Design, Implementation and Evaluations of a Direction Based Service System for both Indoor and Outdoor

Yohei Iwasaki [†]   Nobuo Kawaguchi [‡,†]   Yasuyoshi Inagaki [§]

† Graduate School of Information Science, Nagoya University
‡ Information Technology Center, Nagoya University
§ Faculty of Information Science and Technology, Aichi Prefectural University
{iwasaki,kawaguti}@cogma.org

Abstract

This paper describes a design, implementation and evaluations of a direction based service system named Azim, which utilizes both a position and a direction of a user. In this system, a user's position is estimated by having the user point to and measure azimuths of several markers or objects whose positions are already known. Because the system does not require any other accurate position sensors nor positive beacons, it can be deployed cost-effectively. We have implemented a prototype system using a direction sensor that combines a magnetic compass and accelerometer. We have conducted experiments both indoor and outdoor, and exemplified that positioning accuracy by the proposed method is precise enough for a direction based service.

1 Introduction

As cell phones and other kinds of mobile terminals have become prevalent, and GPS modules have fallen in price, we are seeing an increasing range of location based services, such as ActiveCampus[1], PlaceLab[2], Mobile Info Search[3] and SpaceTag[4]. Global Positioning System (GPS) based methods are common for acquiring positioning information[5], but this approach has some drawbacks: the devices often do not work in street canyons between tall buildings, indoors, and other environments where signals from the GPS satellites cannot reach, and it can take some time until the GPS sensor can be used after power is first applied (cold-start). For indoor environments, a number of position measurement techniques have been developed such as the Active Bat[6] location system that uses ultrasound times-of-flight to ultrasonic receivers whose positions are known, but this system can be fairly costly to deploy the ultrasonic receivers everywhere. In short, today there is no method of position measurement that is both affordable and can be used across a wide range of environments, both indoor and outdoor.

We have already proposed a *direction based services*[7], which are more advanced location based services based on both location and direction of a user. This paper describes a design, implementation and evaluations of a direction based service system named *Azim*, which uses a position estimation method based on azimuth data. In this system, a user's position is estimated when the user points to and measures azimuths of several markers whose positions are known. Because the system does not require any other position sensors nor positive beacons, it can be cost-effectively deployed. Since measuring the azimuths of markers is accompanied by some degree of error, we model an error of azimuth measurement, and calculate the user's likely position as a probability distribution, which can consider the error of direction measurement and the pre-obtained field information such as obstacles and magnetic field disturbance. This method also has an advantage for those who are concerned for their privacy, because the position is never acquired without the user's intention. Since not only the user's position but also azimuths are acquired in this approach, the positions and azimuths can be used to develop more advanced location based services, which we named direction based services. We propose an instance of the direction based service in which the system identifies an object pointed to by a user. In addition, the proposed system utilizes wireless LAN to support these advanced services. In order to test the feasibility of our approach, we have constructed a prototype system based on a direction sensor that combines a magnetic compass with an accelerometer. The position estimation accuracy was evaluated in experiments on the prototype system, and we exemplified the usefulness of the proposed system.

The rest of this paper will be organized as follows: In Section 2 we present a direction based service system named Azim that combines the azimuth based position estimation with a wireless LAN. Section 3 details an Azim prototype system implemented with a direction sensor that combines a magnetic compass with an accelerator, and Section 4 discusses experiments to assess the performance of the prototype system. Section 5 surveys some other studies that are related to this research, and Section 6 concludes the paper and highlights a number of issues for the future.

2 Azim: Direction Based Service System

In this section we present *Azim* system that supports a direction based service which is an advanced service based on both the location and the direction of a user. This system has the ability to acquire a user's position employing the azimuth based position estimation. Taking the example of a direction based service, this system also has the ability to estimate the objects pointed to by the user, and provide services relating to those specified objects.
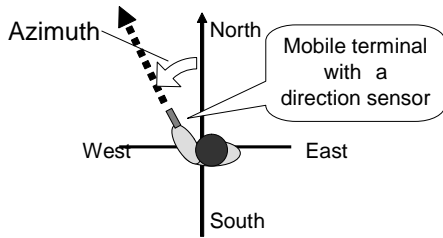
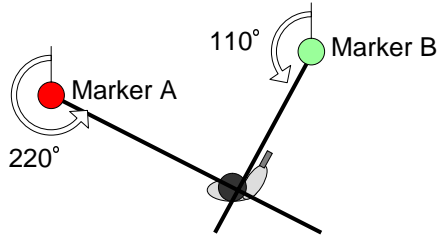Figure 1: Azimuth acquired by a direction sensor

Figure 2: Position estimation based on azimuth data from several markers

2.1 Azimuth Based Position Estimation

We first propose a method based on measuring several azimuth data to estimate a position. For simplicity, we assume that the position coordinate system is a two-dimensional plane. In this approach, markers whose positions are known are placed in various locations throughout an area, and a user's position is acquired by having the user point to several markers and measuring the azimuths. As illustrated in Fig.1, the azimuth is the absolute angle of horizontal deviation from north as an origin, and is measured by a mobile terminal with a built-in direction sensor. Fig.2 shows that the user's position is at the intersection of half-lines drawn from the markers. Since the direction measurements are accompanied by a certain degree of error, the direction measurement error is modeled in our approach, and the user's position is calculated as a probability distribution, which is detailed in Section 2.7.

