introduced several walking assist systems for the visually impaired, which employed fluorescent lights as information transmitters.

In recent years, the development of LED technology to replace conventional illumination methods has made great progress. Compared with traditional lighting methods, LEDs offer the following advantages: energy efficiency, longer lifetime, minimal heat generation, and the ability of being switched on and off at a very fast rate, making it possible to provide a data channel for message broadcasting. Research on communication using LEDs originated in Japan, with the founding of the Visible Light Communications Consortium (VLCC) [3-6] in 2003.

In 2004, an indoor positioning system, which was constructed from a cell phone and an LED light source, was unveiled by NEC Corporation and Panasonic Electric Works (members of the VLCC) [3-7] (Figure 3.6). A photodiode-based receiver plugged into the cell phone is used to receive modulated visible light transmitted by LED lamps. The switching frequency is high enough that the perceivable light appears to be constantly illuminated to the human eye. Finally with the ID of the nearest lamps, position and ambient information can be obtained from the Internet. However, the exact 3D position cannot be estimated using a photodiode and therefore, the results obtained from this system are only approximate, with the position described along the lines of “now you are in the area which is close to the No. xx lamp”. The distance error could be several meters. Moreover, orientation information cannot be provided.

Fig 3.6 Positioning system by NEC Corporation and Panasonic Electric Works

Same with the positioning system developed by NEC Corporation and Panasonic Electric Works, our system also takes advantage of LED light sources. The difference is that LED light source in the system of NEC etc. transmits temporal information while the ID information in our system is conveyed by the spatial feature of rod-like LED tubes (see Section 3.3.1). Although temporal signal could provide a huge volume of information, it has some defects such as: being dependent on special receiver, for example a high-speed camera; requiring intricate controlled digital circuit for infrastructure equipment; without solution of accuracy 3D positioning. These problems restrain a widespread use. Hence, the authors propose this system to hurdle the obstacles to a certain extent. Table 3.1 shows the comparison of the system developed by NEC etc. and the system proposed in this research.

Table 3.1 Comparison of the system developed by NEC etc. and the system proposed in this research

	NEC etc.	This research
Transmitting method	Temporal signal	Spatial signal
Amount of information	Large	Small
Special receiver	Necessary	Unnecessary
Consumption for infrastructure	High	Low
3D positioning	No	Yes

3.3 ID modulation

3.3.1 Optical marker

Among the variable sorts of LED illumination equipments, LED tubes, which could easily take advantage of the existing infrastructure for normal fluorescent, are paid more attention. We could use the inherent spatial feature of the tubes to express identification information. Figure 3.7 shows the LED tube produced by Momo Alliance Co and its length is 50 cm.

Fig 3.7 High intensity LED tubes

Each tube consists of n lamps and the switching on or off of individual lamps could represent a bit string which contains n digits. We make the tubes keep on switching alternately between two states: original state of ID number and inverted state, at a high fixed-frequency(in our experiment, the frequency is 60Hz because of alternating current supplied by Kansai Electric Power Co.), so that the flickering effect will not be sensed by human eyes. Table 3.2 shows the relationship between ID number, original state and the inverted state.

Table 3.2 Relationship between ID number, original state and the inverted state (○ means on and ● means off)

ID number	0 1 1 0 1 0 0 1...
Original state	●○○●○●●○···
Inverted state	○●●○●○○●···

3.3.2 Manchester code

The authors designed a model (Figure 3.8) which could label LED tube with various ID number freely for ID recognition test. The length of LED tube for experiment is 274.5 mm.

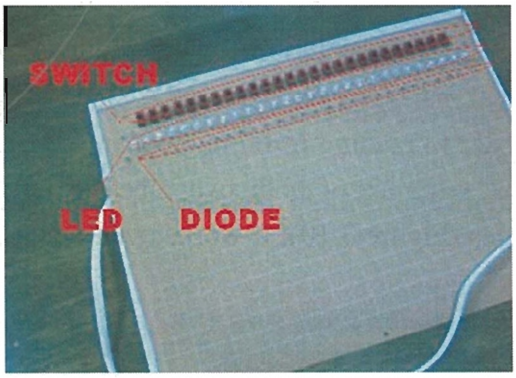


Fig 3.8 LED tube for test

During the test, the authors found that Manchester coding method could provide an accurate ID recognition, a good balance of luminance between two states, and the most important, equal peak values of current in either direction due to the same amount of lighting lamps. In this method, two lamps are used to express one digit of information, as the Table 3.3 shows. Figure 3.9 is the revised circuit for Manchester coding method.

Table 3.3 Manchester coding method

One digit of information	0	1
Original state of lamps	○●	●○

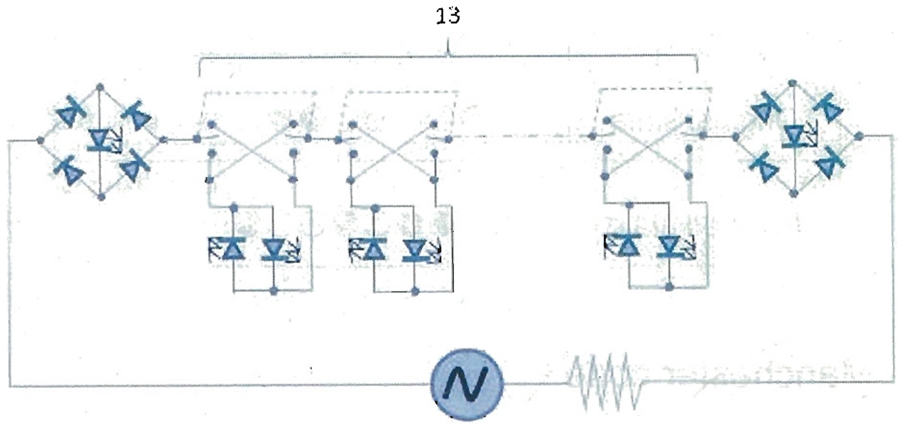


Fig 3.9 Circuit for Manchester coding method

3.3.3 ID modulation for unit of LED tubes

In proposed system, in order to estimate the 3D location, we employ units of couple tubes as the optical markers (see Section 3.4.2), so the ID number is displayed by integrated unit. In order to reading in ID number in the right sequence, "detection code" is attached to the extremes of both two tubes to tell the original state from inverted and reverse states (Figure 3.10). It works even when two of them in one side are seen.

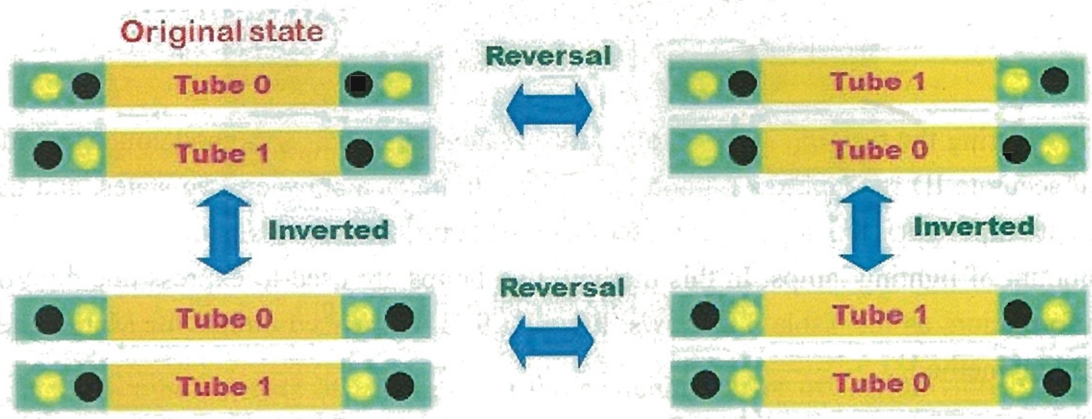


Fig 3.10 Detection code

To locate the endpoints of the tubes easily in the image, the lamps at either end of a tube are configured to be illuminated in both states. This is called the "guard part". Each guard part consists of a single LED and four bridge diodes. The components of a tube are shown in Figure 3.11. Referring to the commercial product of Momo Alliance Co. (Figure 3.x), each tube consists of 28 LEDs.

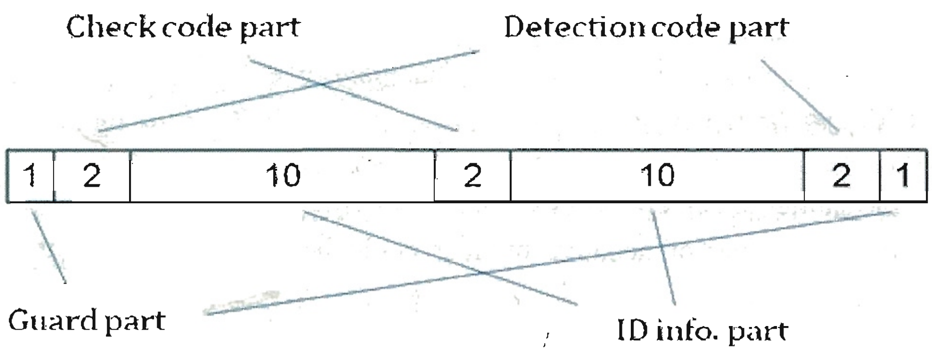


Fig 3.11 Component of one tube

Of the 28×2=56 lamps in a single unit, 4 lamps that are constantly illuminated are used for the guard pattern, 8 lamps are used for the detection code, 4 lamps for the parity check code, and 56 – 4 – 8 – 4 = 40 lamps for indicating the ID number. Therefore, the size available for ID information is 40 / 2 = 20 digits. This means that the number of available IDs is 2^{20} = 1,048,576 or 2^{22} = 4,194,304 without check code. Therefore, the proposed system easily satisfies the requirements for application in a large building or even throughout an entire campus.

The location information of LED tubes is stored in database with the indexes of ID number. Vectors of length and width of LED unit, with which any attitude could be described, also need to be stored in practical application (Figure 3.12).

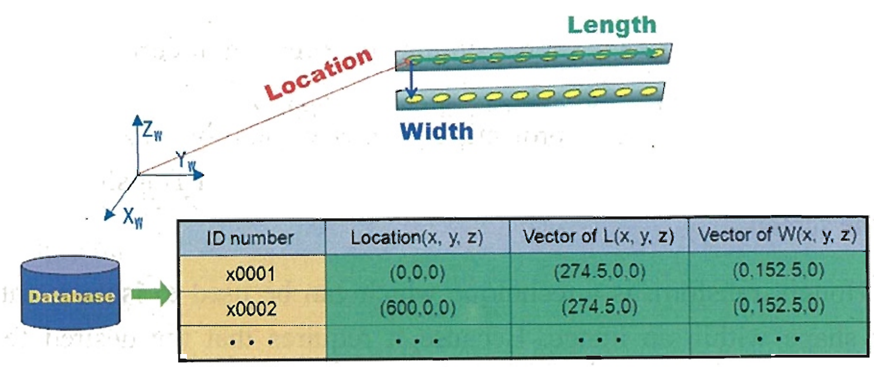


Fig 3.12 Contents in database

In our system, we assume that the position and size of the LED tubes are obtained from the CAD data of the building. Moreover, each LED tube (or each unit) is registered with its ID number in database. Two approaches can be applied for the registration. The first one is taking notes when the LED tube is assigned with an ID (e.g. marking the ID on the body of the LED tube), and the registering the correspondence when the LED tube is installed. The second one is online mapping the building where all LED tubes have been installed, by a pedestrian holding a receiver, which is the method proposed in this research.

3.4 ID recognition

3.4.1 Tube detection

If the shutter of camera is not at the moment the direction of alternative current is changing, ID number or negative number could be caught distinctly in the screen (Figure 3.13)

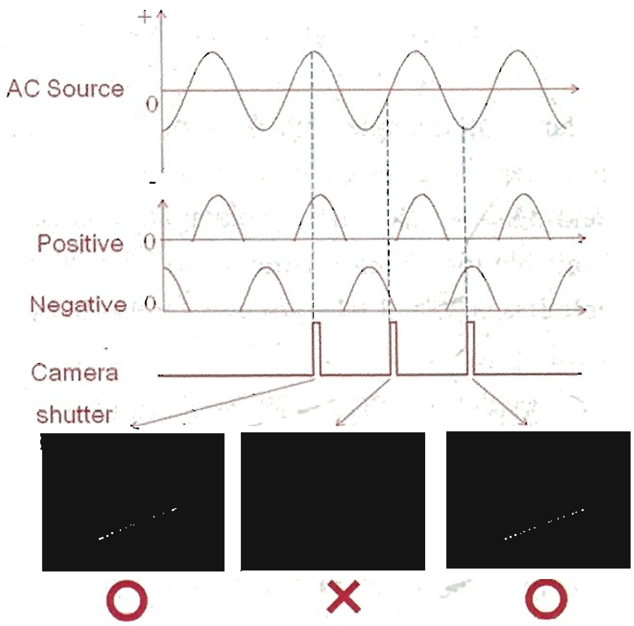


Fig 3.13 Shutter timing and direction of current

According the principles of projection geometry, the projection figure of a linear tube on camera screen is also linear, so we can employ Hough Transform for detecting tubes on the screen.

The Hough transform is a technique which can be used to isolate features of a particular shape within an image. Because it requires that the desired features be specified in some parametric form, the classical Hough transform is most commonly used for the detection of regular curves such as lines, circles, ellipses, etc. The Hough technique is particularly useful for computing a global description of a feature. The main advantage of the Hough transform technique is that it is tolerant of gaps in feature boundary descriptions and is relatively unaffected by image noise. In case of this research, the straight line in image space is described as:

$$\rho(\theta) = x\cos\theta + y\sin\theta \tag{3-1}$$

ρ : The distance between the line and the origin

θ : The angle of the vector from the origin to this closest point

In the Hough space, every line in image space is projected to be a point. And a number of lines plotted going through the point P(x, y) at different angle form a sinusoid in Hough space. Figure 3.14 showed the Hough transform in experiment. The points at which several sine waves intersect can be considered the lines of tubes. After detection lines, noise removal and topological analysis are performed to decide the region of tubes finally.

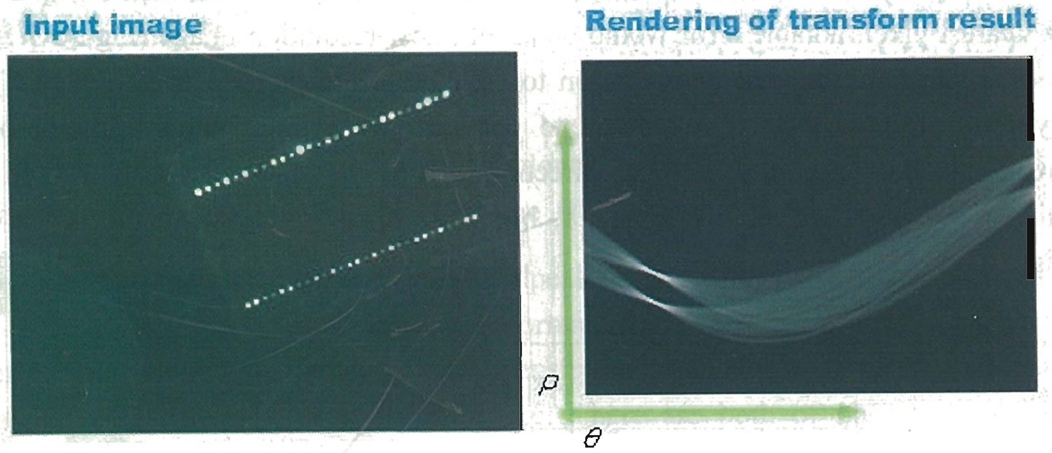


Fig 3.14 Hough transform in this research

3.4.2 Linear intensity diagram

Since the region of tubes has been detected, we make a projection profile of the intensity to express the status of lamps. **L** axis of this diagram represents the direction of the line from one of the endpoints of tube to another, and **I** axis of this diagram is the summation of intensity in the direction vertical to the straight line of tube. Figure 3.15 shows the diagram obtained in experiments. The lighting lamps are showed as peaks in diagram.

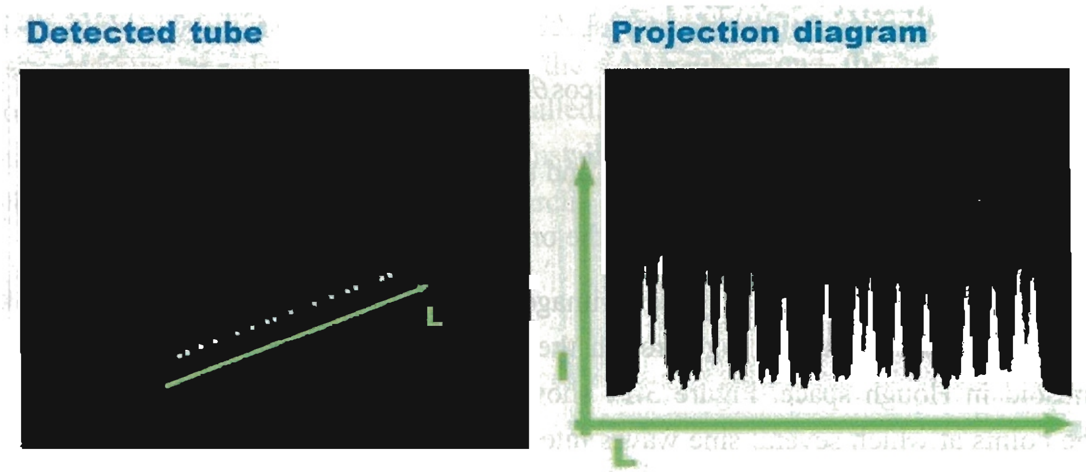


Fig 3.15 Projection of the intensity into LED line

If we just make the intensity value of sampling points for accumulation equal to the nearest pixel, notable error would occur in a low-resolution image (Figure 3.16). We employed the bilinear interpolation to compute a more approximate value. The key idea of bilinear interpolation is to perform linear interpolation first in one direction, and then again in the other direction. Figure 3.17 shows the basic method of bilinear interpolation, and (a, b), (a+1, b), (a, b+1), (a+1, b+1) are the pixels of original image.

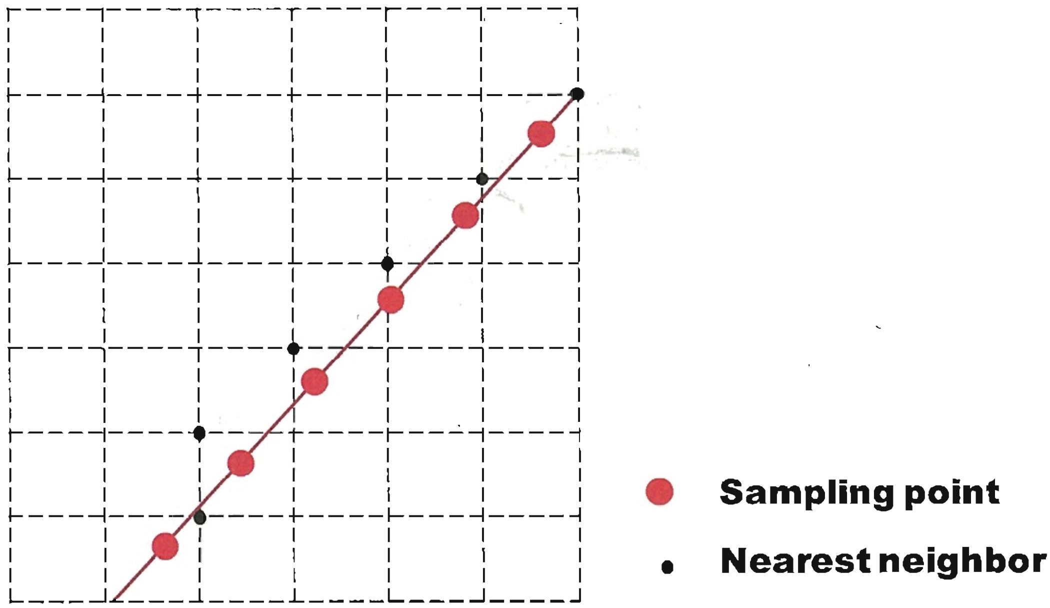


Fig 3.16 Error involved by nearest-neighbor method

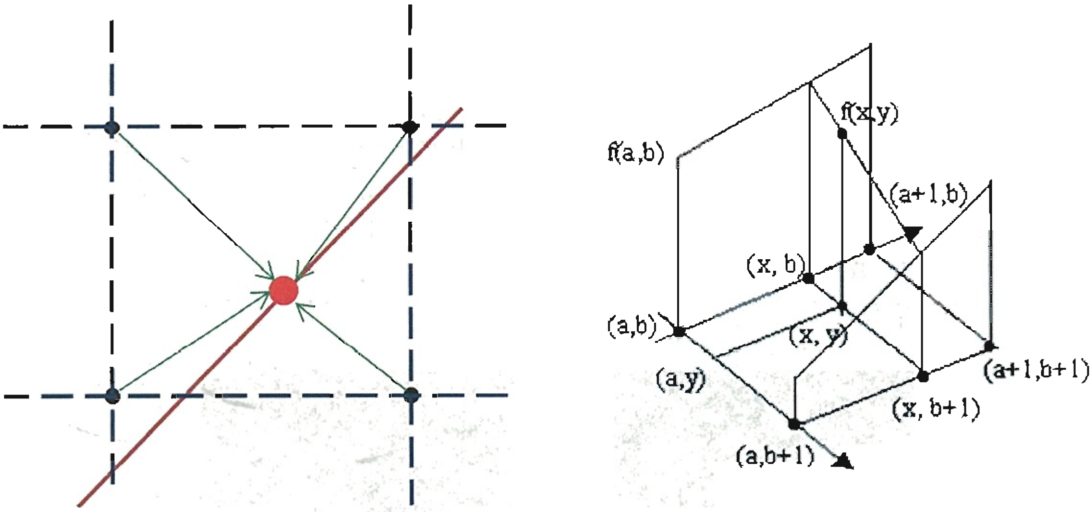


Fig 3.17 Bilinear interpolation

3.4.3 ID extraction

Two available approaches could be adopted to extract ID number from intensity diagram: ①ID extraction from single frame ②ID extraction with subtraction.

