Azim: Direction Based Service using Azimuth Based Position Estimation

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Abstract

In this paper, we propose a system named Azim *that provides service based on both location and direction, which uses potion estimation method based on azimuth data. 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 measurements are naturally associated with some degree of error, the user's position is calculated as a probability distribution. Since both the user's position and azimuth data are obtained in this method, both sources of data are used to realize more advanced services such as identifying the object pointed to by a user. The proposed system utilizes a wireless LAN for supporting these advanced services. Finally, a prototype system was implemented using a direction sensor that combines a magnetic compass and accelerometer, and we exemplify the usefulness of our approach through an experiment.*

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 time-of-flight to ultrasonic receivers whose positions are known, but this system can be fairly costly to deploy the ultrasonic receivers on the environment side 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.

In this paper, we propose a system named *Azim* that provides service based on both location and direction, which uses a potion 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 another 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 considers the error of direction measurement and the pre-obtained field information such as obstacles and magnetic field disturbance. This method 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 a wireless LAN for supporting 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 an experiment 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 es-

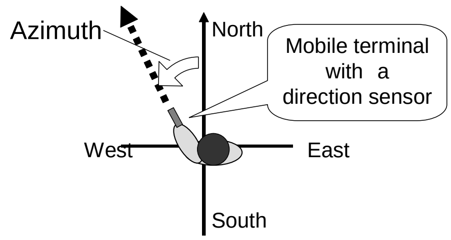

Figure 1. Azimuth acquired by a direction sensor

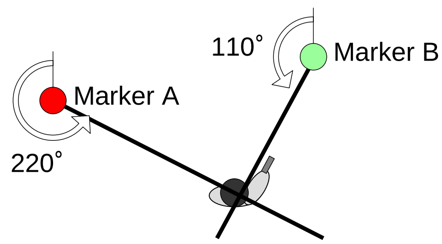

Figure 2. Position estimation based on azimuth data from several markers

timation with a wireless LAN. In Section 3, we present the probabilistic approach for the azimuth based position estimation, and the method of calculating the position distribution and identifying the object pointed to by a user. Section 4 details an Azim prototype system implemented with a direction sensor that combines a magnetic compass with an accelerator, and Section 5 discusses an experiment to assess the performance of the prototype system. Section 6 surveys some other studies that are related to this research, and Section 7 concludes the paper and highlights a number of issues for the future.

2. Azim: Direction Based Service System

In this section we present a system called *Azim* 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. For instance of the direction based service, it also has the ability to estimate the objects pointed to by the user, and provide services relating to those specified objects.

2.1. Azimuth Based Position Estimation

To estimate a position, we first propose a method of estimating position based on several azimuth data. 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 3.

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 place the same colored marker, these marker 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 a magnetic compass with an accelerometer. With a magnetic compass capable of measuring geomagnetic direction and an accelerometer capable of measuring gravitational force direction, one can acquire the posture (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.[7], and the *3D motion sensor* manufactured by NEC Tokin Corp.[8].

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 marker's 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