When acquiring a position with this method, the system has to know which markers the user is pointing to. For this purpose, we distinguish the markers by color (or shape etc.), so all the user has to do is to push a color-coded button to narrow down the markers being pointed to (in this paper, we will only consider the color-coding scheme). To make the system available in wide area, several markers may be coded with the same color. To deploy the same colored markers, these markers should be distinguished by other environmental information such as rough position information obtained by identifying wireless LAN base stations (see Section 2.4). Since the markers are passive and do not require any equipment, the system can be deployed at low cost. Existing landmarks, buildings, or other everyday objects can also be used as markers. In this case, the user selects the name or type of an object instead of a color.

2.2 Direction Sensor

There are direction sensors available for measuring absolute azimuth from north as an origin, such as devices that combine
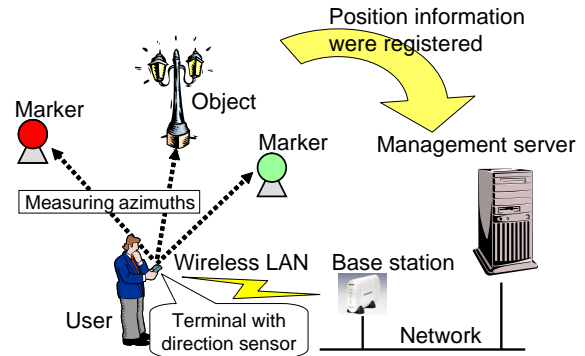

Figure 3: Azim: direction based service system

a magnetic compass with an accelerometer (The north means the magnetic north here, not a true north on the map). With a magnetic compass capable of measuring geomagnetic direction and an accelerometer capable of measuring gravitational force direction, one can acquire the direction (i.e., the pitch, roll, and yaw) of a device, without any other special equipment. Two available devices with these capabilities are the *3DM* manufactured by Microstrain Inc.[8], and the *3D motion sensor* manufactured by NEC Tokin Corp.[9].

2.3 Typical Usage Model

Fig.3 is a schematic representation of the system architecture. The user first measures his own position by pointing to several markers and inputting the marker colors. Then, the user points to an object, thereby enabling the user to receive various application services relating to the specified object. Typical application services might include remote operation of a device that is pointed to, or displaying information on the user's terminal screen about an object that is pointed to. From the same position, the user can also point to other objects. If the user moves and changes his position, the user performs another measurement to determine the new position. However, once a user obtains an absolute position by pointing to the markers, other tracking methods[10] may be used to track the user's position for a short period of time using sensors in the terminal.

2.4 Network Environment

In the last few years we have seen the rapid spread of public wireless LAN services such as hot spots, and use of wireless LANs in residential and office environments. Our method employs a wireless LAN to support communication between the user's mobile terminal and an information management server.

In wireless LAN, the system can know the identity of the base station which the client terminal is connecting to. The base station identity provides rough position information, because the system can know that the user is within the signal reception range, which is about 50-to-100-meter radius when no obstacles. Applying the position distribution calculation procedure described in [7], the prior probability and position space integral range can be confined to this signal reception range. Also only makers that can be seen in the signal reception range can be specified by a user. Accordingly, the system can identify the specified marker if there are other markers
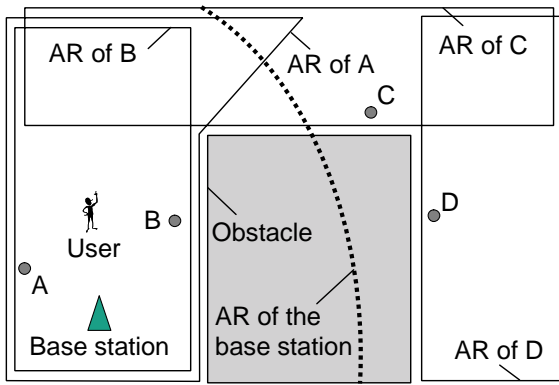
Figure 4: Available region (AR) example

which have the same color outside this range. This means that fewer colors are needed to make up the color scheme.

2.5 Components of the System

The system is composed of the following.

- Client terminal: The client terminal is a lightweight, mobile terminal such as a cell phone or PDA (personal digital assistant) that is carried around by the user. The terminal features a built-in direction sensor that measures azimuths to markers and objects pointed to by the user.

- Information management server: The information management server manages location information for markers, objects, and base stations. The server also calculates a user's position distribution, and identifies the object pointed to by the user.

- Base station: The base station of wireless LAN. The client terminal can acquire the identifier (MAC address, etc.) of the base station it is connecting to.