The first method is that detecting the peak values as the bit '1', and inserting '0' in to the bit string according the space information between two peaks. The second is performing subtraction between two intensity diagrams from temporal-continuous frames with different states of LED tube. There are both of positive peaks and negative peaks in the result diagram of subtraction. So the bit '1' and '0' could be detected simultaneously (Figure 3.18). Though the method with subtraction could provide a higher recognition ratio, prerequisite condition is also stricter comparatively.

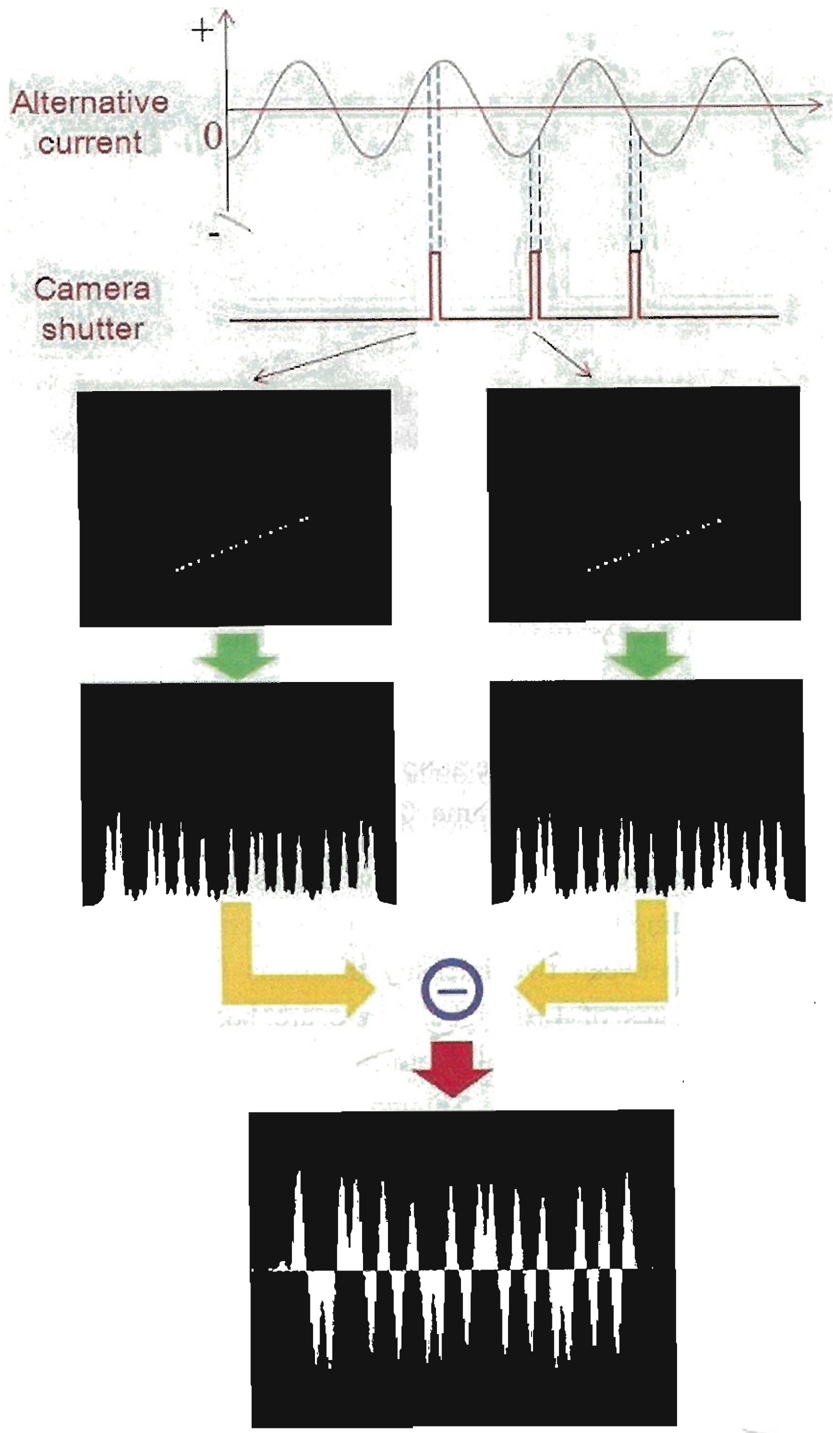


Fig 3.18 Subtraction diagram

Finally, by checking the detection code, the true ID number would be concluded from the result of extraction.

3.5 3D-position estimation

3.5.1 Camera calibration

For a 3D positioning, the calibration for intrinsic parameter of utilized camera is necessary. In proposed system, the technique of Zhang etc. [3-8] is adopted. This technique only requires the camera to observe a planar pattern shown at a few (at least two) different orientations. Either the camera or the planar pattern can be freely moved. The motion needs not to be known. By this technique, the intrinsic parameter **A** of camera and the lens distortion coefficient k_c could be determined. The **A** and k_c represent:

$$A = \begin{pmatrix} f_x & -f_x \cos\theta & u_0 \\ 0 & f_y / \sin\theta & v_0 \\ 0 & 0 & 1 \end{pmatrix} \tag{3-2}$$

$$k_c = \begin{pmatrix} k_1 & k_2 & p_1 & p_2 \end{pmatrix} \tag{3-3}$$

Where f_x, f_y are the focal lengths, $-\cos\theta$ is the skew rate, (u_0, v_0) is the center of screen, (k_1, k_2) is the radial distortion coefficient, and (p_1, p_2) is the tangent distortion coefficient.

Distortion correction is performed with the lens distortion coefficient. The relationship between coordinate (x_d, y_d) before correction and the corresponding coordinate (x, y) after correction is:

$$x_d = x + (k_1 r^2 + k_2 r^4)x + [2p_1 xy + p_2(r^2 + 2x^2)] \tag{3-4}$$

$$y_d = y + (k_1 r^2 + k_2 r^4)y + [2p_2 xy + p_1(r^2 + 2y^2)] \tag{3-5}$$

Where r^2 refers to x^2+y^2. Figure 3.19 shows the camera calibration and the distortion correction.

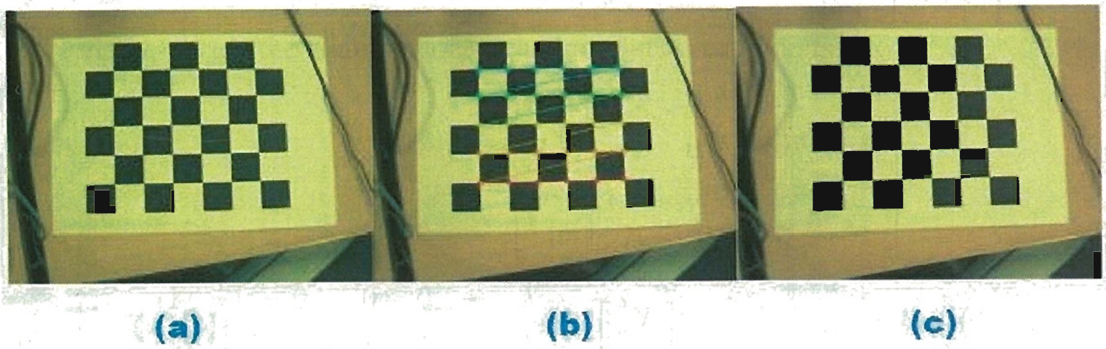


Fig 3.19 Camera calibration

(a) Input image (b) Detection of chessboard corner for calibration (c) Result of distortion correction

3.5.2 Estimation of camera position and attitude

Figure 3.20 shows the relationships of coordinate transformation among the coordinate system of object (marker), camera, and world. Because the location of markers relative to world is fixed, the transformation matrix from so-called world system to object system would not be changed. Hence, in order to computing the position of camera relative to world, we only need to talk about the transformation matrix from object reference system to camera reference system. In this research, I used the method in [3-10] to solve this P4P problem.

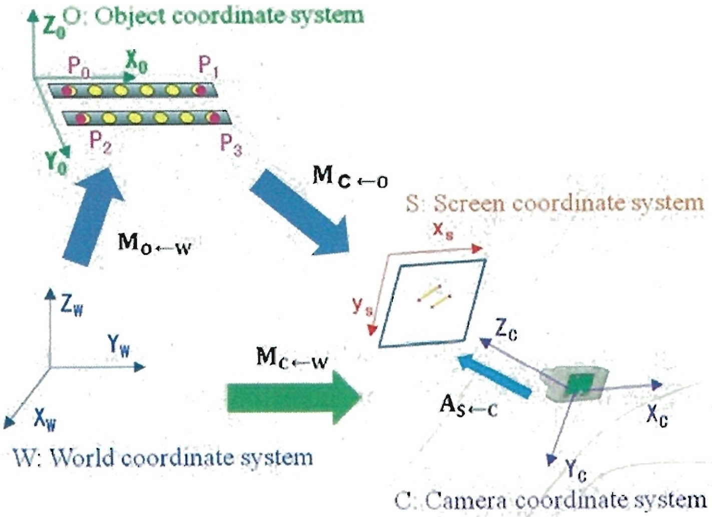


Fig 3.20 Coordinate transformation matrices

The relationship between the coordinate of *i*th LED lamp in object reference system (X_{io}, Y_{io}, Z_{io}) and the coordinate in camera reference system (X_{ic}, Y_{ic}, Z_{ic}) is showed as follow:

$$\begin{bmatrix} X_{ic} \\ Y_{ic} \\ Z_{ic} \\ 1 \end{bmatrix} = \mathrm{M} \begin{bmatrix} X_{io} \\ Y_{io} \\ Z_{io} \\ 1 \end{bmatrix} \tag{3-6}$$

$$= \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{io} \\ Y_{io} \\ Z_{io} \\ 1 \end{bmatrix} \tag{3-7}$$

$$= \begin{bmatrix} & \mathrm{R}_{3\times 3} & & \mathrm{T}_{3\times 1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{io} \\ Y_{io} \\ Z_{io} \\ 1 \end{bmatrix} \tag{3-8}$$

$\mathrm{R}_{3\times 3}$: Rotation component

$\mathrm{T}_{3\times 1}$: Translation component

The relationship between the coordinate value in screen space (u_i, v_i) and the coordinate in camera reference system (X_{ic}, Y_{ic}, Z_{ic}) is determined by camera intrinsic parameter **A** (Section 3.4.1):

$$\begin{bmatrix} X_{ic} \\ Y_{ic} \\ Z_{ic} \end{bmatrix} = \mathrm{A}^{-1} \begin{bmatrix} u_i \\ v_i \\ 1 \end{bmatrix} \tag{3-9}$$

We define:

$$\mathbf{s}_\mathbf{i} = \begin{bmatrix} s_{ix} \\ s_{iy} \end{bmatrix} = \begin{bmatrix} X_{ic}/Z_{ic} \\ Y_{ic}/Z_{ic} \end{bmatrix} \tag{3-10}$$

The next, according to the equation (3.7):

$$\mathbf{s}_\mathbf{i} = \begin{bmatrix} X_{ic}/Z_{ic} \\ Y_{ic}/Z_{ic} \end{bmatrix} = \begin{bmatrix} \dfrac{m_{11}X_{io} + m_{12}Y_{io} + m_{13}Z_{io} + m_{14}}{m_{31}X_{io} + m_{32}Y_{io} + m_{33}Z_{io} + m_{34}} \\ \dfrac{m_{21}X_{io} + m_{22}Y_{io} + m_{23}Z_{io} + m_{24}}{m_{31}X_{io} + m_{32}Y_{io} + m_{33}Z_{io} + m_{34}} \end{bmatrix} \tag{3-11}$$

Because the two LED tubes of one unit are on a planar surface, Z values of all lamps relative to object reference frame are set to be zero and we get equation (3-12) from (3-11):

$$\mathbf{s}_\mathbf{i} = \begin{bmatrix} X_{ic}/Z_{ic} \\ Y_{ic}/Z_{ic} \end{bmatrix} = \begin{bmatrix} \dfrac{m_{11}X_{io} + m_{12}Y_{io} + m_{14}}{m_{31}X_{io} + m_{32}Y_{io} + m_{34}} \\ \dfrac{m_{21}X_{io} + m_{22}Y_{io} + m_{24}}{m_{31}X_{io} + m_{32}Y_{io} + m_{34}} \end{bmatrix} \tag{3-12}$$

Finally, we get the simultaneous equation (3-13) for *i* points:

$$\begin{bmatrix} & \vdots & & & \vdots & & & \vdots & \\ X_{io} & Y_{io} & 1 & 0 & 0 & 0 & -s_{ix}X_{io} & -s_{ix}X_{io} & -s_{ix} \\ 0 & 0 & 0 & X_{io} & Y_{io} & 1 & -s_{iy}Y_{io} & -s_{iy}Y_{io} & -s_{iy} \\ & \vdots & & & \vdots & & & \vdots & \end{bmatrix} \begin{bmatrix} m_{11} \\ m_{12} \\ m_{14} \\ m_{21} \\ m_{22} \\ m_{24} \\ m_{31} \\ m_{32} \\ m_{34} \end{bmatrix} = 0 \tag{3-13}$$

In order to figure out this equation, *i* should be more than or equal to 4 and the points could not be collinear. Normally the lamps at four corners of unit are used, and the lamps in a middle position also could be added to reduce the error. If camera screen has not covered the whole unit, the ordinal numbers of the lamps which are the most close to image borderline are counted based on the result of ID recognition.

With the result of equation (3-13), $T = [m_{14}\ m_{24}\ m_{34}]^T$ is the position of camera relative to marker, and the relationship between rotation matrix **R** and rotation angle is showed as equitation (3-14).

$$
\begin{aligned}
R &= \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \\
&= \begin{bmatrix} \cos\phi\cos\kappa & -\cos\phi\sin\kappa & \sin\phi \\ \sin\omega\sin\phi\cos\kappa+\cos\omega\sin\kappa & -\sin\omega\sin\phi\sin\kappa+\cos\omega\cos\kappa & -\sin\omega\cos\phi \\ -\cos\omega\sin\phi\cos\kappa+\sin\omega\sin\kappa & \cos\omega\sin\phi\sin\kappa+\sin\omega\cos\kappa & \cos\omega\cos\phi \end{bmatrix}
\end{aligned}
\tag{3-14}
$$

ω: horizontal angle

ϕ: vertical angle

κ: rotation angle of optical axis

3.6 Data integration

3.6.1 Introduction of Kalman filter

Noise is involved in the result location estimation of this system due to camera calibration and tube detection. What is more sometimes it fails to capture tube because of shutter timing and sight line. This system employs Kalman filter for reducing the effects of the noise and obtaining a good estimate of the location of the target at the present time (filtering), at a future time (prediction), or at a time in the past (interpolation or smoothing).

Kalman filters are based on linear dynamical systems discretized in the time domain. They are modeled on a Markov chain built on linear operators perturbed by Gaussian noise. The state of the system is represented as a vector of real numbers. At each discrete time increment, a linear operator is applied to the state to generate the new state, with some noise mixed in, and optionally some information from the controls on the system if they are known. Then, another linear operator mixed with more noise generates the visible outputs from the hidden state. The Kalman filter may be regarded as analogous to the hidden Markov model, with the key difference that the hidden state variables take values in a continuous space (as opposed to a discrete state space as in the hidden Markov model). Additionally, the hidden Markov model can represent an arbitrary distribution for the next value of the state variables, in contrast to the Gaussian noise model that is used for the Kalman filter. There is a strong duality between the equations of the Kalman Filter and those of the hidden Markov model [3-9].

In order to use the Kalman filter to estimate the internal state of a process given only a sequence of noisy observations, one must model the process in accordance with the framework of the Kalman filter. The Kalman filter addresses the general problem of trying to estimate the state x of a discrete-time controlled process that is governed by the linear stochastic difference equation:

$$x_k = Ax_{k-1} + Bu_k + w_{k-1}, \tag{3-15}$$

with a measurement z that is:

$$z_k = Hx_k + v_k. \tag{3-16}$$

A is the state transition model which is applied to the previous state x_{k-1}, B is the control-input model which is applied to the control vector u_k, and H is the observation model which maps the true state space into the observed space.

The random variables w and v represent the process and measurement noise (respectively). They are assumed to be independent (of each other), white, and with normal probability distributions:

$$p(w) \sim N(0, Q),$$

$$p(v) \sim N(0, R).$$

In practice, the process noise covariance Q and measurement noise covariance R matrices might change with each time step or measurement. However, in the experiment we assume they are constant.

The operation of Kalman filter is showed as Figure 3.21.

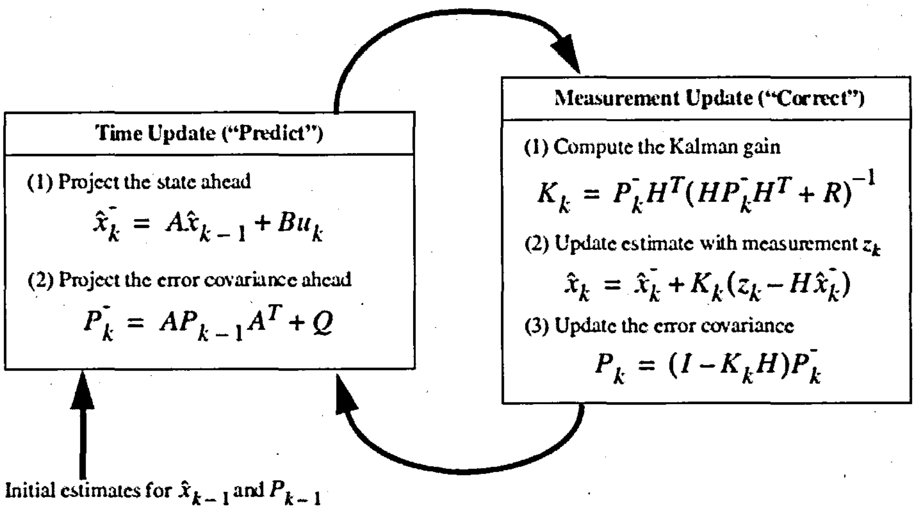


Fig 3.21 Operation of Kalman filter [3-9]

P_k^- and P_k represent priori estimate error covariance and posteriori estimate error covariance respectively. The matrix K is chosen to be the gain or blending factor that minimizes the a posteriori error covariance.

3.6.2 Kalman filter for this research

This research supposes that the velocity of camera is maintained. In the case of missing LED tubes, location could be predicted according to previous state. ΔT is the short space of time between two frames.

The stochastic difference equation is:

$$X_k = A_k X_{k-1} + W_{k-1} \tag{3-17}$$

$$\begin{bmatrix} x_k \\ y_k \\ z_k \\ x'_k \\ y'_k \\ z'_k \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & \Delta T & 0 & 0 \\ 0 & 1 & 0 & 0 & \Delta T & 0 \\ 0 & 0 & 1 & 0 & 0 & \Delta T \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{k-1} \\ y_{k-1} \\ z_{k-1} \\ x'_{k-1} \\ y'_{k-1} \\ z'_{k-1} \end{bmatrix} + \begin{bmatrix} w_{x_{k-1}} \\ w_{y_{k-1}} \\ w_{z_{k-1}} \\ w'_{x_{k-1}} \\ w'_{y_{k-1}} \\ w'_{z_{k-1}} \end{bmatrix} \tag{3-18}$$

The equation of relationship between process state and measurement is:

$$Z_k = H_k X_k + V_k \tag{3-19}$$

$$\begin{bmatrix} z_{x_k} \\ z_{y_k} \\ z_{z_k} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_k \\ y_k \\ z_k \\ x'_k \\ y'_k \\ z'_k \end{bmatrix} + \begin{bmatrix} v_{x_k} \\ v_{y_k} \\ v_{z_k} \end{bmatrix} \tag{3-20}$$

3.7 Experiment

3.7.1 Prototype system configuration

The authors use a notebook and a CCD camera to perform the function of sensory and processing terminal in the evaluation experiment, and the optical marker of LED lamps used in experiment is made by authors. The detailed specification is listed as follows:

Notebook computer:

Model: INSPIRON 9300, Dell Corp.

OS: Windows XP Professional

CPU: Intel® Pentium 1.8GHz

Memory: 1.0 GB

Graphical card: NVIDIA GeForce Go 6800

CCD camera:

Model: Dragonfly® 2, Point Grey Research Inc.

Image Sensor Type: Sony® 1/3" progressive scan CCDs

Interfaces: 6-pin IEEE-1394

Maximum Resolution: 640×480

Flame Rate: 60, 30, 15, 7.5 fps

Gain: Automatic/Manual/One-Push Gain modes 0dB to 24dB

Shutter: Automatic/Manual/One-Push/Extended Shutter modes 0.01ms to 66.63 ms at 15 FPS, greater than 5s in extended mode

Optical marker:

Length: 274.5 mm

Width: 152.5 mm

Lamps per tube: 28

Space between two neighbor lamps: 10.17 mm

Max current: 20 mA

Because the length of real product of LED tubes is about 50~60cm and in practical situation the distance between hand of user holding a cell phone and ceiling is about 1.5m, the location of camera is 80cm away from the ceiling to keep the size of tubes in screen in experiment close to practical application. Figure 3.22 shows the components of prototype system.