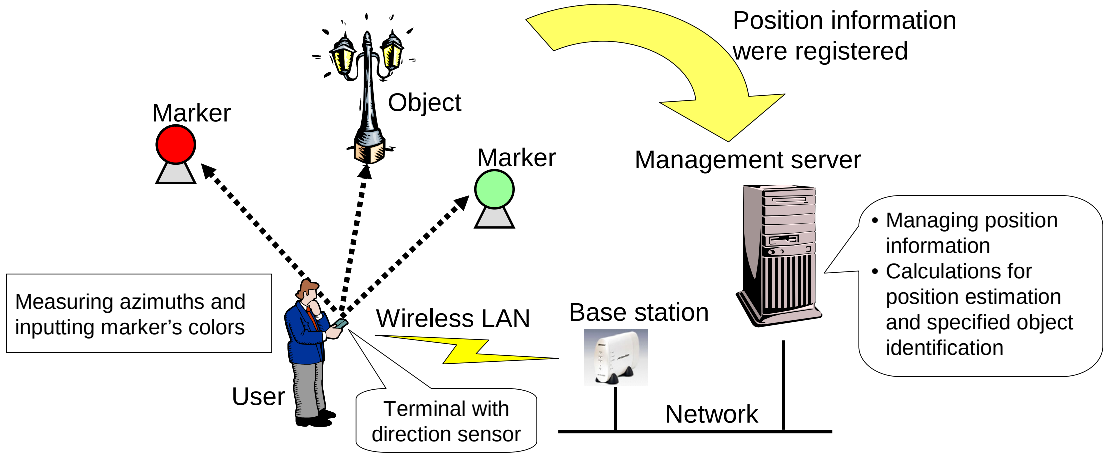

Figure 3. Azim: direction based service system

the user's terminal screen about an object that is pointed to. At 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 method[9] may be used to track the user's position for a short period by 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 within a 50-to-100-meter radius outdoors and within a two-wall area indoors. Applying the position distribution calculation procedure described in Section 3.1, the prior probability $f(p)$ and position space integral range can be confined to this signal reception range. And, 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 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 followings.

- 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, based on the method described in Section 3.
- 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: A marker is some 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

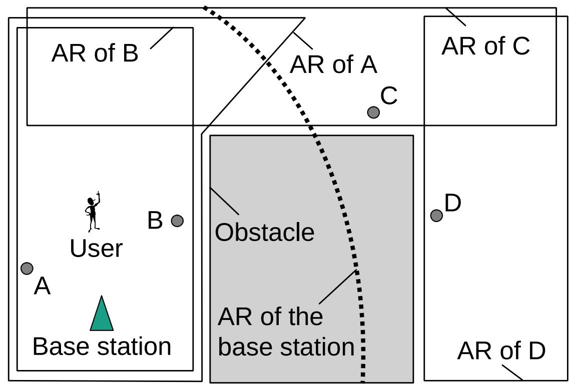

Figure 4. Available region (AR) example

markers and objects can be seen from a particular position, thus enabling the system to make specific calculations using the marker selection model in Section 3.1 and the object selection model in Section 3.2.2. The available region of a base station is the same as 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 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 a 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 at least 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.

3. Probabilistic Approach for Azimuth Based Position Estimation

Since the direction measurements are inevitably 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. In this section, we propose the detail of the probabilistic approach for the azimuth based position estimation.

In the following, actual instances of probabilities (random variables) will be represented by lower-case letters. For example, the actual instance of probability P will be represented by p. Here f represents the distribution function of one or more probabilities (a probability function in the case of discrete values).

3.1. Calculation of Position Distribution

In position estimation, a solution cannot always be derived from the intersection of half-lines along the measured directions from markers. In some cases two half-lines will not intersect at all, and in other cases measurements will be performed more than three times. Even when a solution is obtained, one still does not know how accurate the derived position is. For this reason, we model an error of azimuth measurement, and calculate the user's probable position as a probability distribution.

3.1.1. Introduction of the Probabilities. To formulate the problem, we introduce the following probabilities. Here *specified marker* refers to the marker that has been pointed to (at the *i*th measurement).

- P: User's position (2D vector)
- A_i: Measured azimuth to the specified marker (continuous value)
- C_i: Color of the specified maker (discrete value). Several markers may be represented with the same color.
- M_i: Identifier of the specified marker (discrete value), which uniquely represents the marker that the user is actually pointing to. Each identifier corresponds to just one unique marker.

The user points to a marker along with inputting the color of the marker (i.e., performs a measurement). The user repeats this procedure several times. Let n represent the total number of measurements. A_i, C_i, and M_i are results obtained by each measurement. Note that the system only directly knows A_i and C_i; and M_i is not input.

3.1.2. Azimuth Measurement Model. The azimuth measurement model $f(a_i|m_i, p)$ is a probability distribution, which represents what azimuth is observed when a user points to the marker m_i at the position p.

The true direction of the marker is determined from the marker identifier m_i and the user position p, since the position of the marker is known. The simplest model is a normal distribution with a mean of the true direction. A standard deviation is a model parameter that can be adjusted to the user's pointing skill.

The pre-obtained magnetic field information can also be used to correct an error of an azimuth measurement a_i caused by geomagnetic disturbances.