- Marker: An object or landmark that the user points to in order to measure his position. Markers are differentiated by color (or some other means), which the user inputs when pointing to a marker. Existing landmarks or buildings can substitute for markers.

- Objects: An object is one that a user might point to, including a device or piece of equipment, a shop, a landmark, and so on.

2.6 Available Regions

Let us next consider how this system might be used over a wide area. Since users cannot point to markers or objects that are beyond their field of view, we must consider the available region over which a marker or object can be used. It is also necessary to consider the base station signal reception range. Therefore we define the available regions of markers, objects, and base stations. By defining the available regions of markers and objects, we can specify which markers and objects can be seen from a particular position, thus enabling the system to make specific calculations of the marker selection model and object selection model in [7]. The available region of a base station means the signal reception range of the base station, and

as noted earlier in Section 2.4, this is used to roughly determine a user's position.

Fig.4 illustrates an example of available regions. The available regions should be defined by considering obstacles and distances to objects, since the user cannot point to the object when an obstacle exists between the user and the object, or when the object is too far from the user.

By knowing the base station identity that a client terminal is connecting to, we know that the user is currently within the available region of that base station. It is only when the available regions of the base station and a marker overlap that the marker can be regarded as a specified marker. For example, consider the point A through D in Fig.4 as markers. The user cannot point to marker D even if he is somewhere within the available region of the base station. Considering the marker color scheme, if the markers whose available region overlaps the available region of the base station are assigned a unique color, the system can identify the specified marker.

Let us next assume that the user's position has been calculated. It is only when the available region of an object overlaps with the probable position of the user (i.e., high probability area of position distribution) that the user is able to point to that object. This way, the objects which cannot be seen from the user are never estimated as candidates for specified objects. For example, consider the point A through D in Fig.4 as objects. Only objects A and B whose available regions overlap with the user's position can become specified objects.

2.7 Probabilistic Approach for Azimuth Based Position Estimation

Direction measurements by a user include a certain degree of error, which caused by user's pointing operation itself, or geomagnetic field disturbance by metallic objects. So calculating the intersection of the half-lines is insufficient, because no accuracy information is acquired, and sometimes no intersection. Thus the system calculates probabilistic distribution of a user's position.

The detail calculation formulas are in [7]. We describe only the concept here due to lack of space. The calculation of the position distribution can utilize the following various location based information. First, obstacles influence such as off-limits areas where a user cannot exist, and the occlusions of invisible objects or markers (see Section 2.6). Second, rough position information by wireless-LAN base stations (see Section 2.4). Third, by using pre-obtained magnetic field distribution, robust measurements can be achieved even in geomagnetic disturbance environment.

Fig.5 shows examples of calculations when directions to two markers are measured and a user's position is estimated. In this example, the user is in the center of a square area, and he points first to a marker that is 45 degrees to the left and second to a marker that is 45 degrees to the right.

By calculating the user's position as a probability distribution, the system can identify the specified object in a probabilistic manner with that position distribution and the target direction.
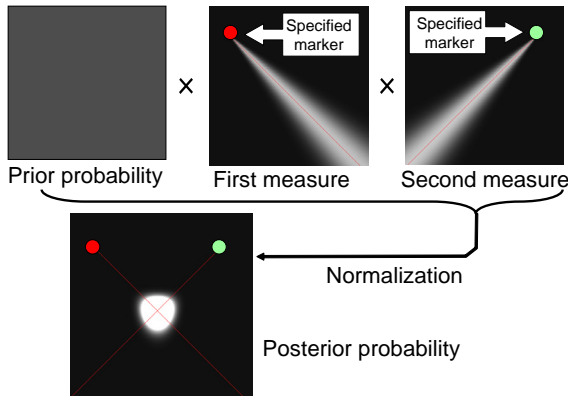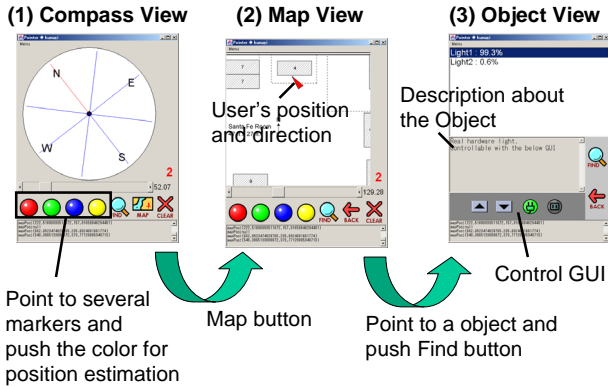
Figure 5: Calculation of position distribution

Figure 6: Screenshots of the client terminal

3 Implementation

We have implemented a prototype of the direction based service system described in Section 2. For the azimuth measurements, we employed the *3DM* direction sensor manufactured by Microstrain Inc.[8] that combines a three-axis magnetic compass with a three-axis accelerometer. For the software development, we used Java 2 Platform SDK 1.4 and *cogma* [11] middleware that supports interworking between network equipment. An IEEE 802.11b-compliant wireless LAN was used for the network environment. In the current version, the available regions of markers, objects, and base stations are not considered.