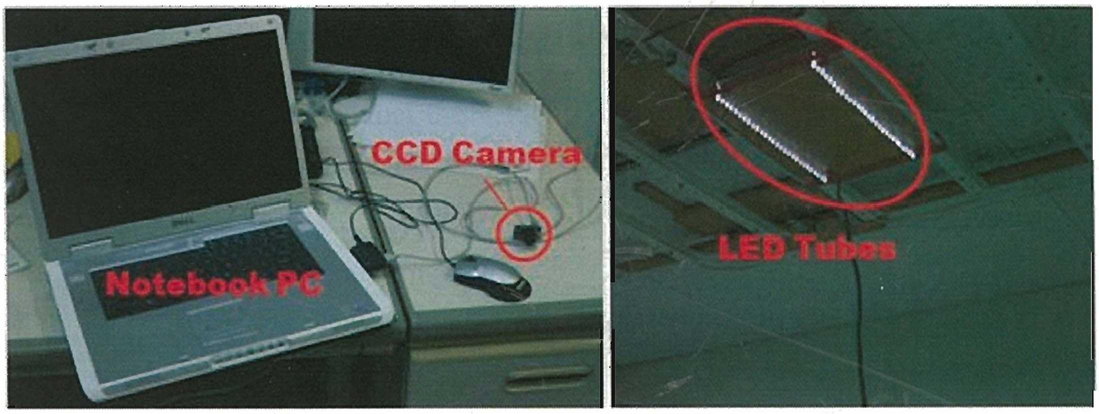
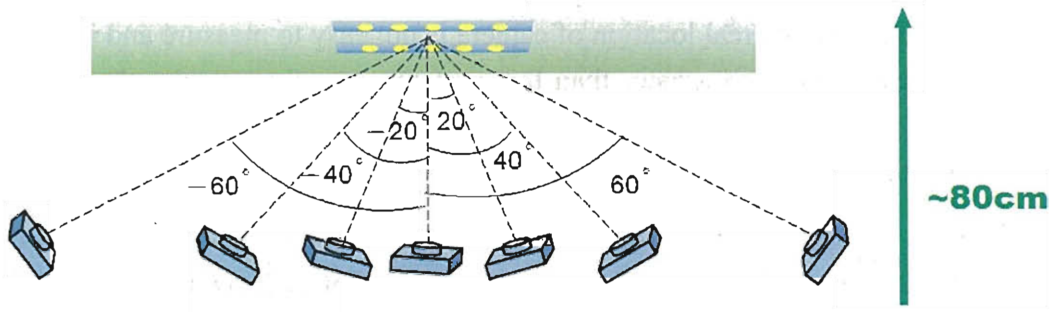


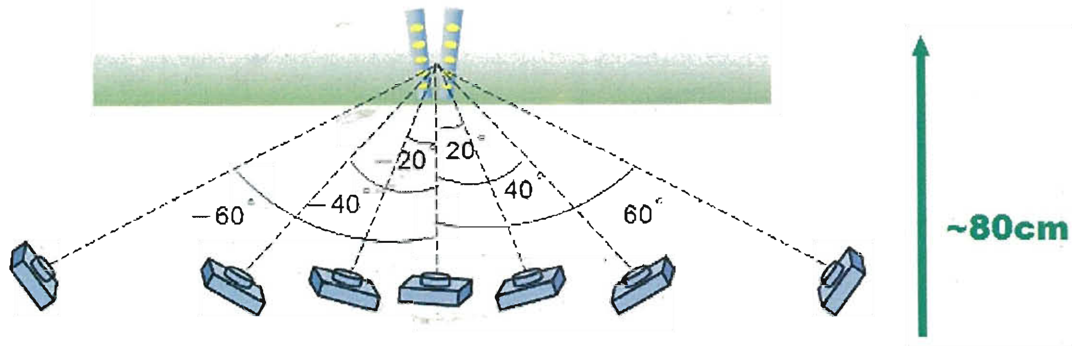
Fig 3.22 Prototype system for experiment

3.7.2 Experiment for recognition rate

The goal of this experiment is to examine the effort of camera poison on the recognition rata of the correct ID number. Only the positions located at two lines are test. The lines, which are respectively longitudinal or vertical to the direction of LED tubes, go across the plumb line from the center of LED marker. The sampling positions, where the angles from plumb line to sight line of camera positions are ±60°, ±40°, ±20° and 0°, are selected in this experiment (Figure 3.23). Table 3.4 shows the result of experiment.



(a)



(b)

Fig 3.23 Sampling locations in experiment for recognition rate
(a) longitudinal direction (b) vertical direction

Table 3.4 Result of experiment for recognition rate

Angle of Direction	-60°	-40°	-20°	0°	20°	40°	60°
Recognition Rate(L)	47.7%	76.4%	87.2%	89.7%	86.4%	79.6%	55.3%
Recognition Rate(V)	79.1%	87.3%	87.6%	89.7%	91.3%	86.2%	76.5%

Result shows that the longitudinal direction has more effect on recognition rate than vertical direction. The cause of this result might be that when the camera moves farther from tubes in longitudinal direction, in captured frame the spot of LED lamps and the space between two neighboring lamps of one tube become less homogeneous, and in fact the angel between sight line and the line of one tube is not changed when camera is shifting in the vertical direction.

3.7.3 Experiment for location estimation error

The goal of this experiment is examine the relation between the inaccuracy of measurement and location. Same with the experiment of Section 4.2, the sampling locations are also on two lines, longitudinal or vertical to direction of tubes. What is different is that in this experiment sampling locations are spaced out 15cm apart on the two lines (Figure 3.24).

Because the accurate real location of camera is not easy to measure and it is easy to involve a new error even greater than this system, we only consider the error of relative location. We supposed that the average value of measurement at the location nearest to center of the LED unit is without error and we get the result of relative location.

Figure 3.25 shows the result of measurement relevant to X-axis. Red diamonds are real values and dots in other color are measured values. Figure 3.26 shows the average of X, Y and Z values of measurement relevant to X-axis. Result shows that maximal error is about 27mm.

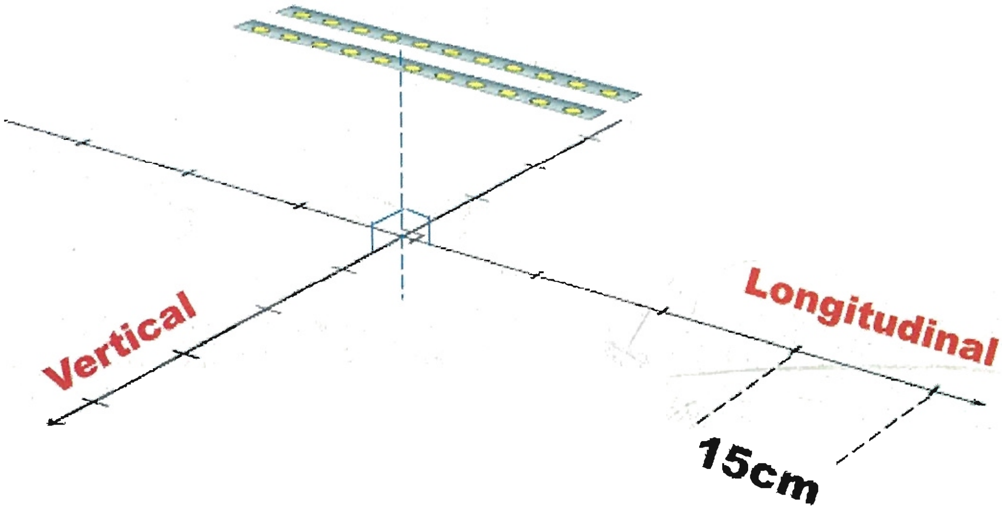


Fig 3.24 Sampling position in experiment for location error

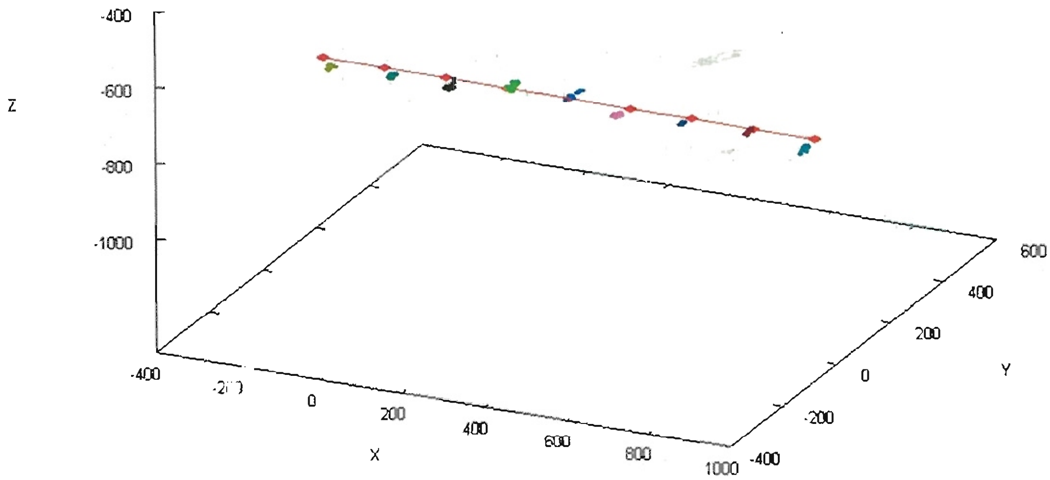
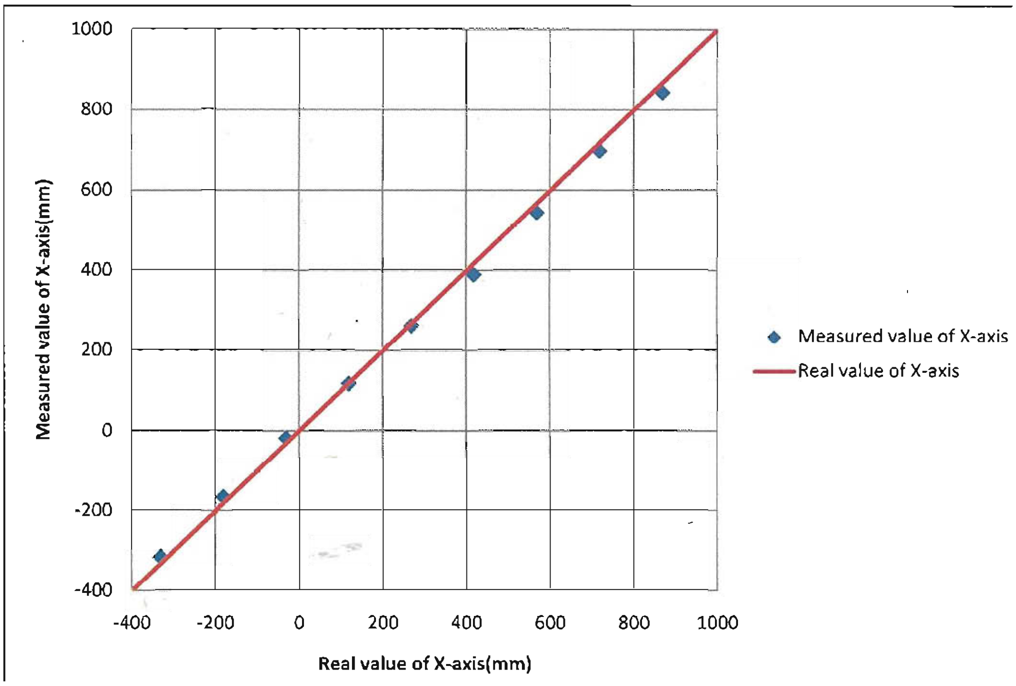
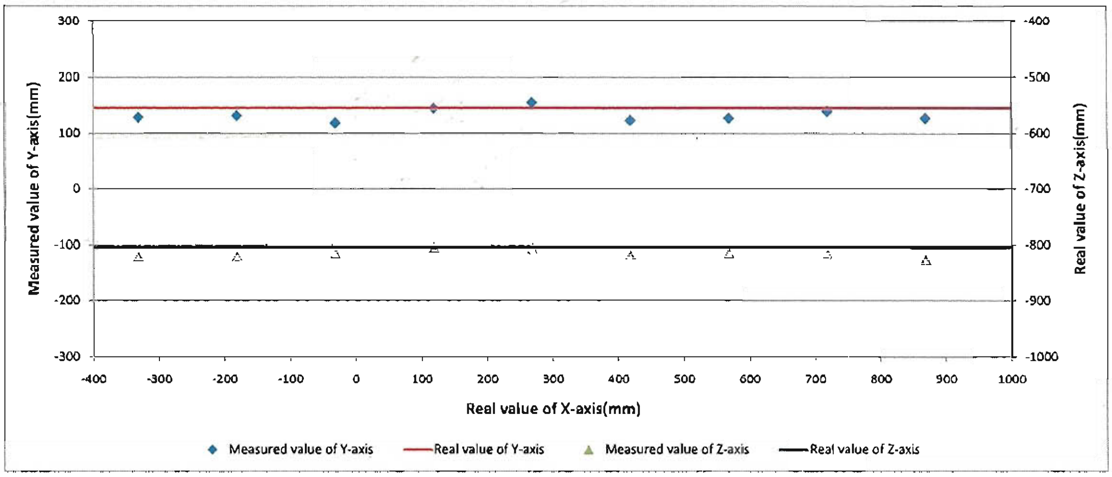


Fig 3.25 Measurement result relevant to X-axis



(a)



(b)

Fig 3.26 Average value of measurement relevant to X-axis
(a) value of X (b) value of Y and Z

Figure 3.27 shows the result of measurement relevant to Y-axis. Same with Fig4.4, red diamonds are the real values and dots in other color are the values of result. Figure 3.28 shows the measured value of X, Y and Z value relevant to Y-axis. Result of this experiment also shows that maximal error is about 35mm.

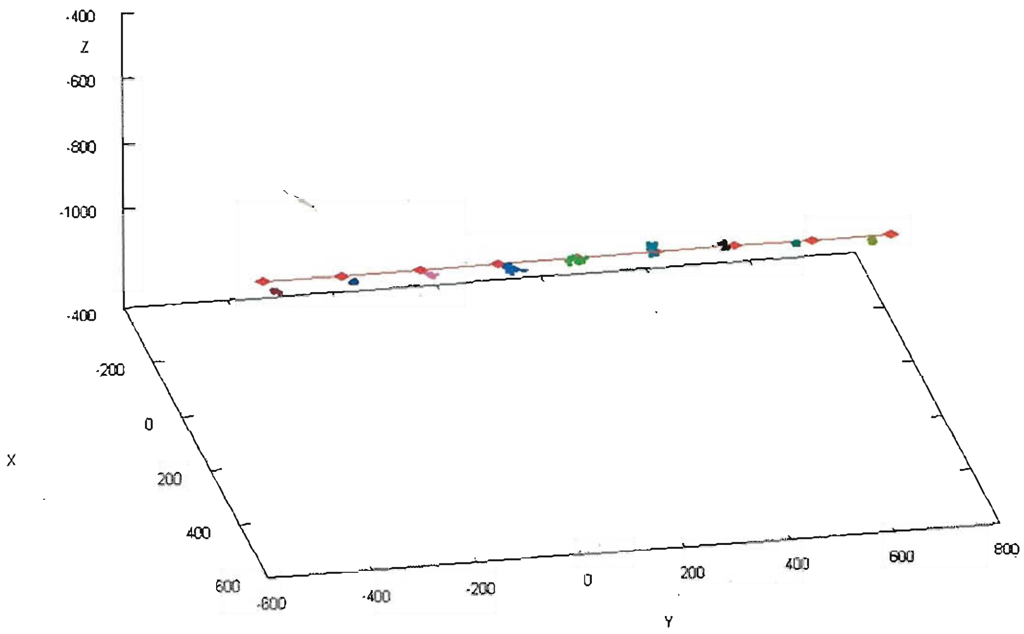
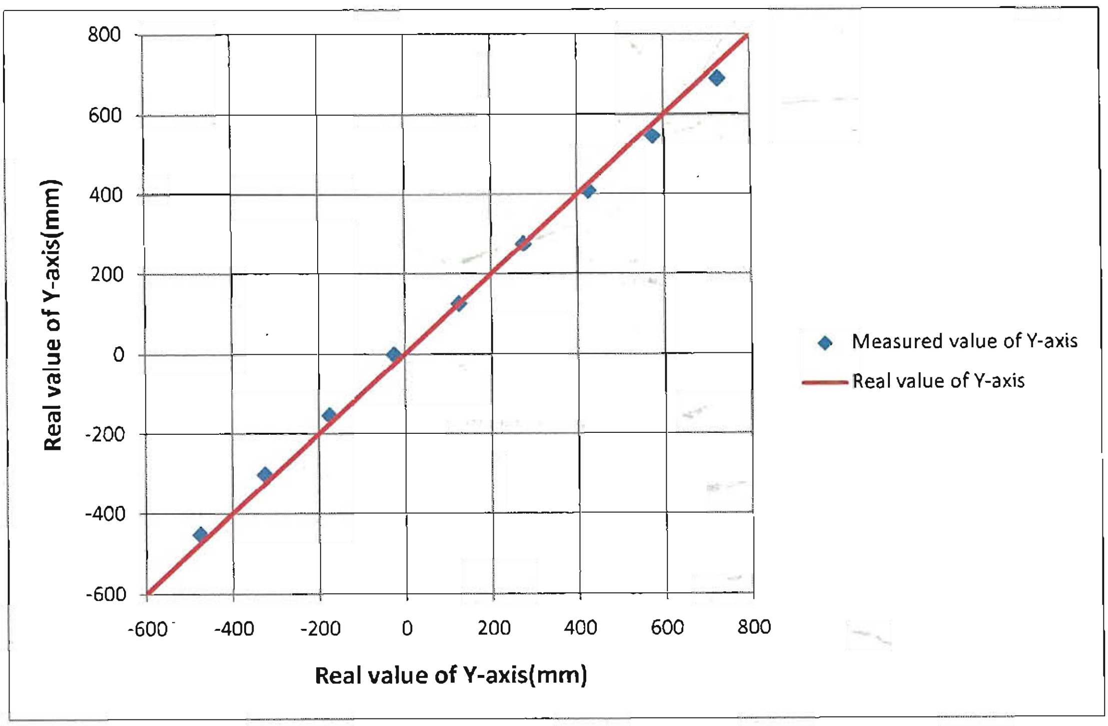
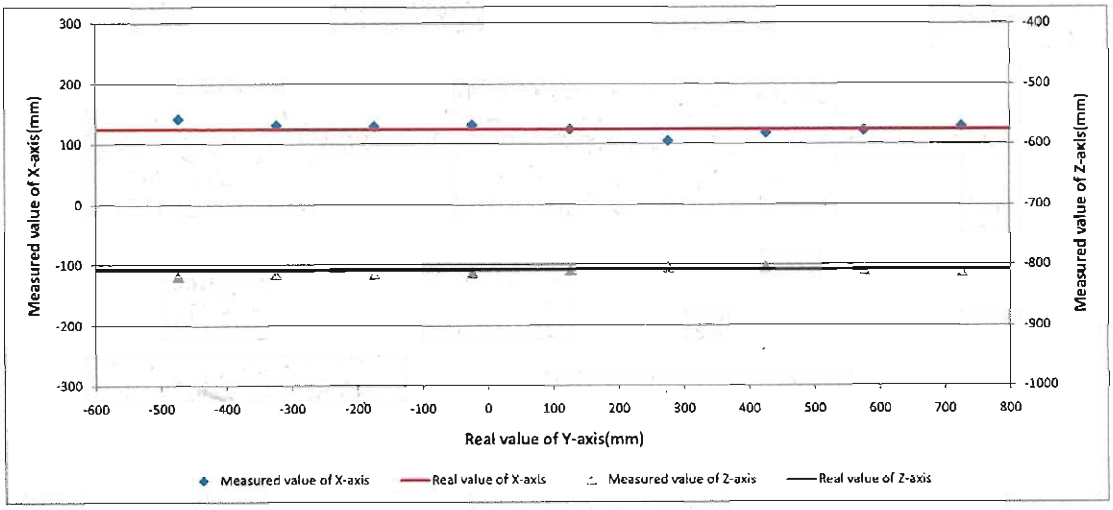


Fig 3.27 Measurement result relevant to Y-axis



(a)



(b)

Fig 3.28 Average value of measurement relevant to Y-axis

(a) value of Y (b) value of X and Z

3.7.4 Experiment for relation of location estimation and attitude

The purpose of this experiment is to examine the effort of attitude of camera on result of measurement. Because for a certain location, the sight line of camera, in whose viewport LED tubes could be detected, is almost determined, and all of the available attitude are limited by just rotating camera about the Z-axis of camera reference system, which is also the sight line (Figure 3.29).If the camera is rotated a little about the X-axis or Y-axis, it tends to miss capturing the tubes.

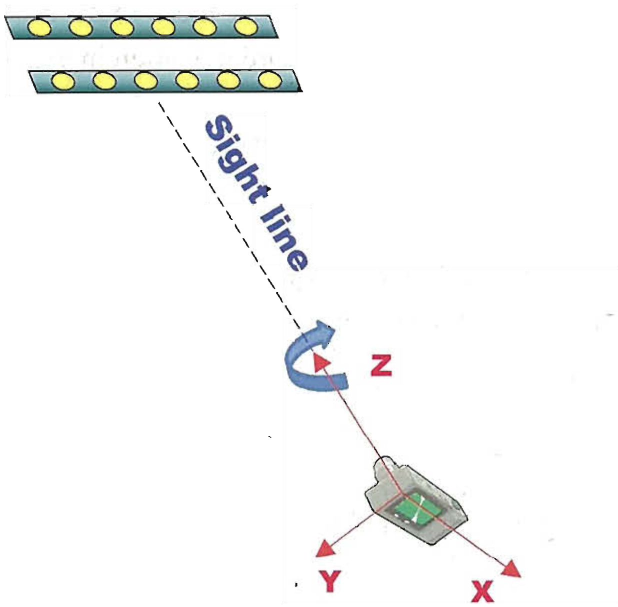


Fig 3.29 Available attitude for detecting tubes

In this experiment, the camera is rotated about the sight line for one cycle, and the sampling position is at the vertexes of a two by two grid with 4 cells, whose size is 22.5cm by 22.5 cm. Result of measurement is showed as Figure 3.30 and the four different colors describe four orientations of X-axis in general.