3.1.3. Assumption of Independence of the Measurements. We assume that when the user's position P is fixed, the ith measurement is not affected by other measurement results (i.e., measurements other than the ith measurement). This means that each measurement result (A_i, C_i) is conditionally independent given P. We can thus assume that the following equation holds:

$$\begin{aligned} & f(c_1, a_1, c_2, a_2, \cdots, c_n, a_n|p) \\ = & \; f(c_1, a_1|p)\, f(c_2, a_2|p) \cdots f(c_n, a_n|p) \end{aligned} \quad (1)$$

By assuming independence, calculation of the position distribution can be simplified.

3.1.4. Formulation of the Position Estimation. The position distribution which is sought is given by $f(p|c_1, a_1, c_2, a_2, \cdots, c_n, a_n)$ — the posterior probability for P when all measurement results c_i, a_i are known — as follows:

$$\begin{aligned} & f(p|c_1, a_1, c_2, a_2, \cdots, c_n, a_n) \\ = & \frac{f(c_1, a_1, c_2, a_2, \cdots, c_n, a_n, p)}{f(c_1, a_1, c_2, a_2, \cdots, c_n, a_n)} \\ = & \frac{f(c_1, a_1, c_2, a_2, \cdots, c_n, a_n, p)}{\int_p f(c_1, a_1, c_2, a_2, \cdots, c_n, a_n, p)dp} \end{aligned}$$

It will also be apparent from Eq. (1) that

$$\begin{aligned} & f(c_1, a_1, c_2, a_2, \cdots, c_n, a_n, p) \\ = & \; f(c_1, a_1, c_2, a_2, \cdots, c_n, a_n|p)\, f(p) \\ = & \; f(c_1, a_1|p)\, f(c_2, a_2|p) \cdots f(c_n, a_n|p)\, f(p) \end{aligned}$$

And,

$$\begin{aligned} & f(c_i, a_i|p) \\ = & \sum_{m_i} f(c_i, a_i, m_i|p) \\ = & \sum_{m_i} \{f(c_i|a_i, m_i, p)\, f(a_i|m_i, p)\, f(m_i|p)\} \end{aligned}$$

Here, $f(c_i|a_i, m_i, p)$, $f(a_i|m_i, p)$, $f(m_i|p)$, $f(p)$ are defined as follows:

- $f(c_i|a_i, m_i, p)$: This represents the color of marker m_i. When the color of marker m_i is c_i, then $f(c_i|a_i, m_i, p) = 1$; otherwise, $f(c_i|a_i, m_i, p) = 0$.
- $f(a_i|m_i, p)$: This is the azimuth measurement model described in Section 3.1.2.
- $f(m_i|p)$: This is the marker selection model of a user. In other words, this represents the probability function of the user selecting a particular marker when the user is at position p and the ith measurement is performed. For example, we adopt a uniform distribution for all markers that can be used (i.e., that can be seen) from position p, which can be obtained by the available regions of markers (see Section 2.6).
- $f(p)$: This is the user's position prior probability. The simplest model is a uniform distribution for the service available area. This distribution can also consider the pre-obtained rough position information, which can be obtained by identifying base stations, or off-limits area like obstacles where the user cannot exist.

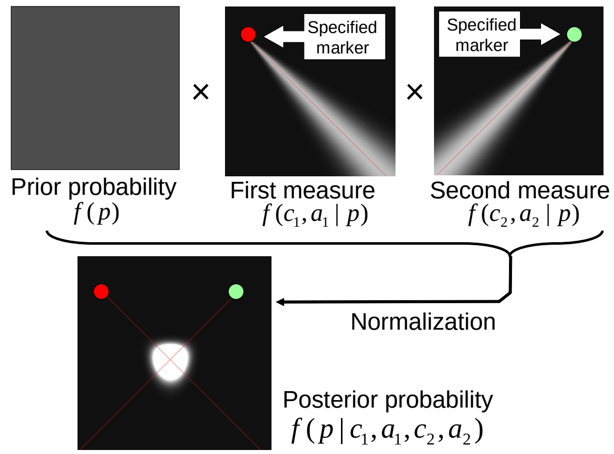

Figure 5. Calculation of position distribution

As above, the distribution can be calculated. 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 somewhere near 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. The squares in the figure represent distribution plots in position space, and the white area shows the area of highest probability for the user's position. As one can see from the posterior probability, it is estimated that the user is near the center of the square area.