Client terminals communicate with an information management server over the wireless network. Fig.6 shows several screenshots of the client terminal. The current pointing azimuth is displayed in the compass view like Fig.6(1). A user points to the direction of a marker and presses the button for that marker's color, then repeats this operation several times to estimate the current position. The user can confirm his position on the map view like Fig.6(2). Then the user points to the direction of an object and presses the Find button (hand lens button), then the system identifies the specified object, and displays candidates on the screen as illustrated in Fig.6(3). The specified object with the highest probability is automatically selected, but the user can manually select another candidate. Once a specified object has been selected, the various application services associated with that object can be accessed. We have developed the following two application services.
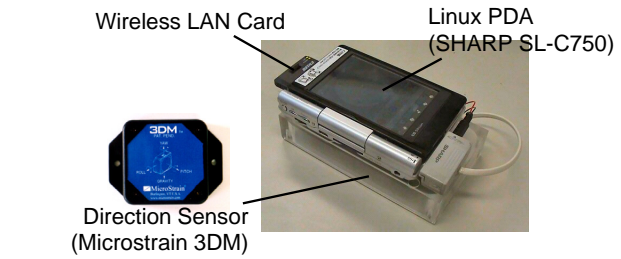

Figure 7: LocPointer: portable client terminal using a Linux PDA

- Universal Remote-controller Service: A user can remotely control a device via a GUI on the client terminal display. The implementation code of the GUI is dynamically loaded from the specified device, by using code mobility function of the cogma[11] middleware.

- Device Connecting Service: A user can request a connection between two distant devices by directly pointing to them. The user can remotely push the button interface of Touch-and-Connect[12] on the client terminal display.

Using the procedure outlined in Section 2.7, the information management server calculates the user's position distribution and identifies the specified object. The user's position distribution is calculated as a 128×128 two-dimensional array. A normal distribution with a standard deviation of 5 degrees is used as the azimuth measurement model[7].

The client terminal software can also work on J2ME environment. As illustrated in Fig.7, we have developed a portable client terminal using Linux PDA (SHARP SL-C750) called *LocPointer*.

4 Evaluation

Experiments were carried out on the prototype system to evaluate the validity of the proposed method. We expect that our method will be effective across a wide range of environments, thus the experiments are conducted both indoor and outdoor.

4.1 Experiment 1 (Outdoor)

First, we conducted a trial in an outdoor environment to evaluate the accuracy of the proposed position estimation method. Fig.8 shows a schematic overview of the trial site, which is the corner of a sports ground.

Markers were set up in two locations (Marker-A and B in the figure). The distance between the two markers was 30 meters. The proposed method was used to estimate the positions of 14 different points scattered in the vicinity of the markers. We pointed at each of the two makers and measured the azimuths by the LocPointer (described in Section 3). Six measurements were conducted for each point.

The experimental result is summarized in Fig.8. The solid black symbols with numbers show the correct positions of the measurement points. The outline open symbols represent the estimated positions (six estimates). Since the user's position is calculated as a probability distribution in our approach, the estimated position is the center of gravity of the distribution.
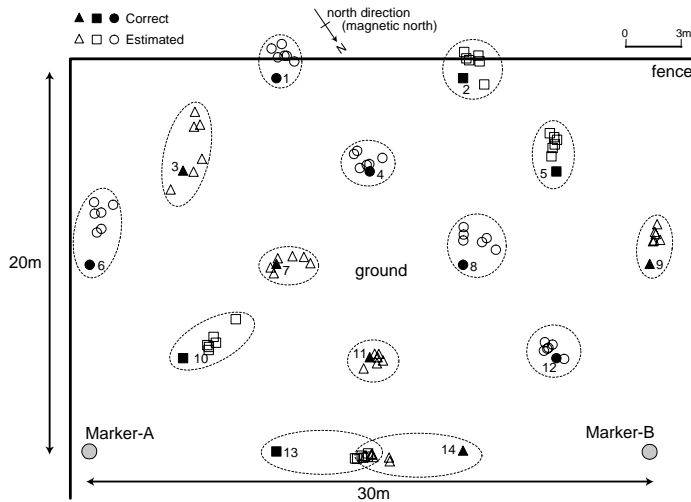
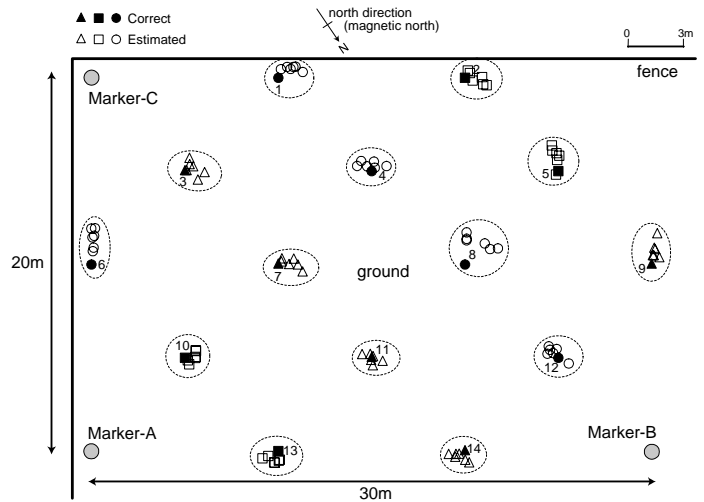Figure 8: Estimated positions (outdoor; 2 markers)