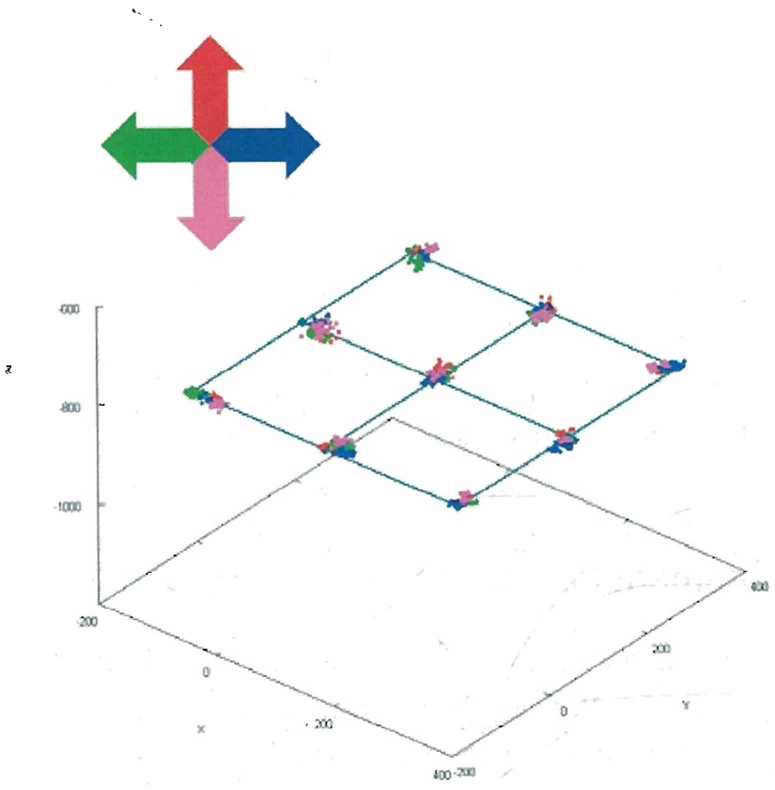


Fig 3.30 Result with various attitudes

Result of this experiment shows that there is no obvious effort of attitude on location estimation. The maximal standard deviation in experiment is about 17.8mm.

3.7.5 Experiment for attitude estimation

The purpose of this experiment is to test the error of attitude estimation. In this experiment the author adopted a tripod equipped with protractor (Figure 3.31). Camera is fixed on the topmost arm.

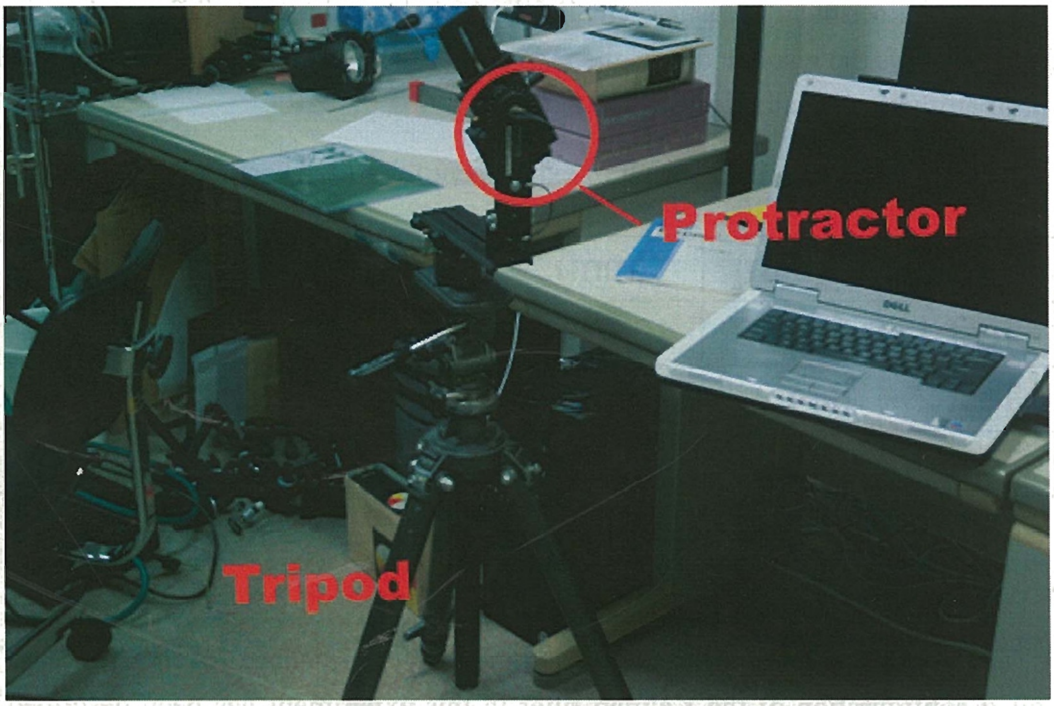
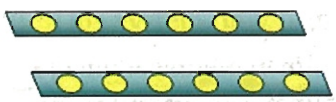


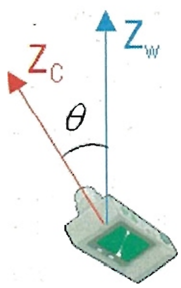
Fig 3.31 Tripod equipped with protractor

Because the real direction of X, Y axis of camera is not easy to measure and it is likely to involve new error even greater than this system. Here the author only considers about the obliquity of camera, whose value could be directly read on the scale of protractor. In Section 3.4.2 we obtained the rotation matrix **R**, whose third column is the vector of Z-axis of camera relative to world reference system. The angle from plumb line to Z-axis of camera could be worked out by computing dot product of the two vectors (Figure 3.32).



$$R = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}$$

$$Z_c$$



$$\theta = \arccos \frac{Z_c \cdot Z_w}{|Z_c| \cdot |Z_w|}$$

Fig 3.32 Computation for obliquity of camera

In this experiment measurement is repeated three times at different locations. Table 3.5 shows the result and θ_0 is the indication of protractor. Result implies that the error of attitude estimation is less than 2 degree.

Table 3.5 Result of experiment for attitude estimation

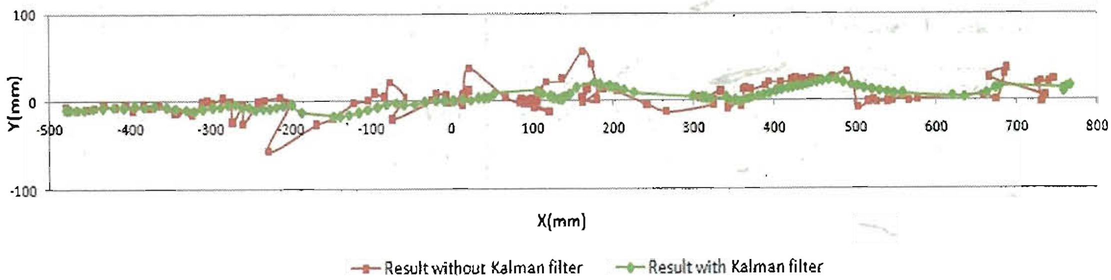
	X(mm)	Y(mm)	Z(mm)	θ(°)	θ_0(°)
Test 1	96.099	1048.4	-729.46	51.58	53
Test 2	844.23	85.606	-733.5	41.64	43
Test 3	313.64	448.23	-731.83	29.1	30

3.7.6 Experiment for Kalman filter

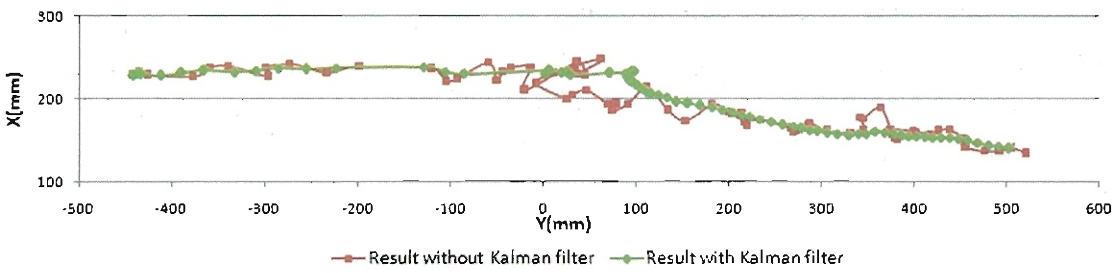
The goal of this experiment is to examine the performance of Kalman filter. The detailed configuration of the Kalman filter in this experiment has been described in Section 3.5.1.

In this experiment, camera is held by hand and moved horizontally. The moving speed is maintained by people to remain roughly constant. Experiment is performed twice and the moving direction is the orientation of X axis or Y axis relative to world reference frame (respectively). What needs a specification is, the direction is also judged by people without precise measurement.

Both of the continuous result of original estimation and the result processed by Kalman filter are recorded. Figure 3.33(a) shows the result of experiment in the direction of X axis and Figure 3.33(b) shows the result in the direction of Y axis.



(a)



(b)

Fig 3.33 Result of Kalman filter

(a) in the direction of X axis (b) in the direction of Y axis

3.8 Conclusion

We proposed a new positioning system using ID modulated LED tube lights and computing terminals equipped with a basic camera. The aim was to provide an exact positioning service with few requirements and at low cost. The strengths of this system are as follows.

This system is imperceptible to users and has no negative effect on interior scenes.

1. Additional markers or base stations are unnecessary.
2. Installation is done merely by replacing the fluorescent tube.
3. Without the need for any logic element, the circuit is simple.
4. These are no requirements for special sensors, such as high frequency receivers.
5. This system only uses a camera with normal shuttering, so it is available with using a camera available on like a cell phone or PDA.
6. Results of the evaluation experiments show that the error in measurement is expected to be less than 10 cm in practical applications. This degree of accuracy is adequate for most applications.

Firstly, as mentioned in Sect. 3.3.3, the amount of available ID numbers exceeds one million. With a conservative assumption that the average area shared per one LED unit is around 4 m^2 in indoor environment, the available ID can be deployed in a large region up to 4×10^6 m^2. The total floor space of Yokohama-Landmark Tower, which is the tallest building in Japan, is 1.6×10^6 m^2. Thus, the proposed system could provide sufficient unique ID numbers in most cases. Secondly, it has been discussed in Sect. 3.1 that the system can provide positioning service seamlessly between two consecutive LED units. As stated above, we think the proposed system is feasible for various indoor position-based applications.

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➢ Chapter 4

ID recognition of embed code by using motion blur

4.1 Introduction

In previous work, in order to capture the ID pattern of an LED tube that is flashing at a high speed (60 Hz in the experiment), camera exposure time is set so that it is far shorter than the flash period (about 2 ms in the experiment). However, most of off-the-shelf camera phones do not provide the ability to adjust exposure time. In this chapter, we introduce a novel method to conduct ID recognition with normal exposure time by producing a motion blur.

4.2 Related research

Adding ID tags to real objects is a key requirement for the proposed system. In general, the tags in these studies can be divided into two types: radio frequency identification (RFID) tags and visual tags.

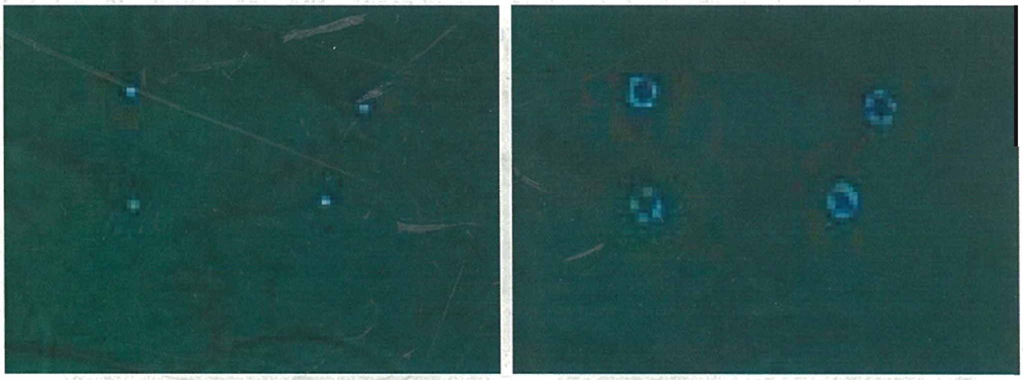
RFID tags [4-1] are attached to an object transmit modulated radio waves that can be received by a nearby reader. The use of RFID tags suffers a lack of directionality and distance accuracy, which impedes the 3D performance for some applications that require knowledge of the location.

One such example of visual tags is barcodes, which can be printed on commercial goods for stock control or painted on walls or roads to convey location information. Barcodes are usually decoded using flying spot scanning with a single photodetector. Recent works put forward plenty of two-dimensional (2D) codes, which are decoded using cameras. They include quick response (QR) code [4-2], data matrix [4-3], and Bokode [4-4]. As a 2D sensor, a camera has the potential to provide spatial information for achieving the relative position from tags. Various kinds of barcode are shown as Figure 4.1.

(a) (b) (c)

Fig 4.1 Various kinds of barcode
(a) 1D barcode (b) QR code (c) Data matrix

Different from printed codes, which only exploit the spatial signal, the use of lighting devices can introduce a new dimension of temporal signals. Lighting signaling can be divided into two types. One that uses a high-speed flickering pattern and a high-speed image sensor [4-5] and the other that uses video-frame-rate image sensors corresponding to a low-rate source [4-6, 4-7]. In general, the frame rate of the sensor should be more than twice the flicker rate of the light source. However, if the flicker rate is less than 30 Hz, the human eyes will inevitably sense the flicker effect. Therefore, with a normal exposure time camera, it is usually hard to capture the information embedded in the imperceptible flickering of an optical marker. Nishiura et al. [4-8] used a fast-moving camera to capture the temporal signal of a modulated LED with only one frame. The content of the signal is presented in the form of a motion blur, and a motor is used to drive the motion of the camera. This method allows the camera exposure to be longer than the blink period of an LED.



(a) (b)

Fig 4.2 Moving Focal Plane Optical ID Maker [Nishiura et al.]
(a)captured ID marker with still camera (b)captured ID marker with moving camera

Similar to Nishiura's work [4-8], the method introduced in this chapter also moves the camera during the exposure. In our proposed system, the LED tube is partitioned into several segments, and the on/off states of these segments are arranged in a specific pattern to convey a specific ID message. We designed a simple circuit that continuously switched an LED tube, ON and OFF, at a high-speed rate (depending on the frequency of the current), first by creating a specific pattern and then its complement. To the human eye or a camera without movement, all LEDs appear to be constantly lit. However, when we shake the camera during the exposure, the imaging positions of the LEDs also move on the imaging plane and a motion blur is captured. Therefore, if the moving direction is approximately perpendicular to the length of the LED tube, a streaked pattern resembling a barcode will be captured, which describes the temporal variation of LEDs within one frame. In contrast with the research of Nishiura [4-8], the movement of the camera is not restricted in our study; thus, making it available for manual operation.

4.3 Using motion blur for expressing ID pattern

In this section, at first the method of ID modulation in our system is introduced. Then the reason why motion blur is needed and the operation how to producing motion-blurred image is depicted.

4.3.1 ID marker in proposed system

Before explaining the usage of blur in our system, we discuss the ID modulation method. One LED tube consists of several separate lamps. If the ON/OFF switching of the lamps occurs in a specific pattern, the whole tube can be used to transmit a specific message. In our research, we use an AC commercial power source to directly drive the flashing of the lamps so that the tube switches between two patterns: the positive pattern and the negative pattern, which are complement of each other. The flashing rate is significantly fast (in our experiment, the frequency is 60 Hz as determined by the local commercial power supply) so that all lamps appear to be of the same brightness.

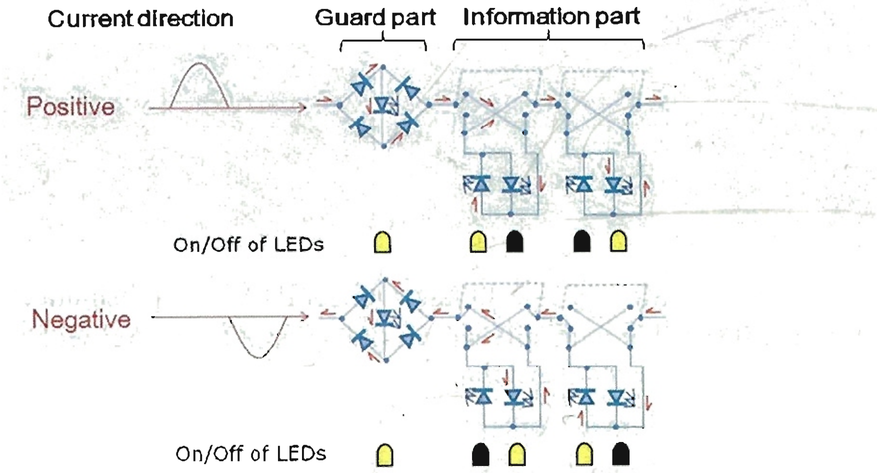


Fig 4.3 A section of the circuit for Manchester coding

Furthermore, we adopt Manchester coding to encode the message. In this method, two consecutive lamps express one digit of information. The main merits of this method are that it provides equal illumination, and it allows an extremely simple circuit with high-power efficiency. This circuit is implemented on our designed prototype model for experiments (Section 3.3.2). Figure 4.3 uses a section of this circuit to show how it works. In this figure, both the guard part and the information part are shown. The guard part is always ON to indicate the endpoints of the tubes, and the state of information part reverses with the change of current direction. The switches are used for changing the binary value of the one digit indicated by this pair of lamps. Because there is no need for a micro controller, the cost of this system reduces further.

4.3.2 Motion-blurred image

In this chapter, motion blur is used to enable a camera with normal exposure time to recognize the ID information from the imperceptible flashing of LED tubes, which is modulated as described above. Moreover, our research seeks to allow motion blur to be produced manually by users. Figure 4.4 shows a still image and a motion-blurred image of the LED tubes from our experiment. The blurred image was captured by shaking the camera manually during the exposure. The experiment was conducted in an environment with normal illumination, and the auto-gain function of the camera made the image background quite dark because of the high intensity of the LED lamps. We can see that the motion blur creates a streaked pattern, which is similar to a barcode and has the potential for conveying ID information. In our experiment, in order to estimate the exact position and orientation, we employed a unit with two parallel tubes to provide more accurate spatial information. If only a single tube is used, the result is an approximate position close to the tube, which is accurate enough for some applications.

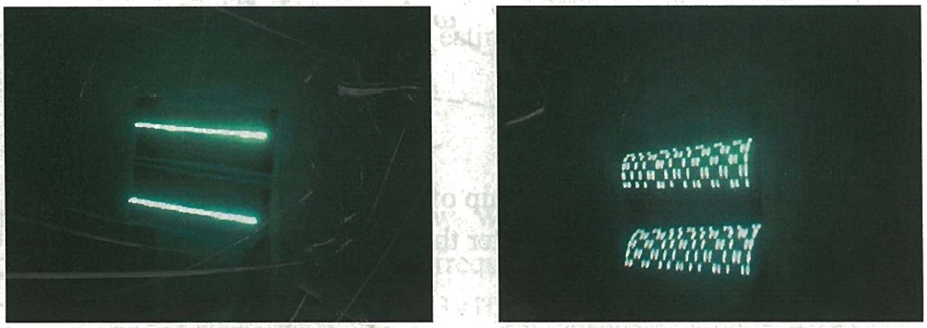


Fig 4.4 A still image (left) and a motion blurred/streaked image (right)

4.3.3 Operation for producing motion-blurred image

Considering that the ID information is implied in the direction along the LED tube, the blur direction needs to be as close to perpendicular direction of tubes as possible, so that the projection of tube at certain moment can be expressed clearly without the interference from other moment. If blur direction is along the tube, there will be a long bright line rather than streaked pattern and no available pattern for ID recognition. Besides the blur direction, the moving speed of lamps on images and distance from the camera to the tubes, also affect the quality of ID information embedded in images. Generally speaking, the long and linear blur makes the streaked pattern more clear and more potential for ID recognition. An analysis about how the system parameters are related to the length of the motion blur is introduced as following.

To enable robust ID recognition, the streaked pattern needs to be as clear as possible. This means the path of the LED lamps on captured images should be long enough for unambiguous detection. An analysis is to be developed for the study of how the system parameters are related to the length of the motion blur.