3.2. Identifying Specified Objects

Since a user in our approach carries a mobile terminal with a built-in direction sensor, he has access to not only his own position but also the directions pointed to. By utilizing both the position and direction data, this makes it possible to realize more advanced location based services, which we named the direction based service. Examples of the direction based service we have in mind include a service that would permit a user to operate a device remotely or display pertinent information by directly pointing to the device, or a service enabling people to search for a particular kind of facility in the specified direction. To realize these services, in this section we presents a calculation procedure for identifying the object pointed to by a user.

The things that might be pointed to by the user are called *objects*, and the object that is actually pointed to is called a *specified object*. Let us assume that the locations of objects are already known. The specified object can be identified from the user's position distribution calculated by the method presented in Section 3.1 and the azimuth to the specified object.

3.2.1. Introduction of the Probabilities. The following probabilities are introduced to formulate the problem:

- P: User's position (2D vector)
- A: Measured azimuth to the specified object (continuous value)
- S: Identifier of the specified object (discrete value), which represents the object that the user is actually pointing to. Each identifier corresponds to just one unique object.

3.2.2. Formulation of the Identification of the Specified Object. The specified object is identified by calculating the probability distribution that an object is the specified object. The sought probability is given by $f(s|a)$ — the probability of that an object s is the specified object when the direction measurement value a is known — as follows:

$$f(s|a) = f(a,s)/f(a) = f(a,s)/\sum_s f(a,s)$$

$$f(a,s) = \int_p f(a,s,p)dp$$

$$f(a,s,p) = f(a|s,p)\ f(s|p)\ f(p)$$

Here, $f(a|s,p)$, $f(s|p)$, and $f(p)$ are defined as follows:

- $f(a|s,p)$: This represents what azimuth is observed when a user points to the object s at the position p. Just like the case of a marker, $f(a|s,p)$ can be calculated from the azimuth measurement model (see Section 3.1.2).
- $f(s|p)$: This is the object selection model of a user. In other words, this represents the probability of the selecting a particular object when the user is at position p. For example, we adopt a uniform distribution for all objects that can be seen from position p, which can be obtained by available regions of objects (see Section 2.6).

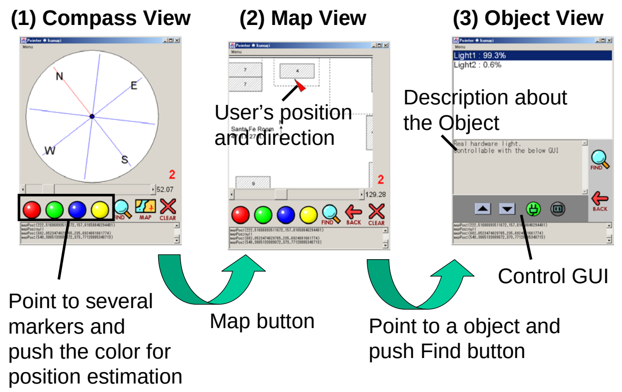

Figure 6. Screenshots of the client terminal

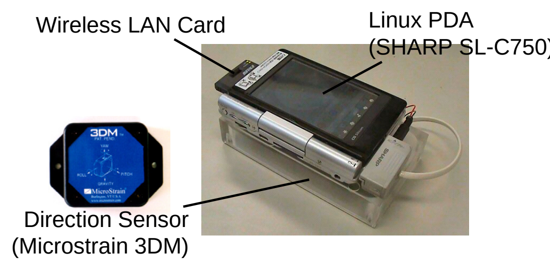

Figure 7. LocPointer: portable client terminal using the Linux PDA

- $f(p)$: This is the user's position probability, which is the position distribution acquired by the calculation in Section 3.1.

4. 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.[7] that combines a three-axis magnetic compass with a three-axis accelerometer. For the software development environment, we used Java 2 Platform SDK 1.3 and *cogma* [10] 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 conpass view like Fig.6(1). A user points to the direction of a marker and pressing the button for that marker's color, then repeating 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 pressing the Find button (hand lens button), then the system identifies the specified object, and displays the candidates for the specified object 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.

- 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 cogma[10] 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[11] on the client terminal display.

Using the procedure outlined in Section 3, 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 (see Section 3.1.2).

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*.