Figure 9: Estimated positions (outdoor; 3 markers)

We adopted different shaped symbols (triangles, squares, circles) in the figure, just to make the results easier to distinguish. Measurement results for the same point are represented using the same symbol shape.

We found that the positions estimated by our method diverged from the correct positions by 1.9 meters on average (80 percent of measurements are within 2.8 meters). We think that this positioning accuracy is precise enough for the direction based service where a user specifies objects by pointing in outdoor environments. We would also note that, since the estimation accuracy is basically proportional to the distance between markers, for situations requiring greater accuracy, a higher degree of position estimation accuracy could be achieved by deploying the markers more densely.

However, at the points on the line between two markers, such as point 13 and 14 in the Fig.8, the estimation accuracy is relatively bad. If the relative angle between the two specified markers is close to a right angle (90 degrees), the estimation accuracy is relatively good. Thus it is a good idea to deploy more than two markers on the service field, and a user can select desirable two markers, or simply measure azimuths of all markers.

By measuring azimuths of more than two markers, the positioning accuracy and robustness improve. Fig.9 shows estimated positions when the subject points to the three markers (Marker-A, B and C in the figure). In this case, the estimated positions diverged from the correct positions by 0.78 meters on average (80 percent of measurements are within 1.1 meters). Note that positioning accuracy is stable on all the positions even between the markers.

4.2 Experiment 2 (Indoor)

Second, a trial were conducted in an indoor environment, which is our test bed room for the ubiquitous computing environment named Cogma Room. In the room, there are four markers (Marker A – D) and eleven display devices (LCD1 – LCD9, Screen, PDP) as shown in Fig.10. We assumed the direction based service where a user points to one of the displays to show a picture.

Generally indoor environments especially concrete buldings

are prone to have geomagnetic disturbance. To correct a azimuth measurement disparities, we obtained a spatial distribution of magnetic field by sampling a magnetic vector in some points in the room. Fig.11 shows the interpolated magnetic field information (abbreviated as MFI later), where the magnetic vector directions are disturbed in the range of 40 degrees. The interpolated magnetic vector in an arbitrarily point was calculated by the weighted mean for the sampled vectors, where the weight is dis^{-3}; dis is the distance to the sampling point. This pre-obtained MFI is used to correct the azimuth measurement (see Section 2.7 and [7]). To evaluate the advantage by using the MFI, we compared the two estimations — *without the MFI* in which magnetic vectors are assumed to parallel to the magnetic north direction anywhere, and *using the MFI*.

We conducted a trial at nine points in the room, Point 1 – 9 in the Fig.12. In each point, the position estimation based on the proposed method is conducted eleven times by pointing to two markers with the LocPointer. The used two markers are Marker A and B in Point 3, 4, 6, 9; B and C in Point 5, 8; C and D in Point 1, 7; D and A in Point 2.

The estimated positions without the MFI are shown in Fig.12. Just like the experiment 1, the solid black symbols show the correct position of the measurement points, and the outline open symbols represent the estimated positions (eleven estimates). The estimated positions diverged from the correct positions by 0.85 meters on average (80 percent of measurements are within 1.51 meters). On the other hand, the estimated positions using the MFI are shown in the Fig.13. The estimated positions diverged from the correct positions by 0.35 meters on average (80 percent of measurements are within 0.60 meters). The two estimations are based on the same measurement data. These results means that the accuracy of the estimated positions are improved by using the MFI. Thus the proposed position estimation method is also useful even in the indoor environment by using the MFI.