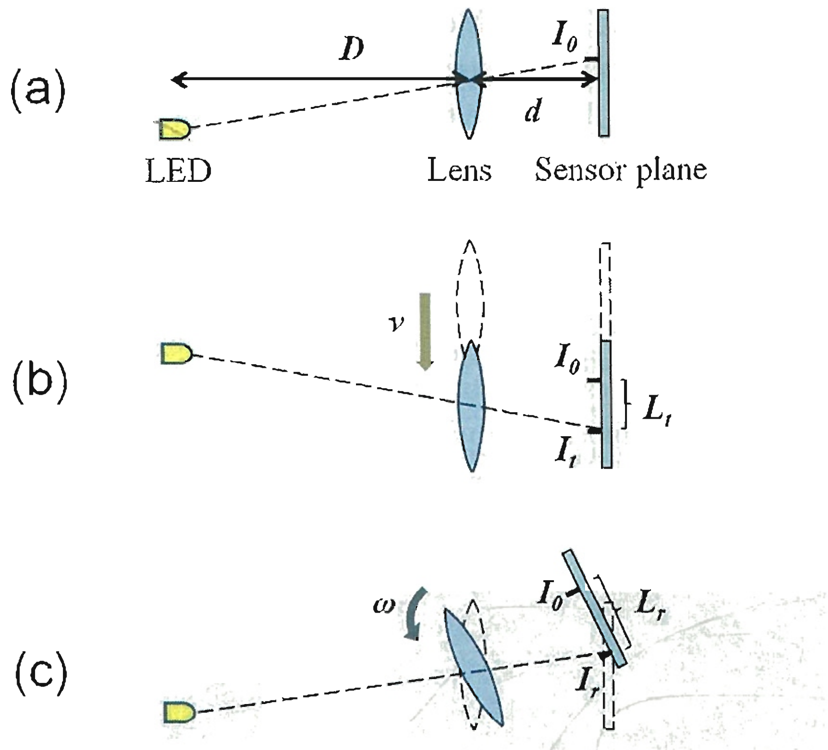


Fig 4.5 The relationship of camera motion and blur
(a) the initial status (b) the status after the translation (c) the status after rotation

The camera motion can be decompounded to be a translation compound and a rotation compound. Regarding the motion direction, with simple analysis we found that the lateral translation produces a longer blur than the translation towards the LED tubes. Moreover, camera yaw and pitch could provide the proper shape of the blur for ID recognition rather than camera roll. We conducted a simple imaging model to study cases when the camera is moving laterally and when its yaw or pitch are rotating. The results are illustrated in Figure 4.5. In this study, we do not differentiate between yaw and pitch, because they do not make a difference when producing a motion blur.

In Figure 4.5:

D perpendicular distance from the camera lens to the object (m);

d distance between the lens and the camera sensor plane (m);

v speed of translation (m/s);

ω angular speed of rotation (rad/s);

I_0 imaging position of the object at the start of the time duration;

I_t imaging position after some time of camera translation has past;

I_r imaging position after some time of camera rotation has past;

L_t length of motion blur on the image produced by translation (pixels);

L_r length of the motion blur on the image produced by rotation.

In addition, the following terms are defined:

t the passage of time (s);

p pixel width on the sensor plane (m);

We assume that the v and ω are constant within one exposure. For the camera translation, the Lt is expressed as

$$L_t = vt\frac{d}{D}\cdot\frac{1}{p} \tag{4-1}$$

For the camera translation, because there is only a slight change in angle within one exposure, we take the approximate estimation assuming the D constant, which can be expressed as

$$L_r \approx \omega td \cdot \frac{1}{p} \tag{4-2}$$

A numerical example is given below. We calculate the length of blur produced within one pulse of the AC source. The frequency of the AC source is 60 Hz, so the duration of one pulse is 1 / (60 × 2) = 8.33×10−3 s. The camera pixel width is 7.4 μm, which is 7.4 × 10−6 m (the resolution of the camera is 640 × 480). The distance between the lens and the camera sensor plane is 6.3 mm, which is 6.3 × 10−3 m. The perpendicular distance from the camera lens to the object is 1 m.

With some simple tests, we found that the human hand could provide a speed of about 1 m/s and an angular speed of about 2π rad/s. Therefore, the length of motion blur produced by translation is

$$L_t = \frac{1\times 8.33\times 10^{-3}\times 6.3\times 10^{-3}}{1\times 7.4\times 10^{-6}} = 7.1\,pixels$$

and the length of motion blur produced by rotation is

$$L_r = \frac{2\pi\times 8.33\times 10^{-3}\times 6.3\times 10^{-3}}{7.4\times 10^{-6}} = 44.5\,pixels$$

According to the results shown above, we made sure that the operation conducted as a rotation around an axis horizontal to the floor was more effective for producing a motion blur than the operation as a translation. Manual operation by users has the potential to produce enough long and clear streaked patterns for ID recognition; however, it would be difficult to produce blurred images suitable for ID recognition from the unconscious behavior of the users. The possible problems include that the motion direction is not suitable for creating a proper streaked pattern (almost parallel to the LED tubes), and the duration of the motion blur is not long enough.

We found that a manual operation could produce the motion blur effectively and steadily by rotating the hand-held terminal up and down monotonously. This operation only moves user's fingers holding the terminal, rather than the wrist or elbow. Figure 4.6 shows the way manual operation to producing motion blur. It is important to note that the camera should be pointed at the LED tubes, and the rotation axis is required to be parallel to the length of the LED tubes as much as possible. Section 4.5.3 discusses the details of this experiment.

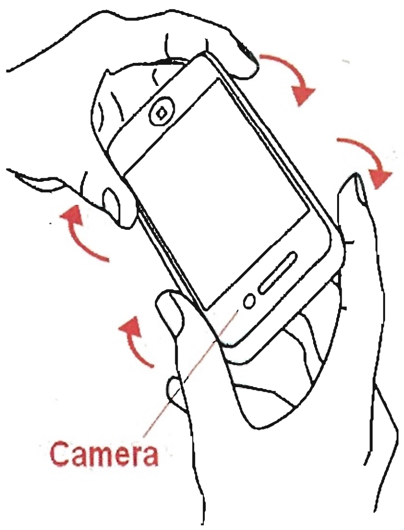


Fig 4.6 Manual operation for producing motion blur

4.4 ID recognition for motion blurred images

In this section, the details of how to retrieve ID number from motion-blurred images are introduced. In simple terms, our method can be divided to be three steps: (1) extracting information from multiple scanning lines; (2) retrieving ID number from each scanning line; (3) concluding the correct ID number from the retrieving result of each scanning line. The three steps are respectively explained as follows.

4.4.1 Scanning line

We retrieved the ID number by scanning the motion-blurred image. In this situation, "scanning" means extracting the linear samples from different positions and directions, and finding ones which contain ID information. The ID information is embedded in the linear arrangement of LED lamps. During the projection from three-dimensional (3D) space to 2D image, the linear property of ID information does not change. The intensity information of the pixels that make up the scanning line, is used to construct a one-dimensional (1D) pattern. Then the region of the LED lamps is extracted according to the intensity threshold (in our experiment, the value of the threshold was set to 220 based on the experience while the upper limit was 255). Finally, before retrieving the ID from the 1D pattern, we modified the histogram. Figure 4.7 shows the pre-processing for ID retrieval.

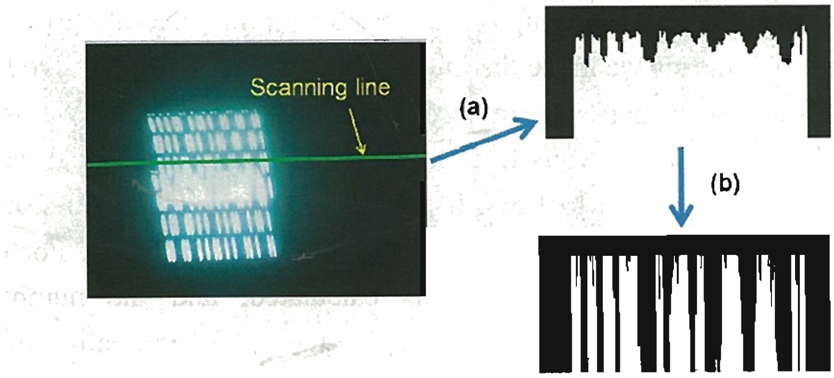


Fig 4.7 Pre-processing for ID retrieval
(a) 1D sampling (b) histogram modification

4.2 ID retrieving using template

We used template matching to locate the position of each LED lamp on one tube in the modified histogram. With this method, we were able to retrieve the ID information from the intensity of every area corresponding to the LED lamps. As mentioned in Section 3.3.2, in our system, ID information is encoded using the Manchester coding method. According to this method, we used a pair of lamps to express one digit of information, and the states of these two lamps must be opposite. Therefore, to match and locate the regions of the lamps, we used a template that consists of several segments corresponding to these pairs of lamps.

The template is shown in Figure 4.8(b). In our experimental setup, the number of segments n in one template was 15 which corresponds to the number of LED lamps. When the template was placed on the 1D pattern, each of the correlation values $\{C_i\}$, between each segment and the region of pattern in the modified histogram covered by this segment, were calculated. For each segment, the value of the right half was 1 and the value of left half was -1. Moreover, the accumulation, C_{sum}, of the absolute values of all the correlations, was determined by

$$C_{sum} = \sum_{i=1}^{n} |C_i| \tag{4-3}$$

If the segment was accordant with a pair of lamps whose states are different, the absolute value of correlation was expected to be significantly larger than other cases. Furthermore, the value of C_{sum} should have been maximum when the whole template correctly matched the region of lamps.

In order to find out the optimal matching, the template was transformed with three parameters: scale, shift, and skew. "Scale" means that we change the length of template from 0.9 to 1.1 at nine levels while we assume the length of 1D pattern to be 1. "Shift" means that we move the template along the direction of 1D scanning line from -0.1 to 0.1 at nine levels (the pattern length is 1) while we assume the origin position is that the central point of template coincides with the central point of 1D pattern. Finally, "skew" means we make the intervals between two consecutive lamps gradually change when the camera is pointing to the ceiling at an angle. We use the ratio between the intervals at two ends to describe the degree of skew and we still change it at nine levels from 1:1.5 to 1.5:1. In our experiment, we use full search to find out argmax(sh, sc, sk) and it is considered to be optimal matching. For every combination of three parameters the C_{sum} is calculated, and the number of computation times is 9×9×9 = 729 times. To calculate the correlation values of each segment, an integral function was used to reduce processing time. Figure 4.8 shows the whole process of ID template matching. In Figure 4.7(c), (sh, sc, sk) stands for the hybrid coordinate axis of the three parameters scale, shift, and skew, respectively.

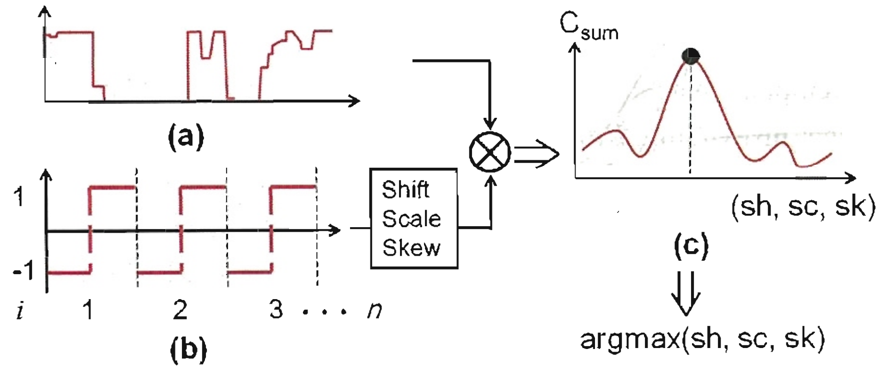


Fig 4.8 The template matching process
(a) modified histogram (b) template for matching (c) matching result

The detail of three parameters is shown as Figure 4.9. According to above processing, optimal set of (sh, sc, sk) can be obtained. Figure 4.10 shows the result of searching for optimal marching.

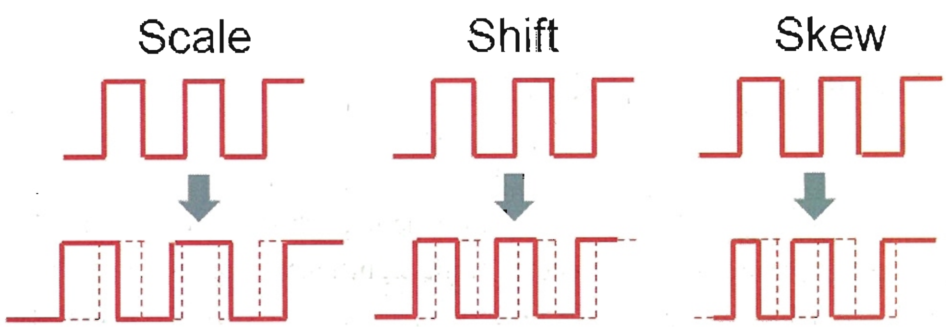


Fig 4.9 Three parameters for transforming

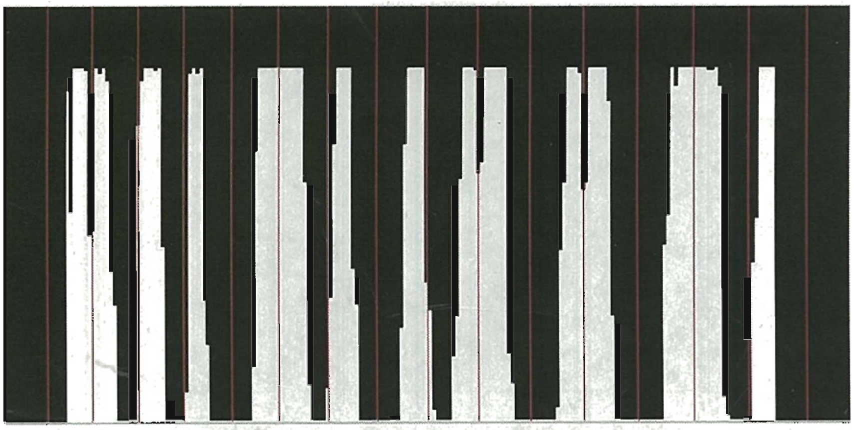


Fig 4.10 Result of template matching

After finding out the optimal matching, we defined an evaluation value to judge whether the result is really the ID pattern or not. This evaluation value is named E, and the computational method is described as Eq.(4-4). This equation uses the normalization of a standard deviation to indicate the dispersion degree of $\{|C_i|\}$. In the ideal case, the dispersion degree equals to zero. If the value of E is close to 1, the result is likely to be a true example.

$$E = 1 - \frac{Stdv\{|C_i|\}}{Ave\{|C_i|\}} \tag{4-4}$$

4.4.3 Concluding ID from an image

We introduce the strategy of how to scan the motion-blurred image. It is easy to reach an inference that the position and direction of the LED tube on the image should be limited within a certain range because of the camera shaking way. If the motion were outside this range, then the retrieval of ID information from captured images would be difficult. Considering manual operation method introduced in Section 4.3.3, we selected all of the sampling spots from the vertical midline of each image, and each scanning line goes through one of the sampling spots. At each sampling spot, multiple scanning lines were tested in different directions, and only the example with the highest E value was recorded (Figure 4.11). The spot and direction used for the sampling intervals are respectively 8 pixels and 5 deg, and the scanning line direction from one spot ranges from −25 deg to 25 deg.

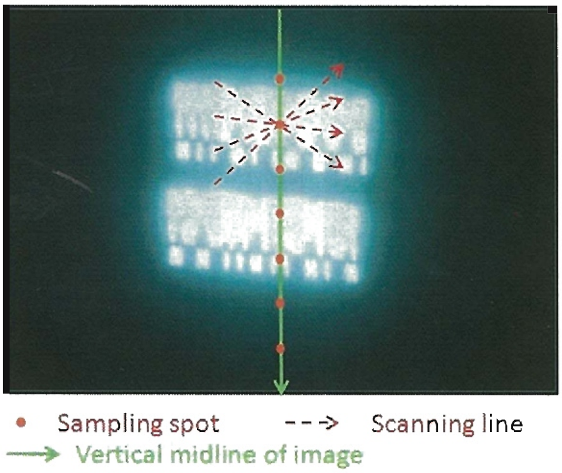


Fig 4.11 Scanning a motion-blurred image

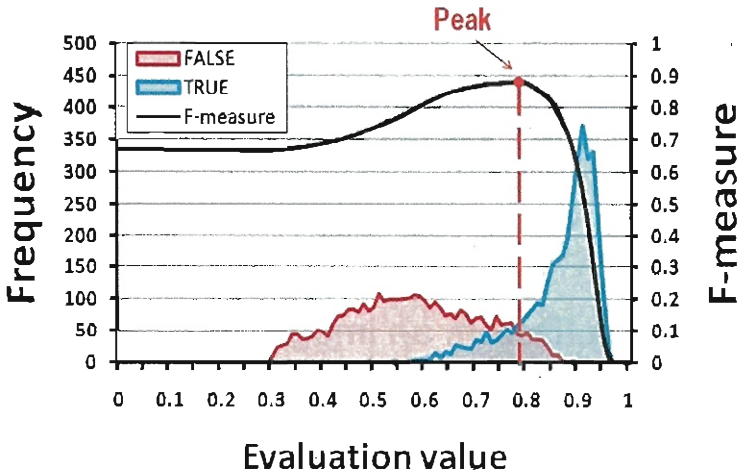


Fig 4.12 Frequency distribution of E values

We used a threshold to filter the values of E to distinguish true examples from false examples. The threshold value was decided by a preliminary experiment. An image sequence with 400 frames was scanned sequentially by using the method described above. When compared with known ID information, recorded examples can be identified to be either true or false. The results of our preliminary experiment are shown in Figure 4.12, which shows the frequency distributions of E values associated with true and false examples.

The threshold is decided according to F-measure, the harmonic mean of precision and recall.

$$F-measure = 2 \cdot \frac{precision \cdot recall}{precision + recall} \tag{4-5}$$

In Figure 4.12, the lateral axis value, which corresponds to the peak of F-measure, is considered to be the threshold. As an approximate result, 0.8 is selected as the threshold value. In the preliminary experiment, of all the examples that passed the threshold filtering, the percentage of true examples was 94.3%.

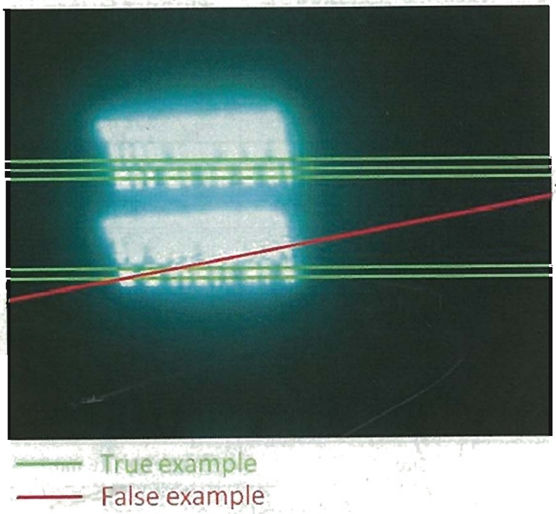


Fig 4.13 Results of threshold filtering

Although for one image the filtering result is possibly mixed with false examples (Figure 4.13), the number of true examples with same retrieved ID is normally larger than that of false examples with same retrieved ID. Therefore, for one image, among the retrieved ID numbers the two numbers that have the highest frequency are considered to be the true IDs. After further assessments, such as an error code check and a relative position check, these two ID numbers compose the ID of the whole unit.

4.5 Evaluation experiment for ID recognition

This section describes the experiments and the results for evaluation ID recognition method. Section 4.5.1 is the introduction of system configuration; Section 4.5.2 is the experiment for comparing the recognition rate between still images and motion-blurred images under different exposure time; Section 4.5.3 to Section 4.5.5 is the experiments for investigating the recognition rate under varying conditions; Section 4.5.6 is the experiment for untrained users; and Section 4.5.7 is conclusion for experiments.

4.5.1 System configuration

The parameters of the prototype system in our experiment are shown in Table 4.1. This prototype system consists of a unit of LED arrays, which has been introduced in Figure 3.22, and a notebook PC equipped with a camera.

Table 4.1 Parameters of the prototype system

Unit of LED arrays	
Length of tube	275 mm
Distance between two tubes	152 mm
Amount of lamps per tube	28
Frequency of flicker (AC source)	60 Hz
Camera	
Field of view	30 deg
Resolution	640 × 480
Shutter rate	30 Hz
Exposure time	33 ms
Size	72 × 60 × 16 mm
Notebook PC	
CPU	Inter core i5 2.67G
Memory	4.0 GB

In the experiment, the prototype unit of LED tubes was fixed on the ceiling. A web camera was used as the image sensor because its size was similar to that of a mobile phone and a user could shake the web camera in a way that was similar to shaking a mobile phone. The distance from the camera to the ceiling was about 1 m, and a notebook personal computer (PC) was used as a processor. The processing time for retrieving the ID number from one frame was about 83 ms on average.

4.5.2 Alteration of the exposure time and comparison with still images

We captured both two types: still images and motion-blurred images, which are under different exposure time. The shutter rate was always set to be 30 Hz. For every different combination of capturing types and exposure time, about 400~500 images were captured. The Figure 4.14 shows the experimental result.

From the experimental results, we can see when exposure time is more than 10 ms, the still images are no longer being feasible for ID recognition. Otherwise, the recognition rate with motion-blurred images keeps on a high level.

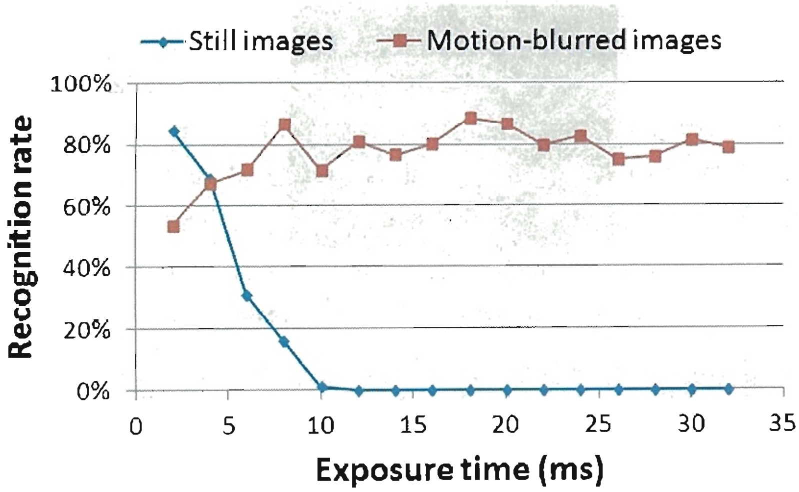


Fig 4.14 The experiment with alternations of exposure time

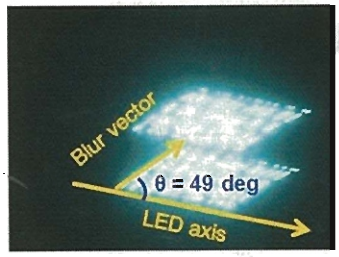
4.5.3 Alteration of the blur direction

In this experiment, the images are classified according to the angle between the blur direction and the direction along the tube, and for each level, the recognition rate and the average E value of true examples are calculated. The results are shown in Figure 4.15. The number of testing frames is 1200.