5. Evaluation

An experiment was carried out on the prototype system to evaluate the accuracy of the proposed position estimation method. We are confident that our method will prove effective across a wide range of environments both indoor and outdoor, but the trial was conducted in an outdoor environment that is little affected by geomagnetic disturbances. Fig. 8 shows a schematic overview of the trial site.

Markers were set up in two locations at opposite ends of a building (Building A in the figure). The distance between the two markers was 30.5 meters. The proposed method was used to estimate the positions of 20 different points scattered in the vicinity of the markers. A measuring device consists of the 3DM direction sensor [7] for azimuth measurements and a guide stick to help aiming. We pointed at the two makers and measured the azimuths (*pointing* measurements). Ten measurements were conducted at each point. Moreover, in order to assess the degree of error caused by the pointing operation itself, we sighted through the guide stick with one eye, and conducted a measurement with the measuring device accurately aimed right at the marker (*guided* measurements). The exact correct positions of the measurement points were determined by measuring the distance from the two markers to each point with an ultrasonic range finder (STMS-850B).

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 (ten estimates) based on the *pointing* measurements. Since the user's position is calculated as a probability distribution in our approach, the positions are the estimated as a center of gravity of the distribution. Finally, the symbols with the dot in the middle are the estimated positions obtained by the *guided* measurements. To make the findings a bit easier to understand, we enclosed the measurement results for each point with a dotted line. We also adopted different shaped symbols (triangles, squares, circles), just to make the results easier to discriminate. Measurement results for the same point are represented using the same symbol shape.

We found that the positions estimated by our method (the pointing measurements) diverged from the correct positions by 2.7 meters on average. Yet the figure also reveals much larger disparities from the true positions for points 1, 2, 3, and 8. We attribute these larger disparities to magnetic disturbances due to rebar in the concrete, steel sheets, and so on, which caused the distortion of measured azimuth data.

Indeed, we found that the estimated positions using the guided measurement to aim in the correct direction also diverged from the correct positions by an average of 3.1 meters, so it is clear that the measured azimuths include error caused by geomagnetic disturbances. At the same time, we also found that the average distance between the positions estimated by the pointing measurements and by the guided measurements was only 1.35 meters, which are relatively close. In addition, the distribution of relative azimuth (where a negative value is also possible) between the pointing measurements and guided measurements averaged $+0.34$ degrees with a standard deviation of 3.3 degrees. This indicates that the adverse effects of errors caused by the pointing operation itself were relatively small, and it should be possible to substantially improve the positioning accuracy by correcting the azimuth measurement disparity caused by geomagnetic disturbances. If we can obtain an average positioning accuracy of 1.35 meters by compensating for the geomagnetic disturbances, this would be precise enough for the direction based service such that a user specifies objects by pointing in outdoor environments. We would also note that, since the estimation accuracy is basically proportionate to the distance between markers, for situations requiring greater accuracy, a higher degree of po-