We also evaluated the usefulness of the direction based service. After each position measurement, the subject points to one of the display devices shown in Fig.10. The system estimates the specified display using the position distribution and the display direction (see [7]). The result of the estimation is
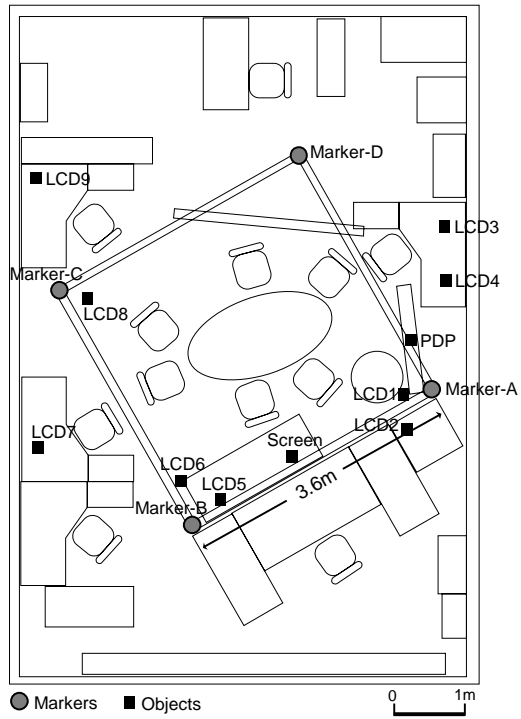
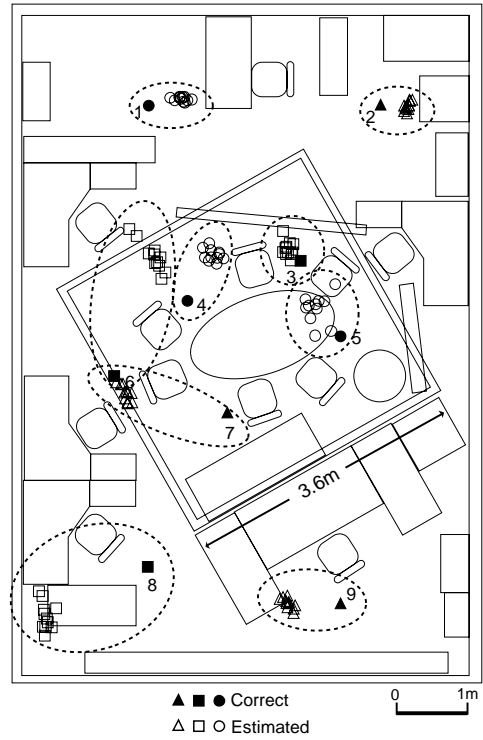Figure 10: Objects map in the indoor environment
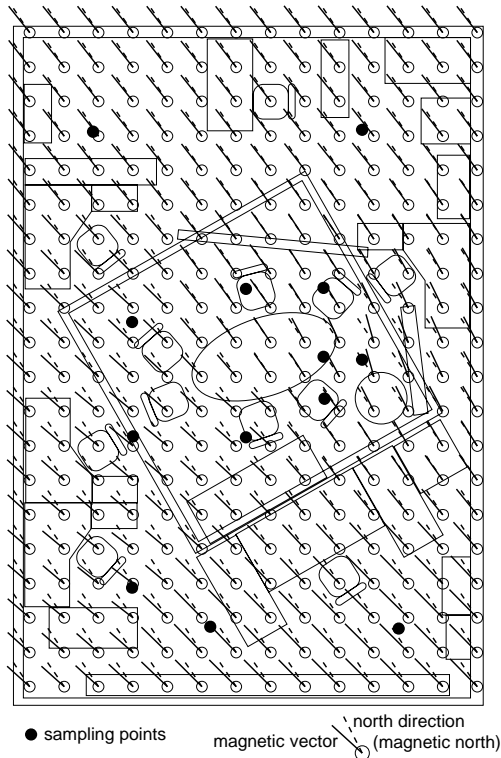

Figure 12: Estimated positions without the MFI

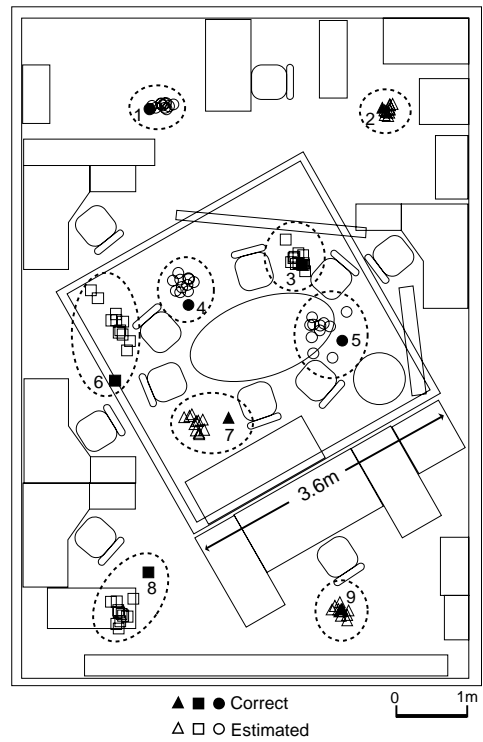Figure 11: Pre-obtained magnetic field information (MFI)

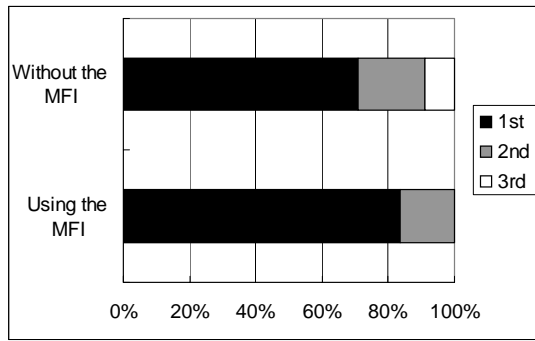Figure 13: Estimated positions using the MFI