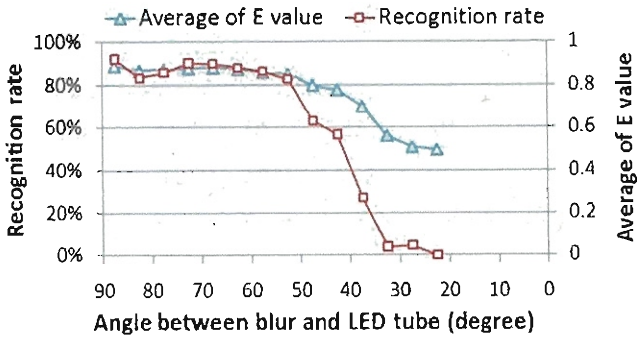
From the results of the experiment, it can be seen that two evaluation indices generally get smaller as the angle decreases. In addition, near the angle of 45 degree, there is a quick drop of the recognition rate. The reason is that if the angle gets sharp, during the exposure time, the position of certain lamps at a certain moment would be superposed by another lamp at another moment on the image. This problem makes ID retrieval difficult. It can be expected that the effective range of the angle is between about 50 degree and 90 degree.

4.5.4 Alteration of the blur length

The motion speed of the camera also affects the recognition result. In this experiment, we used the length of the motion blur to reflect the motion speed. We defined that for one image the blur length is the average width of the streaked pattern areas that correspond to one pulse of AC supply. The results are shown in Figure 4.16. The number of testing frames is 1200.



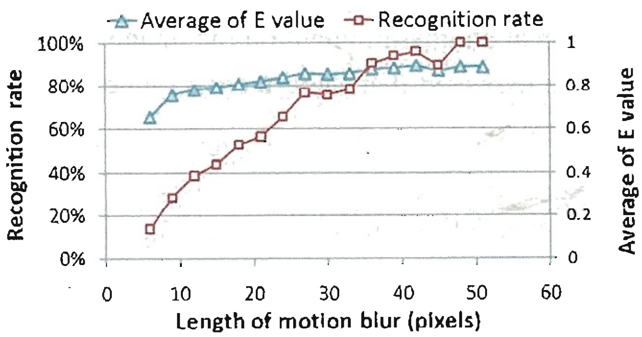
(a) The example image



(b) Line graph of results

Fig 4.15 The experiment with alterations of blur direction

(a) The example image



(b) Line graph of results

Fig 4.16 The experiment with alterations of blur length

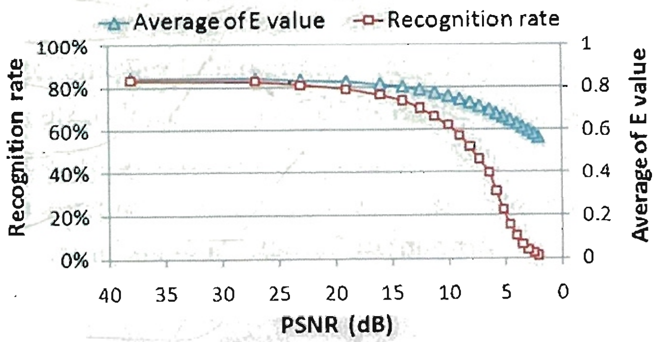
From the experimental results, it can be seen that two evaluation indices get larger as the blur length increases. These results occur because, if motion speed is low, the area on the image that corresponds to a dark LED lamp at a certain moment tends to be affected by both the area of the neighboring bright LEDs and the area that corresponds to itself at a previous pulse or next pulse when it is bright. Hence, the area of the streaked pattern where it is supposed to be dim becomes brighter. Namely, the streaked pattern is not clear enough for ID recognition.

4.5.5 Alteration of image noise

The characteristics of the camera influence the quality of captured images. One important factor is the image noise that is produced in signal gathering, quantifying, and transmitting processes. In this experiment, we added simulated random noise at different levels to the same image sequences, and we assumed that the image noise of the original images was zero. The results are shown in Figure 4.17. The number of original testing frames is 400, and 20 different levels of noise were added separately to all of the testing frames.

From the experimental results, we found that two evaluation indices get smaller as the image noise increases. When the image noise is lower than a certain degree, two evaluation indices do not make obvious changes.

(a) The example image



(b) Line graph of results

Fig 4.17 The experiment with alterations of image noise

4.5.6 Recognition results from untrained users

The purpose of this experiment is to study the performance when untrained users conducting the ID recognition. Nine students in their twenties participated in this experiment. None of the subject had the experience of manual operation of this system and they behaved according to a brief oral instruction. For each subject about 1000 images were captured. Experiment results are shown in Figure 4.18.

We can see that the untrained users are possible to shake the camera at a proper direction (within the range 60 deg ~ 90 deg). However, the recognition rate is not a high level comparing to experienced user. The main problem is that they could not control the shaking speed and the direction of camera optical axis well. Here we use the recognition rate with several consecutive frames to evaluate the performance. The consecutive frames are considered to be a set and ID recognition is conduct with this set. We study the recognition rate with different amount of frames in one set. Figure 4.19 shows the result.

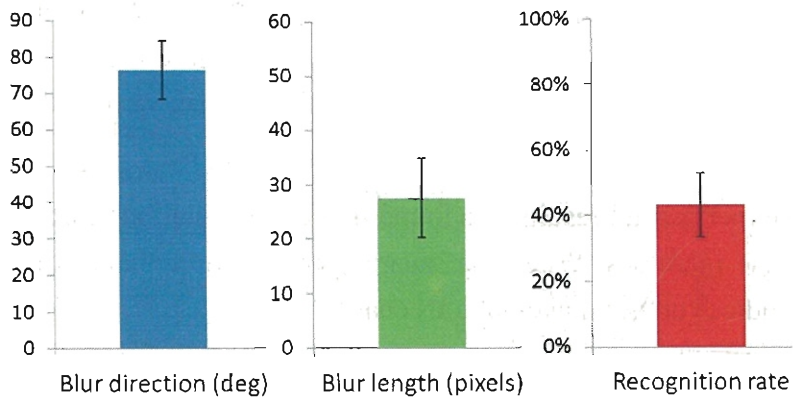


Fig 4.18 The experiment for untrained users

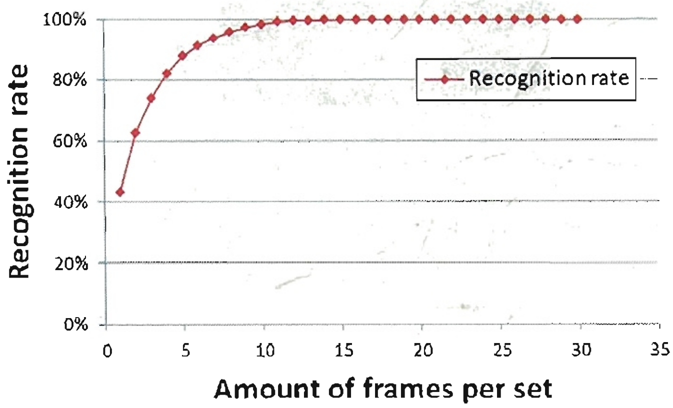


Fig 4.19 Recognition rate for set of consecutive frames

If we conservatively assume that the processing speed is five frames per second, we can see that the recognition rate reaches 100% when even an untrained user shakes the camera for three seconds.

4.5.7 Conclusion of ID recognition experiment

Section 4.5.3, 4.5.4 and 4.5.5 show that, for any parameter of the blur direction, the blur length, or image noise, there is a considerable range within which the recognition rate can become more than 80% and the amount of false acceptances was zero.

It is obvious that the controlling of camera optical axis is important. If the LED tubes are not included in the view field of camera, the captured image is not available for ID recognition.

Section 4.5.6 shows the experiment studying the performance of untrained users. Despite that the untrained users yielded a low recognition rate with one frame, the recognition rate with set of consecutive frames reaches 100% when continues capturing for more than 3 seconds. Therefore, users do not need experience and much attention to be able to access the ID number of tube lights that are close to them.

4.6 Position estimation from motion-blurred images

In this section, the method of position estimation from motion-blurred images and the experimental results are introduced.

4.6.1 Method introduction

Using the ID number of the LED tube unit, the system has already achieved an approximate position of the user. However, for some applications, such as spatial querying in one room, accurate position and orientation is necessary. In this section, we attempt to conduct position estimation from motion-blurred images. It is possible to achieve the camera position from still images by detecting the endpoints of the LED tubes on image. In order to distinguish the two tubes of the same unit, the tracking information from the preceding motion-blurred image is required. However, because of the phenomena of "blooming" caused by the imaging mechanism of the camera, it is difficult to locate the endpoints of the tubes correctly from the massive overexposed regions in the still image (Figure 4.20). In this case, a large error may occur when estimating the position, due to the difference between the estimated position of the endpoints and their actual position.

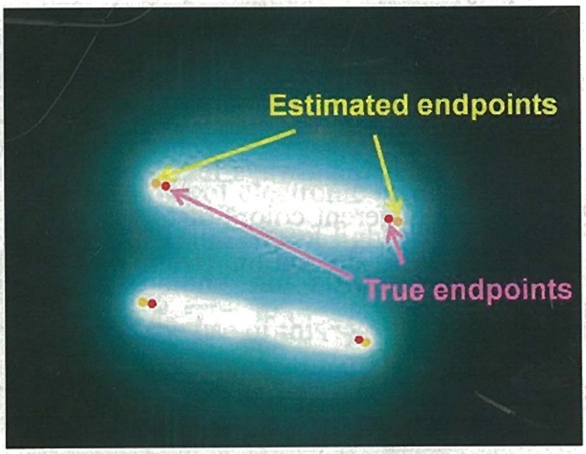


Fig 4.20 Locating the endpoints of LED tubes from a still image with over-exposed regions

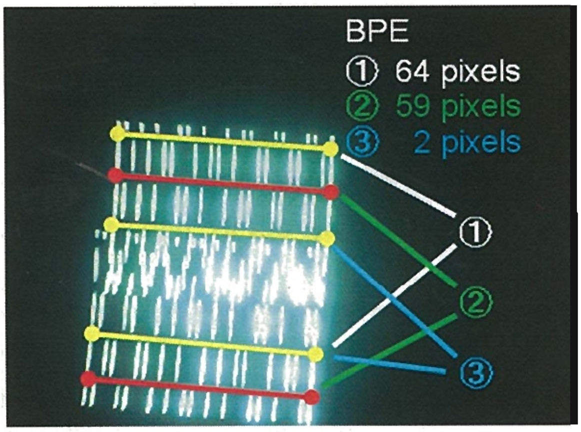


Fig 4.21 Using the back projection error to filter out the wrong pair of lines

However, it is possible to locate the position of tube endpoints accurately on a motion-blurred image. The line between two pattern regions corresponding to different AC source phases must occur at the instant when current direction changes. The lines between an adjacent positive region and a negative region are extracted using dense scanning, and the possible pairs of two lines respectively corresponding to each tube are used to estimate the camera position. Among all of the pairs of extracted lines, some are not correct combinations, and it is necessary to analyze the results. At first, we filtered out the impossible pairs according to the direction of alternation. For example, the pair of two lines both representing the current direction alternation from positive to negative was consider to be a possible pair. With the four endpoints, the camera position and direction is estimated as a P4P problem [4-9]. After estimating the position from a pair of lines, we used the back projection error (BPE) to further judge whether the pair was correct or not. "Back projection" is locating the positions of endpoints on image when camera is at the estimated position and direction, and "back projection error" is the difference between located positions and original location. The BPE is expressed as the summation of differences corresponding to four endpoints, and we use the size of one pixel as a unit of length. In our preliminary experiment, when the pair was correct, the sum of the back projection error for all four points was always less than 3 pixels. This processing is shown in Figure 4.21. The two different colors of the extracted lines denote the two different directions of AC source alternation (from positive to negative or from negative to positive).

4.6.2 Evaluation experiment for position estimation

The precision of the position estimation with motion-blurred images was tested. The camera was held by the user and moved roughly in a circular trajectory around the unit of the LED tubes. While moving the camera, the user shook it in the proper direction to intermittently produce a motion blur. Then, in the captured frame sequence, both motion-blurred images and still images were observed. Before applying the location estimation to one frame, the identification for the motion-blurred frame and the still frame was conducted according to the shape of the bright area. A receiver of electromagnetic motion tracking system, FASTRAK, was attached to the camera, and the tracking results of FASTRAK were used as a reference to verify the accuracy of the position estimation. The distance from camera to the ceiling was about 1m. The tracking results are shown in Figure 4.22.

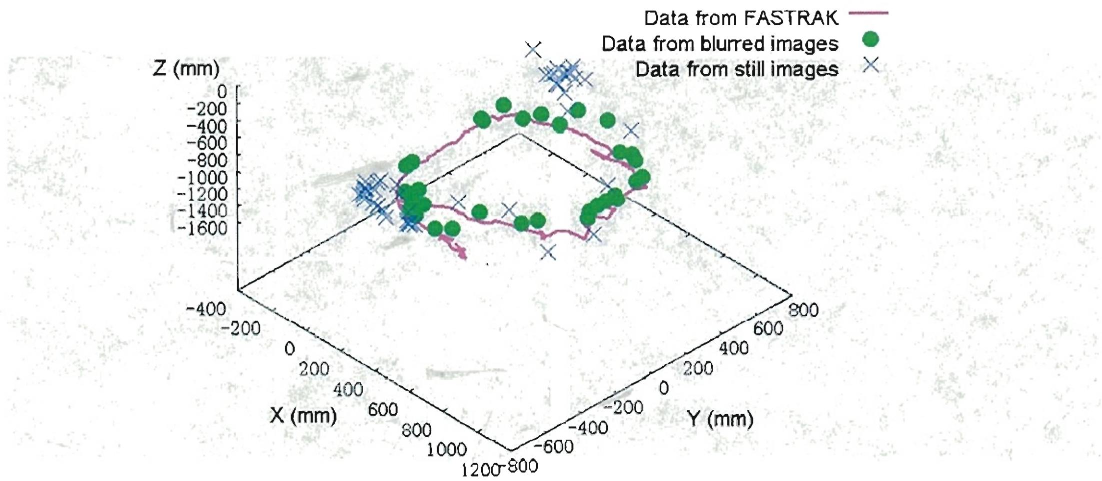


Fig 4.22 The results of position estimation experiment

The experiment shows that the positions estimated from motion-blurred images are more precise than the results from still images. In the experiment, the error of the results from motion-blurred images is less than 50 mm and it is expected that the maximum error would be less than 100 mm in practical situations. The average processing time for estimating the position from one motion-blurred image is about 300 ms.

4.7 Conclusion

The proposed system provides location information using unconscious optical markers without any modifications of electronic infrastructures. To install the system, one simply replaces conventional fluorescent light tubes with special LED tube lights. Because ceiling light infrastructures are already available at a large number of locations, it is easier to expand the use of this system into more areas rather than using radio or ultrasonic systems; especially, in locations where LED tube lights are expected to be the main source of illumination in the near future. Unlike the unsightly appearance of 1D and 2D codes, the proposed system does not require the attachment of any extra objects in these environments.

In this chapter, we focused on increasing the accuracy of localization and ID recognition when using a camera with an exposure time that is longer than the power supply cycle, which tends to create a streaked image. With the experimental model, the results showed that with a small amount of attention (pointing the camera at tubes and shaking it in the proper direction), an untrained user can use a mobile terminal camera to recognize the ID number of LED tube lights at a high recognition rate. This approach promises the possibility of expanding our system to off-the-shelf camera phones. Although we have not installed this algorithm for practical use on smart phone, we have confirmed that it successfully retrieved the correct ID from the image sequences captured with an iPhone 4 (Figure 4.23).

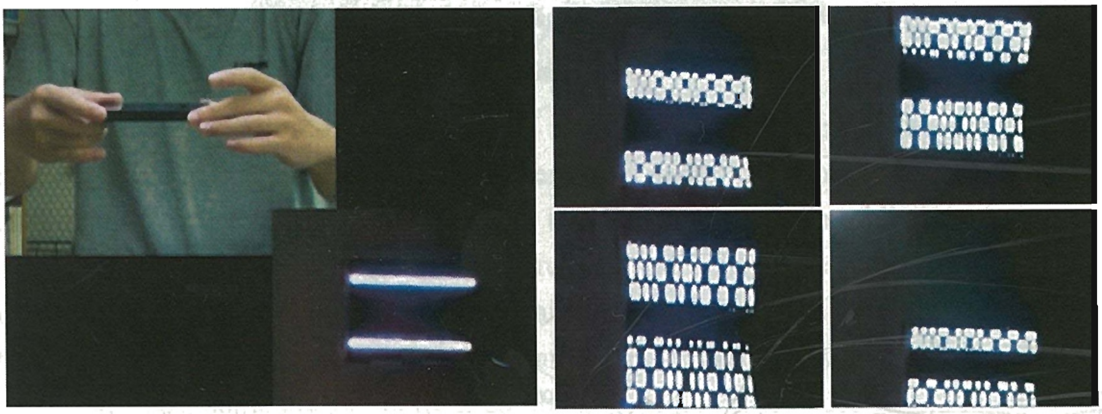


Fig 4.23 Experiment using iPhone 4 and captured pictures

There are still some problems, which require to be studied for installation in practical applications, such as depending on the other environmental lighting (for example, when a plastic panel or a louver covers the LED lamps), the specification of camera, or other conditions, the images captured of an LED lamp, could change and influence the reliability of ID recognition and the accuracy of localization. After we solve the above problems, the essential problem still remains that is, the trade-off problem between the reliability of ID recognition and the measurable area. The large-sized streaked pattern increases the reliability of ID recognition, but decreases the measurable area. We have to find a suitable balance for the view angle of the camera, which determines the above trade-off situation.

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➢ Chapter 5

ID mapping using pedestrian model for camera-based indoor positioning system

5.1 Introduction of the ID mapping problem

In order to make a positioning system work correctly, it is important to locate the reference objects in advance. This process is called offline positioning. In our proposed system, it is necessary to store the LED tubes with their correct IDs and positions in database. Since the reference object employed is the illumination infrastructure, the proposed system has a special point in comparison with other systems. The positions of the lamp holders relative to the building have been decided when the building structure was been designed. This is to say, it is easy to get the candidate positions of the LED tubes from the architectural CAD data. What needs to be done is registering the correct ID number to the candidate positions. The processing of registering ID to all LED tubes is called "ID mapping". As Figure 5.1 shows, it is necessary to make the ID of any LED tube in virtual map equal to the ID of corresponding LED tube in physical space (V1=P1,V2=P2,V3=P3). If this precondition is not satisfied, the system will not be capable for provide the user with correct positioning information.

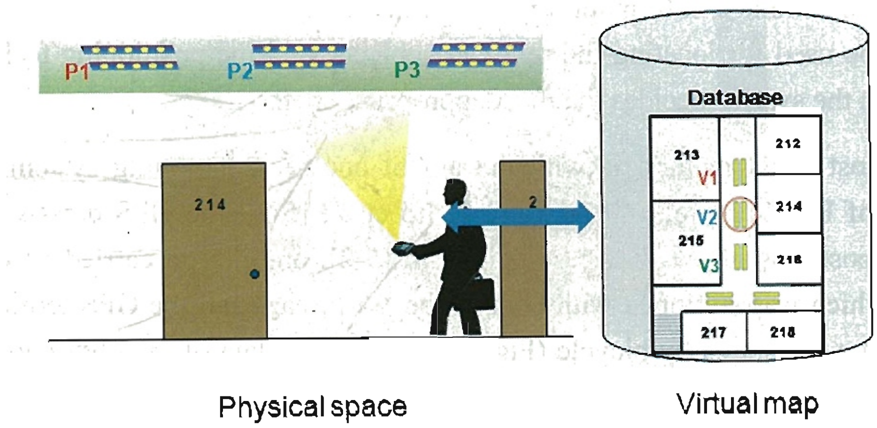

Fig 5.1 Relation of physical space and virtual map

There are two problems which are possible to cause the conflict between the IDs of LED tubes:

1. If the ID mapping is conducted by human work completely, the ID is possible to be registered at another tube rather than the correct one, or an in correct ID is registered.
2. One or more LED tubes are replaced with new tubes whose ID are different to the previous ones, and this replacement is without update in database. The cause of replacement may be that the tubes were broken after the initial installation and ID mapping.

With the purpose of reaching the correct ID correspondence, "pedestrian model" is proposed as an assistant to the ID mapping. By using this model, the wrong ID correspondence is possible be detected and the correct ID mapping can be estimated. The basic principle of this model is using the constraint of walking speed to evaluate the possibility of the distance between two LED tubes. As a simple example, if two ID were detected successively in a fairly short period, in physical place the distance between these two corresponding LED tubes can be expected to be short. Therefore, from the using record lists of the users, it is possible to find out the incorrect ID correspondence between the real world and the database. What is more, the database can update itself to correct ID mapping automatically by amending the incorrect correspondence. The detail of this proposed pedestrian model will be introduced in the following parts of this chapter. Simulation experiment is also operated to evaluate its feasibility.

5.2 Related research

As motioned above, for a positioning system, it is necessary to locate the reference objects in advance. Without their locations the system will not be able to provide the positioning information of the target object. There are various methods which can be used for locating the reference objects, and the positioning technology employed in the system decides the most appropriate method.