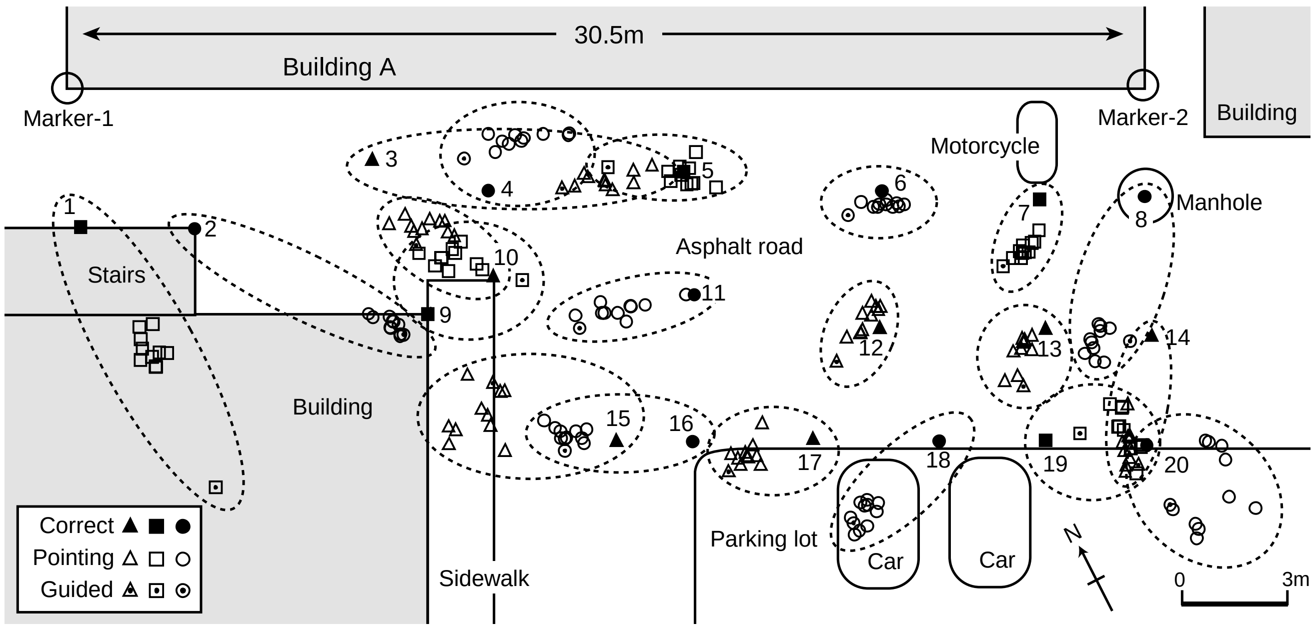

Figure 8. Estimated positions

sition estimation accuracy could be achieved by deploying the markers more densely.

Although the proposed method has good potential for indoor use as well, indoor environments are especially prone to high levels of geomagnetic disturbance. For example, we found that in our own research laboratory, the reading for magnetic north was about 40 degrees off from true north. Developing a reliable technique to correct such large azimuth measurement disparities is therefore especially critical for indoor environments. Assuming that magnetic directions will not change over time, we could measure magnetic directions in various locations throughout the service area, and learn the spatial distribution of magnetic fields for the area. Then, when calculating the azimuth measurement model $f(a_i|m_i,p)$ as described in Section 3.1.2, we could use the learned spatial distributions of magnetic fields to correct the azimuth measurement value a_i.

6. Related Research

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

6.1. 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[12], 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 time-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 on the environment side everywhere.

Another approach that has been suggested for position measuring uses the RF signal strength from (or to) several wireless LAN base stations[13][2]. In our proposal, this approarch can also be used to improve the accuracy of the preobtaind 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 [14] 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 learn 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 5, we can use a similar approach in which a robust position measurement is achieved even in the face of geomagnetic fluctuations, by learning 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 learning magnetic field distributions, 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 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.

6.2. 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 rich 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 service exists* by sweeping around with the client terminal. If the service exists in the direction, the terminal informs by sound or vibration.

6.3. Image Recognition Based Identification of Specified Object

Several methods using image recognition have been proposed for identifying specified objects. For example, InfoPoint [15] attaches a 2D matrix barcode describing ID information to an object. Then, by shooting the object with a camera-equipped mobile terminal, the system can identify objects pointed to by the user. One problem with this approach is that it is difficult to read the barcode when it is some distance from the object. In AirReal [16], a camera is attached to the wall of a room, and image recognition is applied to obtain the coordinates that are pointed out by the user with a laser pointer. The obvious limitation of this approach is that the system can only be used in places where the camera is set up to shoot. By contrast, our approach involves minimal cost for equipment on the environment side, and can also be used over a wide range of environments.

7. Conclusions

In this paper, we have proposed a system named *Azim* that provides the direction based service, which based on both location and direction information 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 exemplify the usefulness of our approach through an experiment.

There are a number of areas calling for further study. First, research should focus on an easy method for learning the spatial distribution of magnetic fields. Learning the magnetic distribution, we could obtain accurate position measurements even for environments exhibiting geomagnetic fluctuations, as suggested in Section 5. One approach is to combine another position measurement sensor in the learning phase. The learning is carried out by moving over the service area with this sensor. An alternative method is to perform positioning estimates using relative angles between markers in the learning phase. Specifically, by treating the distortion of geomagnetic direction as a variable, a user's position could be narrowed down by measuring azimuths of more than three markers. Spatial distributions of magnetic fields are naturally learned through a process of repeated position estimation using relative angles at the beginning stage.

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.

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