Figure 14: Order of the specified object in the estimated list

a list of the estimated objects in order of high probability. The measurements are conducted only on Point 3–7, because the displays are out of sight on the other points. Fig.14 shows the proportion of the order of the specified object in the estimated list. Using the MFI, the specified object is on the top of the estimated list in the 84 percent of the measurements, whereas 71 percent without the MFI. The result means that the proposed method is precise enough for the direction based service assumed here. We expect that the result improves using three-dimentional information such as the altitudes of objects and an elevation angle (pitch) of the pointing device, because some of the objects are overlaped in a azimuth angle but not overlapped in a elevation angle. We will consider that in our future work.

5 Related Research

In the following we will differentiate this research from other related researches in several aspects.

5.1 Position Acquisition Technologies

GPS-based methods of position acquisition are now widely available[5]. In outdoor environments where there is unobstructed line-of-sight, positioning accuracy to within 10 meters can be obtained by GPS. However, GPS is often ineffective in street canyons between tall buildings, indoors, and other environments where signals from the GPS satellite cannot reach, and in environments where waves are reflected. Another shortcoming of GPS is that it can take some time until the sensor can be used after power is first turned on (cold-start).

One technology that has been used in the measurement of cell phone positions is Assisted-GPS[13], where the base station catches the GPS satellites and provides this information to cell phones to cut the time for cold-start. Another location measurement technique for indoor environments is the Active-BAT location system[6] that uses ultrasound times-of-flight to ultrasonic receivers whose position is known. The major drawback of both these systems is that they tend to be quite costly to deploy the system for wide areas.

Another approach that has been suggested for position measuring uses the RF signal strength from (or to) several wireless LAN base stations[14][2]. In our proposal, this approach can also be used to improve the accuracy of the pre-obtain rough position information (about 10 meters) instead of just using the identification of a base station (about 100 meters). Therefore,

the number of marker colors can be reduced, or the markers can be deployed more densely.

However, especially for indoor environments, radio waves are spatially and temporally disturbed by the effects of reflection and absorption by obstacles. Reference [15] describes a scheme in which RF signal strength from several wireless LAN base station is measured in advance for various points in the system service area, and this data is used to obtain the spatial distributions of RF signal strength for the area. This achieves position measurements that are robust against fluctuating RF signals. As described in Section 4, we can use a similar approach in which a robust position measurement is achieved even when geomagnetic fluctuations exist, by obtaining the spatial distribution of magnetic fields of a service area in advance.

Let us briefly highlight the key advantages of the proposed position estimation method in comparison with the existing position measurement methods.

- **Cost Effective for Deployment:** Compared to schemes that require special equipment deployed on the environment side, our method only involves a deployment of markers, and because the markers do not require power or other operating costs, the environment side costs are minimal. In fact, if landmarks and other existing structures are used for markers, then no dedicated markers need to be deployed at all. Our system is cost effective even when it works over a wireless LAN, since wireless LAN base stations are inexpensive and already widely deployed [2].

- **Available Anywhere:** By using a magnetic compass and obtaining magnetic field distributions in advance, our approach works very well over an extensive range of environments, both indoor and outdoor.

- **Low-cost Client Terminal:** For the direction based service, since both the user's position and azimuth data are obtained from only direction sensor without any other position sensors, which means that the client terminal can be implemented at a low cost.

- **Quick Start-up:** One advantage of our approach compared to GPS systems is that position data can be obtained immediately as soon as the mobile terminal is turned on.

- **Privacy:** As long as the user does not intentionally measure his own position, the user's position remains unknown to the system. While this might seem like a shortcoming in some situations, it is actually an advantage for those who are concerned for their privacy because it prevents the user's movements from being tracked.

5.2 Location Based Services

Several location based services are proposed. In the SpaceTag system[4], information can be accessed only from limited locations and limited time period. The kokono Search service of the Mobile Info Search[3] provides "location-oriented robot-based search", in which WWW documents that contain location information such as an address are automatically collected, and a user can search these documents based on a location. In the Follow-me Application service[6], the system determines the locations of users with supersonic sensors, and

the display which is the closest to the user is selected automatically as a workspace.

The main advantage of our proposed system is that our system utilizes not only the location but also the direction of a user, which provides more advanced and flexible service. With only location data, the user can get information about *where he is*. More finely with direction data, the user can get about *what he sees* or *what he points to*. We have also planned a direction based search service, where the user can get about *which direction the desired service exists* by sweeping around with the client terminal. When the service exists in the direction, the terminal informs by sound or vibration.