The most usual method is with the aid of another positioning system. In the researches of F. Alsehly et al. [5-1] and S. Ito et al. [5-2], the GPS data is used to decide the positions of Wi-Fi access points. In [5-2], one person carried a notebook computer which was equipped with both of the Wi-Fi card and the GPS terminal and wondered at a huge area by bicycle (Fig 5.2). A mass of data of the GPS coordinates and the unique MAC addresses of the detected access points are recorded as well as the signal strength. For each unique MAC address, the weighted mean value (the weight is correlative to signal strength) of the GPS coordinates is thought to be the position of the access point corresponding to the MAC address.

However, as discussed in earlier chapters, GPS makes large errors in indoor environment. In the research of D. Hahnel et al. [5-3], the positions of RFID tags are estimated by a moving robot at first. On the robot the laser rage finder is equipped as well as two RFID readers (Figure 5.3). The range finders can help the robot to understand its indoor position. The position of RFID is narrowed down step by step by analyzing the positions of robot when RFID tag is detected, as well as the strength and direction of received RFID signal.

Fig 5.2 Locating the Wi-Fi access points[5-2]

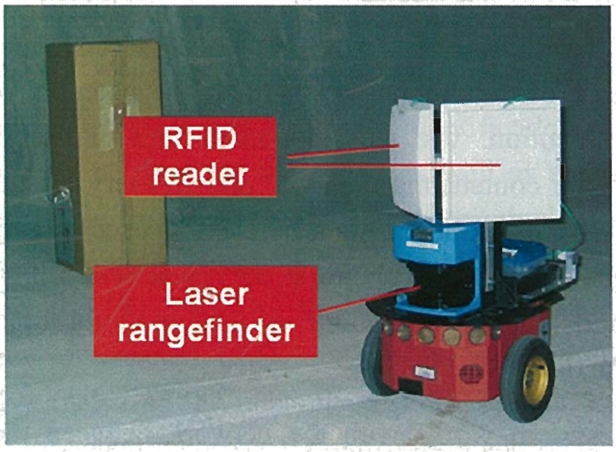

Fig 5.3 Robot for locating RFID tags [5-3]

Sensors of autonomous navigation also are used for more accurate map matching. In a research project conducted at the University of Melbourne the integration of map matching techniques within the Kalman filter like other navigation sensors such as GPS, gyroscopes, odometers, etc. was proposed as a means of providing additional measurements that can be used to improve position and attitude determination [5-4].

In some researches, part of the reference objects can be estimated according the other reference objects whose positions are known. For this method the precondition is that more than one reference objects can be detected simultaneously. In the research of [5-2], new access point can be located according other ones when users are utilizing this system. It is close to the method used in camera-based positioning system without artificial markers. In the research of [5-5], the position of newly detected feature can be estimated according other features in the view fields.

5.3 Web-based service

In recent years, high performance mobile terminal like smart-phone have been popularized widely. Moreover, the mobile communication technology and infrastructure have gained enormous development as well. In Japan, all of the main mobile communication service providers have deployed their respective 4G communication systems (Wimax, LTE etc.) and the base stations covers the inhabited regions where more than 99% of the nation population lives.

As a result, the number of web-based services and applications that are provided to mobile terminals has increased explosively. As a marked feature of the novel generation mobile communication system architecture, not only the services of operators, but also the services provided by other individuals or companies can be easily taken advantage of by the users [5-6]. With the application market of App Store [5-7] and Android Market [5-8], the application authors can conveniently publish their works to public. By now the number of applications on App Store has exceeded 500,000.

With the increase of the mobile applications, the potential of user involvement became been paid attention. The most common form of user involvement is the content provider in the content management and delivery architecture of proposed system [5-9]. In [5-10], the collected data by users is used in exploiting sensors and crowd for the AR games on mobile phone. In the research of T. FUKUDA et al. [5-11], the feedback of tourists via smart phone will be used for improving the tourism management of attractions.

The proposed system works with the network between the database and the mobile terminals. We postulate that the network is Internet which is most popular because the smart phone can easily connect to Internet via the mobile communication provided by the operators. The web-based architecture of proposed system is shown as Figure 5.4. The mobile terminals link to the server via the base station of mobile communication operators and Internet. The terminals transmit the ID of detected LED tubes and receive the current positions from the server. Multiple terminals can communicate with the server at the same time. GPS coordinate can be used for specifying the building when the GPS signal is available but the error is great. If the GPS signal is totally blocked by the concrete structure of the building, the approximate position of the building still can be narrowed down by employing the positioning technology based on the base stations of mobile communications. The user can also share his current position to other users via Internet.

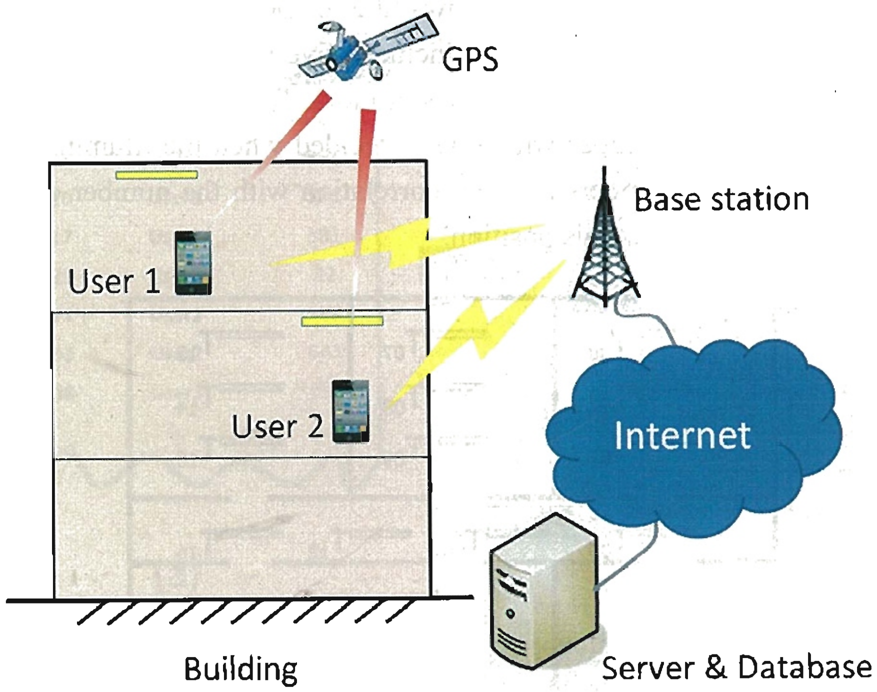

Fig 5.4 Web-based architecture of proposed system

We assume that the terminal sent its unique identification number and the time, when the LED tube was detected, to the server as well as the ID of detected LED tubes. Then detailed usage history including ID of terminal, ID of LED tubes and detection timings would be stored on database. With this kind of usage history, the time series of detected LED tubes by the same terminal can be extracted. This extracted time series of detected LED tubes is the precondition of our proposed pedestrian model. By analyzing the intervals between two detected LED tubes, it is potential to find out the latent incorrect ID registration and revised it. In next section the detail of proposed pedestrian model will be introduced.

5.4 Pedestrian model

In this section, the detail of proposed pedestrian model, as well as the method of using this model to find out incorrect ID registrations and reaching the correct ID mapping, is introduced. Subsection 5.4.1 introduces the indoor architecture used in simulation experiment and the format of time series records. Subsection 5.4.2 describes the correlation between temporal intervals and spatial distances. Subsection 5.4.3 introduces how to make a comparison between two ID mapping arrangement to decide which one is more likely to be the correct one. Subsection 5.4.4 introduces how to modify the incorrect ID registrations. Finally in Subsection 5.4.5 the situation that two or more LED tubes have the same ID is introduced.

5.4.1 Indoor architecture for simulation and time series records

In this chapter, the evaluation experiments are conducted in the way of simulation on computer. Figure 5.5 shows the indoor architecture used in our simulation experiments. This architecture includes five rooms and one passage. And there are totally 19 ID modulated LED tubes or units. T_{00}~T_{18} are the numbers of the candidate positions of LED tubes which have decided when the illumination system was designed, and these numbers have no correlation with the number conveyed by the ID modulated LED tube at this position.

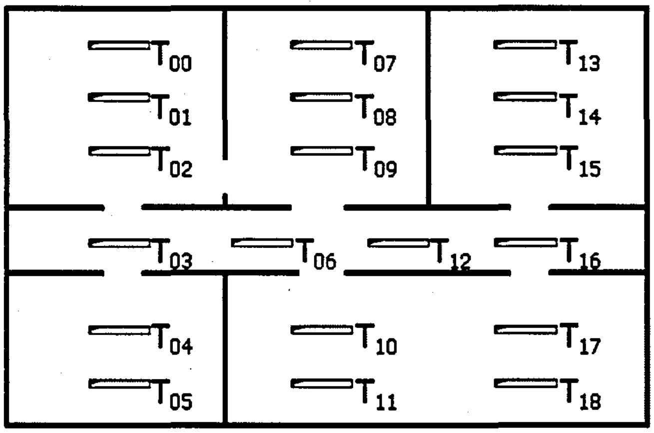

Fig 5.5 A simple indoor architecture

It is assumed that if one user detects a certain LED tube with his private mobile terminal, the unique ID of the terminal as well as the detection time and the detected ID will be stored on the server. As Figure 5.6(a) shows, the original records are listed with the index of time. With the purpose of analyzing the user moving and detected IDs, it is necessary to extract the time series records of the users respectively (Figure 5.6(b)). We take the time series records of user 2 in Figure 5.6 as the example. At time 13:46:08 user 2 detected the LED tube whose ID is 571 and at time 13:46:17 he detected the LED tube whose ID is 891. It means that in 9 seconds the user moves from the LED tube of No.571 from the LE tube of No. 891. In the same way, we can learn that in 16 seconds, the user moves from the LED tube of No.891 to the LED tube of No.643. As a general thinking, in a short period, the user cannot move a long distance. By using this principle, we can evaluate the possibility that the ID correspondence is correct. The detail of evaluation strategy will be introduced below.

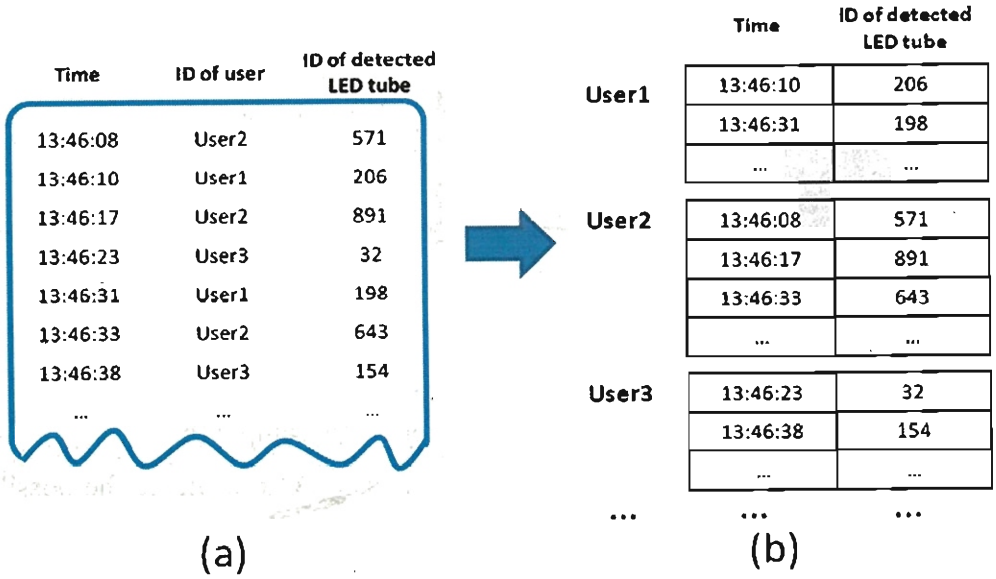

Fig 5.6 Extract out the respective time series
(a) Original records (b) Expected respective time series of users

5.4.2 Movement distance and time interval

As motioned in preceding subsection, it can be expected that the user cannot move a long distance in fairly short time. At first we consider about the distribution of walking speed. We assume that walking speed of various users shows normal distribution (Figure 5.7). The average value and standard deviation are preliminarily set to be 0.8 m/s and 0.2 m/s.

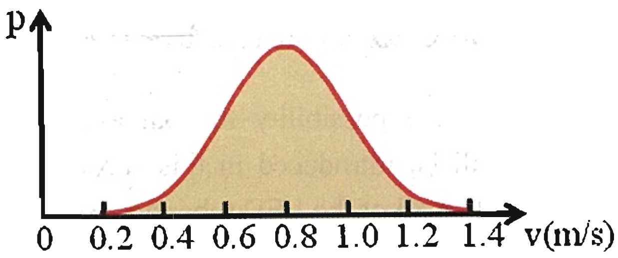

Fig 5.7 Distribution of walking speed

Next we analyze the relationship between final movement distance from standing point and time. The moving path of the user is complicated (for example, stopping and wondering back and forth), so that it is difficult to quantize the distribution of possibility at the near region. However, we can expect that when the distance exceeds a certain bound the possibility drops (Figure 5.8(a)). We set the bound is the product of average speed and time interval.

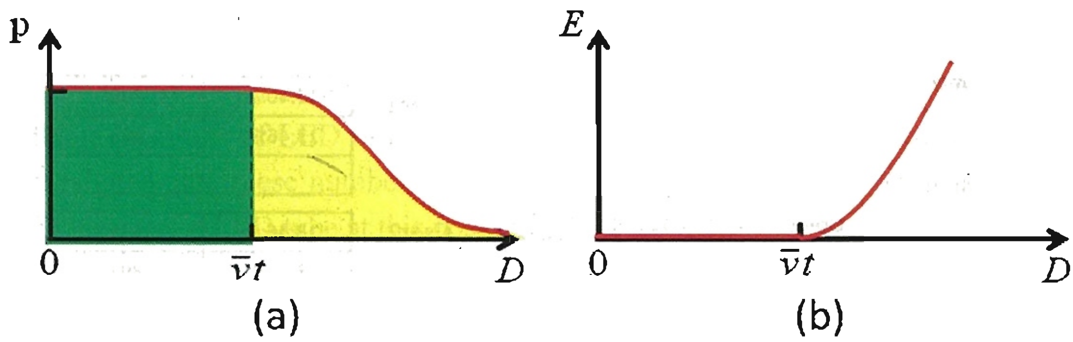

Fig 5.8 Distribution of possibility of movement distance (a) and the curve of energy value for single sample (b)

We define a kind of energy value for a single sample to evaluate the possibility of final movement distance from standing point. The relation between the energy value and the distance is shown is Figure 5.8(b). When the distance is under the bound, the energy is zero. If the distance exceeds the bound, the energy value ascents rapidly. A high energy value means a low possibility.

The energy of sample *Es* is expressed as following totally:

$$Es = \begin{cases} 0 & D \leq \bar{v}t \\ (\frac{D}{t} - \bar{v})^2 & D > \bar{v}t \end{cases} \tag{5-1}$$

where *D* is final movement distance.

5.4.3 Using energy value to evaluate the ID mapping

The strategy of evaluate the possibility that an assignment of complete ID mapping is correct or not will be introduced in this subsection. An assignment of complete ID mapping means that all of the LED tubes are assigned with an ID number. If even only one LED tube is assigned with another ID number, it will be totally a different assignment.

We assume that there are sufficient time series records for evaluations. If the time interval of two detected ID number by the same user is lower than a certain limit, we name the combination of the two ID number and the time interval (*id*, *id'*, *t*) as a "sample". The evaluation is conducted by using the set of the samples. The reason of setting a limit to the time interval is that long time interval would be of a low meaning for evaluating the distance between the LED tubes. In this subsection, for simplicity there are no two LED tubes have a same ID number. Therefore we can get the distance between the two LED tubes whose IDs are *id* and *id'*. With the distance and time interval t we can calculate the energy value of this sample.

At first for a certain LED tube we calculate the average of all the energy values of samples involving its ID number. If both of the two ID correspondences are correct, the average of energy values can be expected to be relatively low. We call the average value "the energy of this LED tube *Et*". It is shown as Equation (5-2).

$$Et = \frac{\sum_{i=0}^{amt} Es_i}{amt} = \overline{Es} \tag{5-2}$$

where Es_i means the energies of the samples which involves the ID number of the specific LED tube and *amt* the amount of these samples.

Finally we use the highest energy value of all the LED tubes in an assignment to evaluate this assignment. We call the highest energy value "the energy of this assignment *Ea*". It can be deduced that the assignment which is correct has the lowest energy. The energy of assignment *Ea* is shown as Equation (5-3).

$$Ea = \max\{Et_i\} \tag{5-3}$$

where Et_i means the energies of the LED tubes which are included the architecture.

Figure 5.9 shows the distribution of the energy values of the correct and incorrect assignments from our simulation. We can see that there is an apparent gap between the energy values of the correct and incorrect assignments.

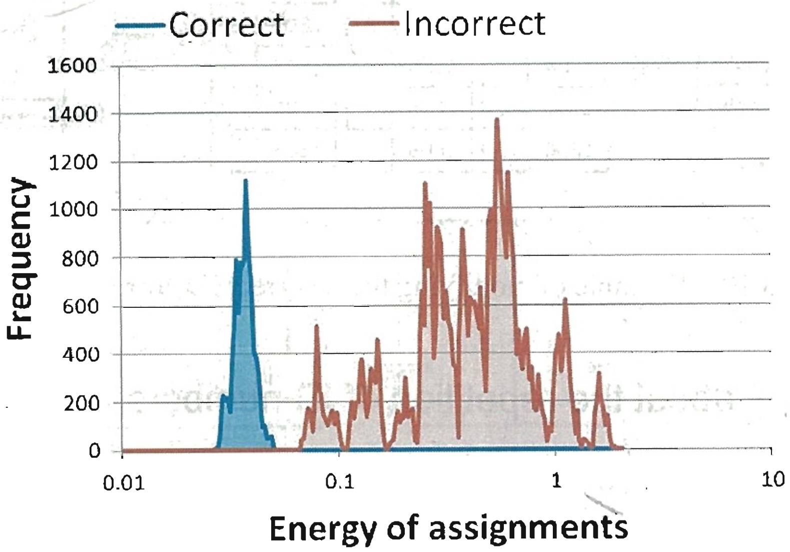

Fig 5.9 Distribution of energy of the assignments

5.4.4 Modifying the incorrect ID correspondences

At first, if there is a LED tube whose ID is not detected or a detected ID tube does not exist in the assignment of a complete ID mapping, we thought that it is possible to be an incorrect ID correspondence (we assume that the possibility recognizing the LED tube to be a wrong ID number is 0%). Besides this, we use two threshold values to looking for the possible incorrect ID correspondences.

The first threshold is used to analyze single sample. If the average speed of this sample is quicker than 2 m/s, the two ID correspondences involved in this sample are possible to be incorrect. The second threshold is used to analyze the energy of a signal LED tube. If the energy of this LED tube is higher than 0.1, the ID of this LED tube registered in database is possible to be wrong. For a LED tube, if either threshold is exceeded, this tube is in doubt.

In the assignment, the ID correspondences of the tubes in doubt will be cleared. This changed assignment is a partial assignment rather than a complete one. Then all of the possible complete assignments based on this partial assignment will be evaluated. Of cause one of the preconditions is that all of the detected ID numbers should exist in the possible assignment. Finally the assignment which has the lowest energy is thought be the correct assignment. Sometimes the correct assignment will be in doubt and the final result is the original one. A simple example of this processing is shown as Figure 5.10.

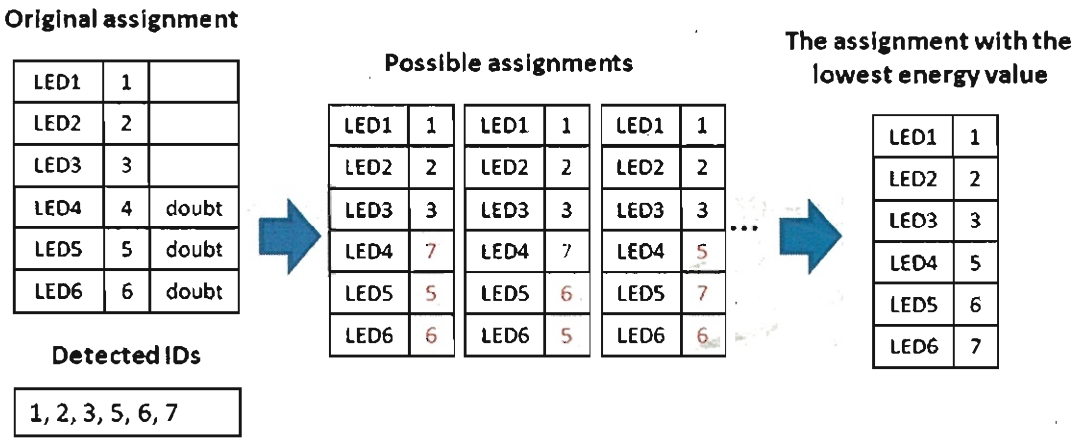

Fig 5.10 Example of modifying the incorrect ID correspondences

5.4.5 Study about the repetition of ID numbers

Because the amount of the available ID numbers is fairly large, the repetition of ID numbers in a limited area is of a very low possibility. However, in this subsection we discuss the situation the ID numbers of the LED tubes are totally random. Under this assumption, sometimes the position of user cannot be narrowed down to a unique place by observing only one LED tube. If two near LED tubes are captured successively in a short time, the user position can be narrowed down to a unique one at a possibility extremely close to 100%.

If there are more than two LED tubes whose ID numbers are same, for a certain sample involving this number we think the corresponding LED tube is the one which makes a lower energy. For example, there are two LED tubes T_{02} and T_{07} whose ID number are both No.11. And there is a sample (15, 11, t). If the No.11 corresponds to T_{02} makes the energy of sample to be 0.04 and this ID corresponds to T_{07} makes the energy to be 0.81, we choose T_{02} to calculate the energy. Sometimes the ID number is in a time series, and the ID number in sequential two samples from this time series corresponds to the same LED tube. In this situation the LED tube makes the lower summation of energy value will be chosen. For example, there are sequential two samples (15, 11, t_1) and (11, 12, t_2). The LED tube T_{02} makes the energy values of these two samples to be 0.04 and 0.05; the LED tube T_{07} makes the energy values of these two samples to be 0.81 and 0.03. Because $(0.04+0.05) < (0.81+0.03)$, we choose T_{02} to correspond both of the two ID number No.11. The strategy of modifying the incorrect ID correspondences is same with the situation mentioned above.

5.5 Simulation experiments

5.5.1 Pre-setting of simulation experiments

In this subsection, the presumptions and conditions for simulation will be introduced. As motioned above, we assume that users move in a simple indoor architecture (Figure 5.11). As a further assumption for simplification, the users only move along the shortest route between two neighbored LED tubes as Figure 5.11 shows. The distances between two neighbored LED tubes are appointed in advance. Moreover, the distances between two tubes which are not neighbors are obtained according to Dijkstra algorithm.

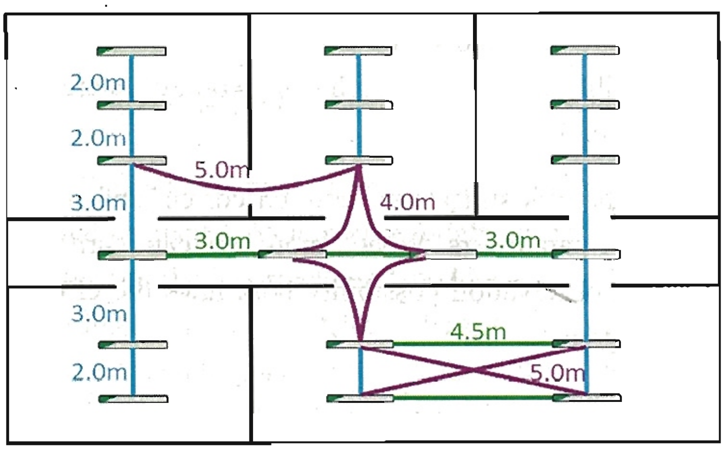

Fig 5.11 The routes and distances between neighbored tubes

We assume that the walking speed of users represents a normal distribution, which has been mentioned above as well. We adopt the normal distribution whose average value is 0.8m/s and standard deviation is 0.2m/s as the default parameter. We also use the normal distribution whose average value is 0.8m/s and standard deviation is 0.3m/s (Figure 5.12) for contrast experiments.

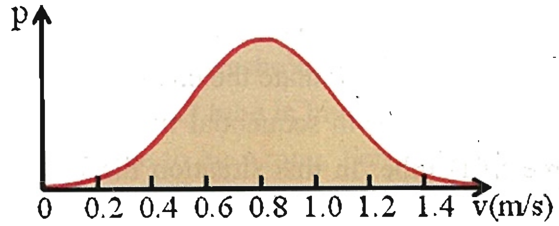

Fig 5.12 Distribution of walking speed for contrast experiments

The method of producing time series records for simulation is introduced as following. We assume that a user walks from one certain tube to a random one of its neighbors in a random speed. When he reached the target LED tube, he may observe this tube in a possibility and walks to next random neighbor. The default value of the possibility of observing the LED tube at that time used in simulation is 50%. We also use 20% for contrast experiments. This process will be repeated to produce time series records. The length of one separate time series is also a random number in a discrete uniform possibility distribution from 2 to 10.

5.5.2 Simulation experiment for energy of assignments

The distribution of the energy of assignments under the default parameters has been introduced in Subsect. 5.4.3. There is an apparent gap between the energy values of the correct and incorrect assignments. In this subsection we will investigate the distributions under the parameters for contrast experiment. Figure 5.13 shows the distribution when standard deviation of walking speed is 0.3m/s and observation possibility is 50%. Figure 5.14 shows the distribution when standard deviation is 0.2 and observation possibility is 20%. For each calculation of energy value, the amount of checked samples is 1000.

We can see that there is still a gap between correct and incorrect assignments despite the alteration of parameters. What's more, we can learn that the decrease of standard deviation and observation possibility both have the effect to make the gap increase at a certain degree.

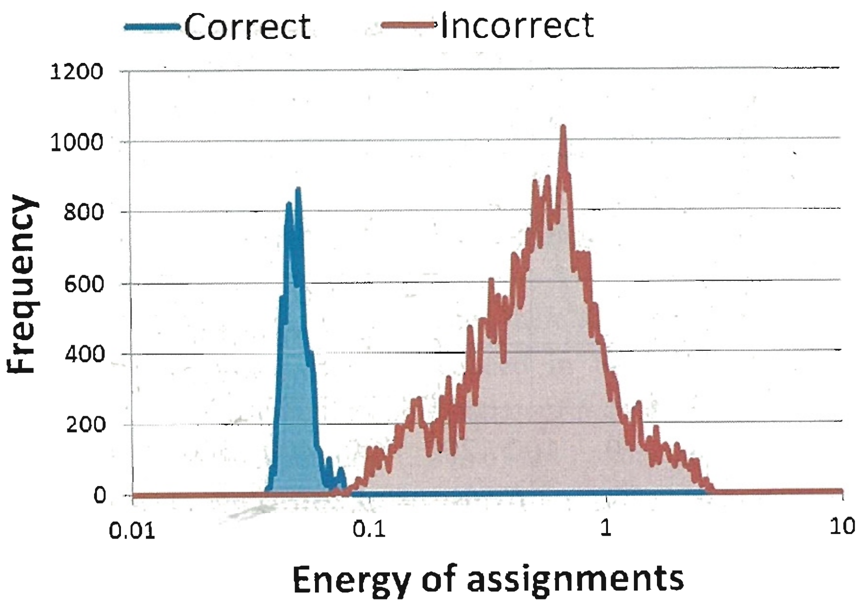

Fig 5.13 Distribution of energy of the assignments (standard deviation 0.3m/s)

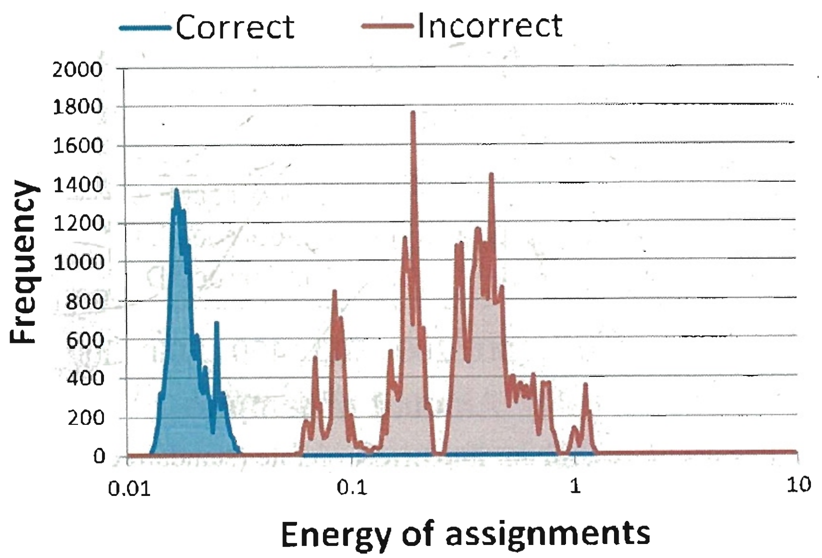

Fig 5.14 Distribution of energy of the assignments (observation possibility 20%)

5.5.3 Simulation experiment for correction rate

"Correction rate" means the possibility that the incorrect ID correspondences are detected and modified correctly. As a simple judgment, the correction rate relates to the amount of samples and the incorrect correspondences. In this subsection, results of the simulation experiments for investigating these relationships will be introduced. The experiments with default parameters are conducted as well as the contrast experiments (Figure 5.15, 5.16, 5.17). In this subsection, it is assumed that there is no repetition of ID number. 1000 different assignments respectively with 2, 4, 6 incorrect IDs are produced for simulation.

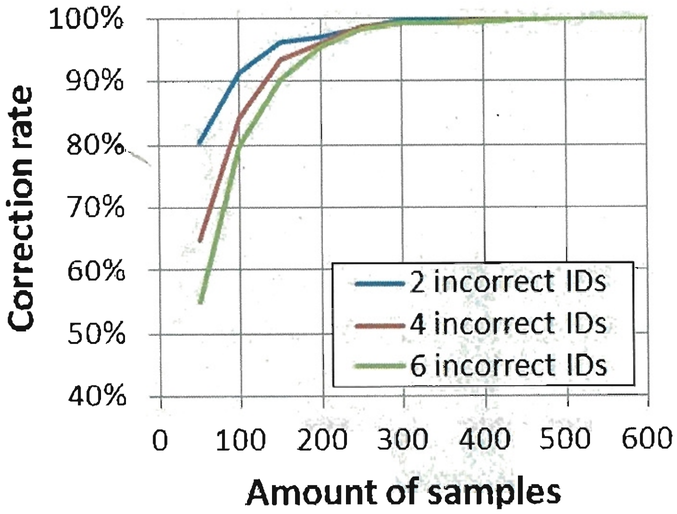

Fig 5.15 Results of experiment for correction rate (default parameters)

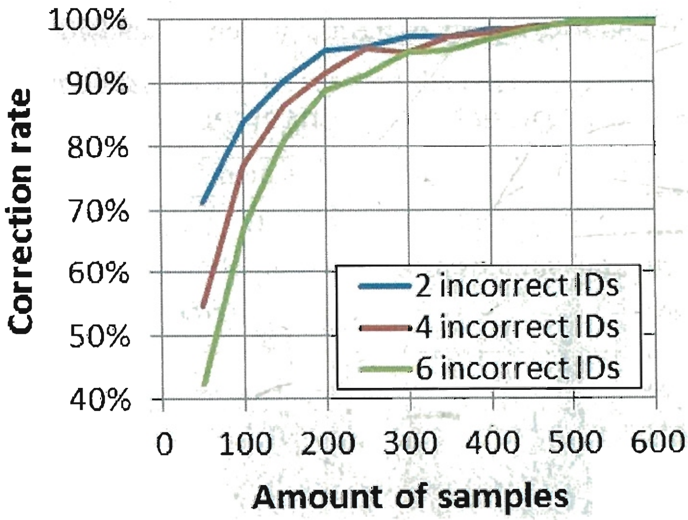

Fig 5.16 Results of experiment for correction rate (standard deviation 0.3m/s)

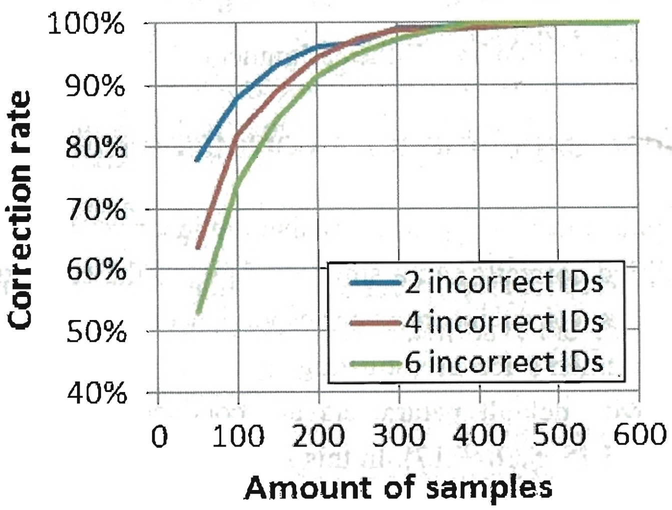

Fig 5.17 Results of experiment for correction rate (observation possibility 20%)

From the simulation result, we can learn that the amount of incorrect ID correspondences makes a decrease of correction rate when the amount of samples is not enough. Generally when the amount of samples is more than 500, the correction rate can reach 100%. Moreover, the standard deviation makes a decrease of correction rate and the observation possibility rate has no obvious effect on correction rate.

5.5.4 Simulation experiment for repetition of ID numbers

In this subsection, the correction rate when there are repetitions of ID numbers is investigated. The strategy has been introduced in Subsect.5.4.5. Six groups of simulation experiments which are the combination of number of repetitions (1, 2) and number of incorrect ID corresponding (2, 4, 6) are conducted. For each group, the number of assignments for test is 1000. The time series records used for these experiments are produced with the default parameters. The results of experiments are shown as Figure 5.18 and Figure 5.19.

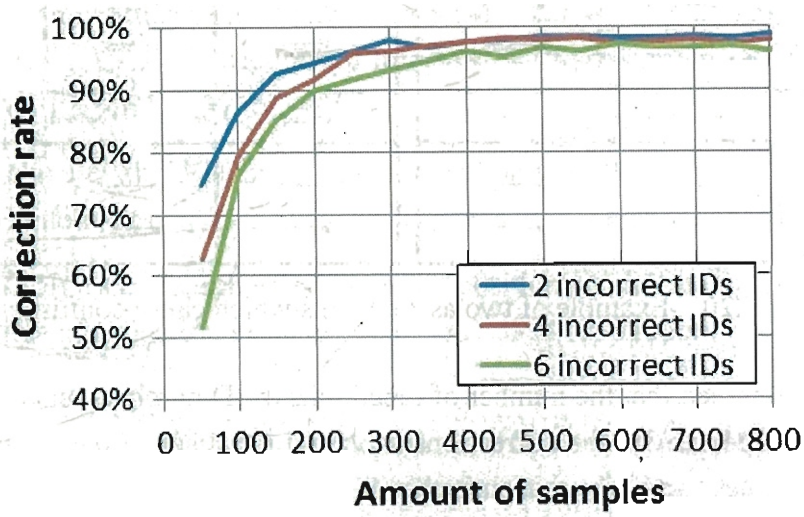

Fig 5.18 Results of experiment for correction rate (1 repetition of ID numbers)

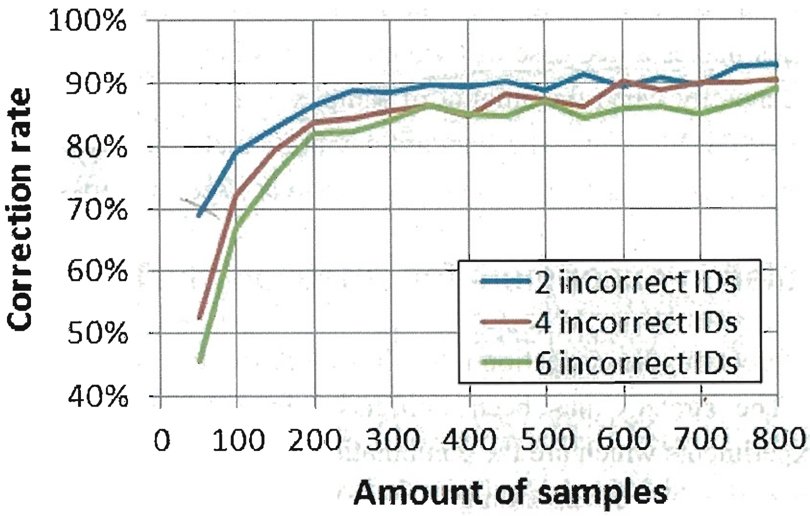

Fig 5.19 Results of experiment for correction rate (2 repetitions of ID numbers)

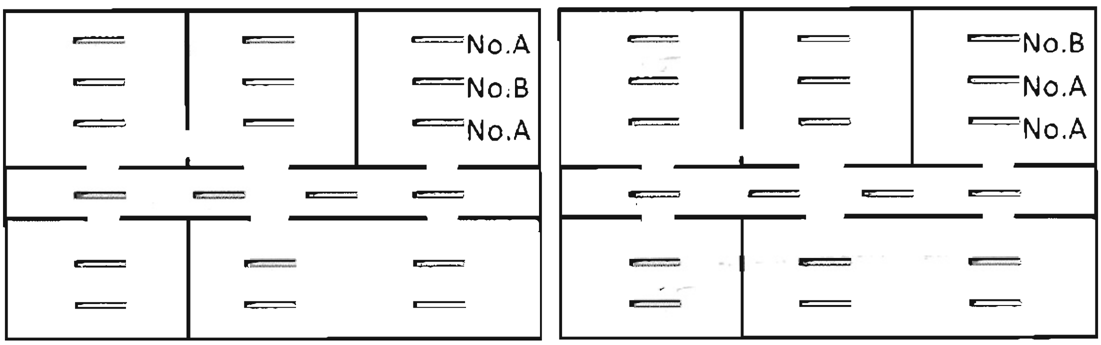

Fig 5.20 Example of two assignments which cause confusion

It can be learned that the number of repetitions of ID numbers makes decrease of correction rate. Moreover, the correction rate could not reach 100% even though the amount of samples rises. The reason is that some assignments are very difficult to be distinguished from the records. This problem mainly occurs when the LED tubes with same ID number are close in physical spaces. One example is shown as Figure 5.20.

5.6 Conclusion

In this chapter, we proposed a pedestrian model as an assistant for ID registration. This model uses the constraint of walking speed to evaluate the possibility that the ID assignment is correct or not. With this model, the positioning system has the ability to detect and modify the incorrect ID correspondences when there are enough usage records of users. One of the preconditions for this model is that all candidate positions of LED tubes can be obtained from CAD data of the building.

The results of simulation experiments show that the proposed model is practicable. For a simple architecture of 19 LED tubes whose ID numbers have no repetition, the correction rate can reach 100% when there are more than 500 samples. Moreover, if repetition of ID numbers appears, the correction rate is difficult to reach 100% because some ID assignments are hard to be distinguished. With the purpose of rapid verification, in this chapter only the simulation experiments are conducted. The experiments in physical space are needed for further investigating and perfecting this model. Moreover, the data from electromagnetic compass or acceleration sensor equipped in smart phone can be used to expend this model.

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➢ Chapter 6

Conclusion

This thesis presented the design, implementation, and evaluation of a novel camera-based information transmission system for indoor positioning. The proposed system uses ID modulated LED tube lights as the reference objects whose positions are known, and the ID information implanted in the tube lights can be received by a camera phone and has no harm at the illumination function. This system is of particular benefit on installation consumption and suitable for the deployment in large area.

Our work around proposed system can be divided into three parts, which are introduced in Chapter 4, 5 and 6 respectively. In Chapter 4, the basic study of proposed system, including ID modulation and ID recognition, is introduced. In Chapter 5, we presented a novel ID recognition method by using camera motion blur to extend proposed system to the cameras with various lengths of exposure time. In Chapter 6, we presented a pedestrian model for finding out the incorrect ID correspondences from the usage records of the users.

The features of proposed system will be described in the key issues of indoor positioning technologies which have been listed in Section 2.1.

1. **Coordinate system configuration and location information expression**

The coordinate value of estimated position depends on the form of the positions of LED tubes stored in database. It is manageable that the positions of LED tubes are the values based on the independent coordinate system of the building. Finally, the indoor and out coordinate system can be integrated by using the absolute position of the building in the world.

2. **Security about location information estimation and sharing**

The proposed system has a special advantage on security problem. In order to obtain the current position, the operation from the user is necessary. Without pointing the camera to LED tubes or shaking the camera, it is impossible to get the position and certainly give way the privacy. Therefore, the users can pay no worry on the hacker programs that make the positioning function run automatically.

3. **Positioning accuracy**

The proposed system can yield accuracy within 10cm when the units of two tubes are used. If only individual tubes are used, the error will be within 2~3m because the result is in the form that the user is close to a certain LED tube.

4. **Tracking and orientation discrimination**

Because the 2D sensor camera is employed, no meter the units of tubes or individual tubes, this system can provide the orientation information on the horizontal plane and the error is within 2 degrees.

5. Identification ability

We assume that the terminal used in this system is smart phone. Because smart phone is a kind of a personal effect for mobile communication, the user can be easily identified by the server.

6. Device dependence

The proposed system avoids using any expensive and special equipment. The LED tubes are assumed to already exist in the building as the illumination devices, and the smart phones equipped with camera are very popular in current years. This system is very cheap on the installation consumption.

7. System stability

The reference objects in this system are LED tubes which are the illumination devices. Therefore, the positions and ID numbers of the reference objects hardly change while the daily using. Moreover, we presented the pedestrian model to automatically modify the incorrect ID correspondences, which would occur when a few of LED tubes are replaced.

Finally, as mentioned in Section 3.3.3, the amount of available ID numbers exceeds one million. With a conservative assumption that the average area shared per one LED unit is around 4 m2 in indoor environment, the available ID can be deployed in a large region up to 4×106 m2. The total floor space of Yokohama Landmark Tower, which is the tallest building in Japan, is 1.6×106 m2. Thus, the proposed system could provide sufficient unique ID numbers in most cases. As a conclusion, we think the proposed system is feasible for various indoor position-based applications.

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August, 2012

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- Chang Li, Kosuke Sato, "Indoor Navigation System using ID Modulated LED Tube Lights", IEEJ Transactions on Electrical and Electronic Engineering, Vol.7, No.5, 2012 (in print)
- Chang Li, Daisuke Iwai, Kosuke Sato, "Recognizing ID of Modulated LED Tube Lights by Using Camera Motion Blur", IEEJ Transactions on Electrical and Electronic Engineering, Vol.8, Supplement, 2012 (in print)
- Chang Li, Kosuke Sato, "ID Mapping using Pedestrian Model for Camera-based Indoor Positioning System", IEEJ Transactions on Electrical and Electronic Engineering (preparing to submit)

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- Chang Li, Daisuke Iwai, Kosuke Sato, "An ID and Position Recognition Method Employing Camera Motion Blur for Modulated LED Tube Lights", Proceeding of 12th IAPR Conference on Machine Vision Applications, pp562-565, 2011

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