6 Conclusions

This paper describes a design, implementation and evaluations of a direction based service system named Azim, which based on both location and direction of a user. In Azim, the user's position is estimated by having the user point to and measure azimuths of several markers whose positions are already known. Azim uses a wireless LAN for supporting these services. Finally, a prototype system was implemented using a direction sensor that combines a magnetic compass and a accelerometer, and we exemplified the usefulness of our approach through experiments in both indoor and outdoor environment. Using two markers outdoors whose interval was 30 meters, the positioning error was 1.9 meters on average. When using three markers, the error was 0.78 meters on average. And using two markers indoors whose interval was 3.6 meters, the error was 0.85 meters on average without MFI (magnetic field information), which improved to 0.35 meters using MFI.

There are a number of areas that need further study. First, further study is required for an easy method for learning the MFI (see Section 4.2). For example, using another positioning method, such as using only relative azimuths, in the beginning phase. And the magnetic field information grows with daily use.

Second, although we assumed that the position coordinate system was a two-dimensional plane for simplicity, our approach could be easily adapted to three-dimensional space by using both the azimuth and angle of elevation (pitch angle) obtained from the direction sensor.

References

[1] W. G. Griswold, P. Shanahan, S. W. Brown, R. Boyer, M. Ratto, R. B. Shapiro, and T. M. Truong, "ActiveCampus - Experiments in Community-Oriented Ubiquitous Computing", Technical Report CS2003-0750, Computer Science and Engineering, UC San Diego, 2003.

[2] Bill N. Schilit, Anthony LaMarca, Gaetano Borriello, William G. Griswold, David McDonald, Edward Lazowska, Anand Balachandran, Jason Hong, and Vaughn Iverson, "Challenge: ubiquitous location-aware computing and the "place lab" initiative," Proceedings of the 1st ACM international workshop on Wireless mobile applications and services on WLAN hotspots (WMASH'03), pp.29–35, 2003.

[3] Katsumi Takahashi, Nobuyuki Miura, Seiji Yokoji, and Ken-ichi Shima, "Mobile Info Search: Information Integration for Location-Aware Computing, " Journal of the Information Processing Society of Japan, Vol.41, No.4, pp.1192–1201, 2000.

[4] H. Tarumi, K.Morishita, M.Nakao, and Y.Kambayashi, "SpaceTag: An Overlaid Virtual System and its Application," International Conference on Multimedia Computing and Systems (ICMCS'99), Vol.1, pp. 207-212, 1999.

[5] Rashmi Bajaj, Samantha Lalinda Ranaweera, and Dharma P. Agrawal, "GPS: Location-Tracking Technology, " IEEE Computer, Vol. 35, No. 4, pp. 92–94, 2002.

[6] Andy Harter, Andy Hopper, Pete Steggles, Andy Ward, and Paul Webster, "The anatomy of context-aware application," Proceedings of the fifth annual ACM/IEEE international conference on Mobile computing and networking (MOBICOM'99), pp. 59–68, 1999.

[7] Yohei Iwasaki, Nobuo Kawaguchi, and Yasuyoshi Inagaki, "Azim: Direction Based Service using Azimuth Based Position Estimation," The 24th International Conference on Distributed Computing Systems (ICDCS 2004), pp.700–709, Tokyo, Mar. 2004.

[8] MicroStrain, Inc, "3DM: solid state 3-axis pitch, roll, & yaw sensor," http://www.microstrain.com/3DM.html

[9] NEC TOKIN Corporation, "3D Motion Sensor," http://www.nec-tokin.com/

[10] Seon-Woo Lee, Kenji Mase, "Activity and Location Recognition Using Wearable Sensors, " IEEE Pervasive Computing, Vol. 1, No. 3, pp. 24–32, 2002.

[11] Nobuo Kawaguchi, "Cogma: A Middleware for Cooperative Smart Appliances for Ad hoc Environment," Proc. of International Conference on Mobile Computing and Ubiquitous Networking (ICMU2004), Jan. 2004.

[12] Yohei Iwasaki, Nobuo Kawaguchi, and Yasuyoshi Inagaki, "Touch-and-Connect: A connection request framework for ad-hoc networks and the pervasive computing environment," First IEEE Annual Conference on Pervasive Computing and Communications (PerCom 2003), pp. 20–29, 2003.

[13] Goran Djuknic, and Stephen Wilkus, "Geolocation and wireless multimedia," 2001 IEEE International Conference on Multimedia and Expo (ICME 2001), pp.581-584, 2001.

[14] Paramvir Bahl and Venkata N. Padmanabhan, "RADAR: An In-Building RF-based User Location and Tracking System," IEEE Infocom 2000, pp.775-784, 2000.

[15] Andrew M. Ladd, Kostas E. Bekris, Algis Rudys, Lydia E. Kavraki, Dan S. Wallach, and Guillaume Marceau, "Robotics-based location sensing using wireless ethernet," Proceedings of the eighth annual international conference on Mobile computing and networking (MOBICOM 2002), pp.227–238, 2002.