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Azim: Direction-Based Service System for Both Indoors and Outdoors

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SUMMARY In this paper, we propose an advanced location-based service that we call a *direction-based service*, which utilizes both the position and direction of a user. The direction-based service enables a user to point to an object of interest for command or investigation. We also describe the design, implementation and evaluations of a direction-based service system named Azim. With this system, the direction of the user can be obtained by a magnetic-based direction sensor. The sensor is also used for azimuth-based position estimation, in which 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 this approach does not require any other accurate position sensors or positive beacons, it can be deployed cost-effectively. Also, because the measurements are naturally associated with some degree of error, the position is calculated as a probability distribution. The calculation considers the error of direction measurement and the pre-obtained field information such as obstacles and magnetic field disturbance, which enables robust position measurements even in geomagnetically disturbed environments. For wide-area use, the system also utilizes a wireless LAN to obtain rough position information by identifying base stations. We have implemented a prototype system for the proposed method and some applications for the direction-based services. Furthermore, we have conducted experiments both indoors and outdoors, and exemplified that positioning accuracy by the proposed method is precise enough for a direction-based service.
key words: *location-based service, direction-based service, direct manipulation interface, magnetic compass, mobile computing, ubiquitous networks, wireless LAN*

1. Introduction

As cell phones and other types of mobile terminal 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) 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, though it can be fairly costly to deploy the system's 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 indoors and outdoors.

In this paper, we propose a system named *Azim* that provides a location-based service founded on both the location and direction of a user. The direction of the user is obtained by a direction sensor based on a magnetic compass. The sensor is also used for azimuth-based position estimation. A user's position is estimated by having the user manually point to and measure azimuths of several markers or objects whose positions are already known. This approach does not require any other accurate position sensors or positive beacons, and it can be deployed cost-effectively.

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 about their privacy, because the position is never acquired without the user's intention. Since not only the user's positions but also directions are acquired in this approach, both the positions and directions can be used to develop 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 is organized as follows: In Sect. 2 we present a direction-based service system named Azim that combines azimuth-based position estimation with a wireless LAN. In Sect. 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

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Azim prototype system implemented with a direction sensor that combines a magnetic compass with an accelerator, and Sect. 5 discusses experiments to assess the performance of the prototype system. Section 6 surveys some other studies that are related to this research, and Sect. 7 concludes the paper and highlights a number of issues for the future.

2. Azim: Direction-Based Service System

In this section we present the *Azim* system, which supports a direction-based service that is an advanced location service based on both the location and the direction of a user. This system employs hand-operated position estimation technique based on azimuths toward several markers. 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.

2.1 Hand-operated Position Estimation Based on Azimuths

We first propose a hand-operated position-estimation technique based on azimuths toward several objects. 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 manually point to several markers and measuring the azimuths toward the markers. As illustrated in Fig. 1, the azimuth is the absolute angle of horizontal deviation from north as the origin, and is measured by a mobile terminal with a built-in direction sensor. Figure 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 explained in Sect. 3.

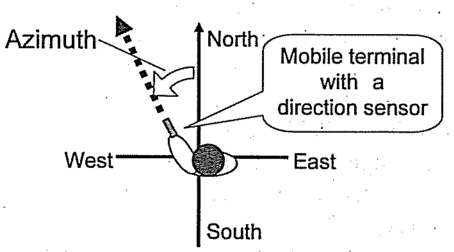

Fig. 1 Azimuth acquired by a direction sensor.

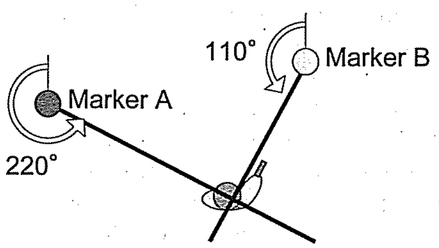

Fig. 2 Hand-operated position estimation based on azimuths toward several markers.

When acquiring a position with this method, the system has to know toward which markers the user was pointing. For this purpose, we distinguish the markers by color (or shape etc.), and have the user push a corresponding color-coded button to narrow down the markers being pointed to. To make the system available across wide areas, 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 Sect. 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 object instead of a color.

2.2 Direction Sensor

There are direction sensors available for measuring absolute azimuth from north as the origin, which consist of a magnetic compass and an accelerometer. Note that north means magnetic north here, not true north on the map. Two available devices with these capabilities are *3DM*, manufactured by Microstrain [7], and *3D Motion Sensor*, manufactured by NEC Tokin [8]. With a magnetic compass capable of measuring geomagnetic direction and an accelerometer capable of measuring gravitational force direction, the system can acquire the direction (i.e., the pitch, roll, and yaw angle) of a device without any other special equipments.

2.3 Typical Usage Model

Figure 3 is a schematic representation of the system architecture. The user first measures his or her 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 the displaying of information on the user's terminal screen about

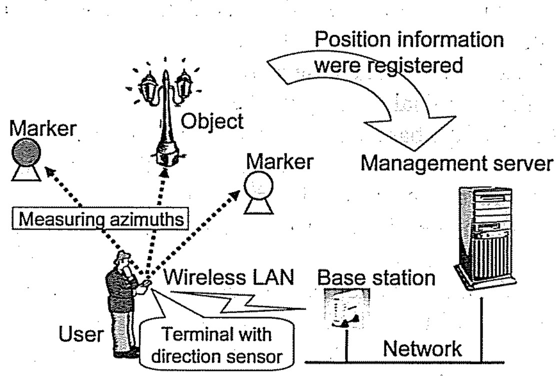

Fig. 3 Azim: direction-based service system.

the object that is pointed to. From the same position, the user can also point to other objects. If the user moves and changes his or her 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 [9] may be used to track the user's position for a short 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 to which the client terminal is connecting. 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 a 50-to-100-meter radius when there are no obstacles. Applying the position estimation procedure described in Sect. 3.1, the prior probability $f(p)$ 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 even if there are other same-colored markers outside that 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 stations: The base stations of wireless LAN. The client terminal can acquire the identifier (MAC address, etc.) of the base station to which it is connecting.
- Markers: Objects or landmarks that the user points to in order to measure his or her 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: Things that a user might point to for application services, including a device or piece of equipment, a shop, a landmark, and so on.

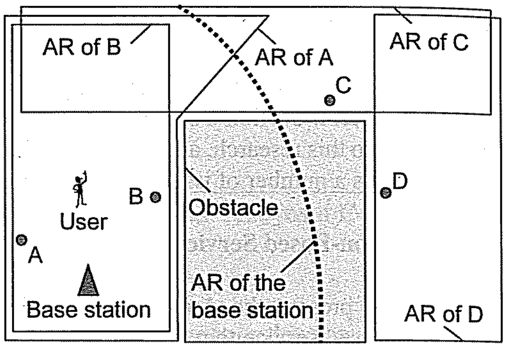

Fig. 4 Available region (AR) example.

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 user's marker selection model and object selection model in Sect. 3. The available region for a base station means the signal reception range of the base station, and as noted earlier in Sect. 2.4, this is used to roughly determine a user's position.

Figure 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 to which a client terminal is connecting, the system can know that the user is currently within the available region of that base station. Only when the available region of a marker overlaps with the available region of that base station can the marker be regarded as a specified marker. For example, consider the points A through D in Fig. 4 as markers. The user cannot point to marker D even if the user is somewhere within the available region of the base station. Considering the marker color scheme, for each base station, the markers whose available region overlaps with the available region of the base station should be assigned a unique color, so that the system can identify the specified marker uniquely.

Let us next assume that the user's position has been calculated. Only when the available region of an object overlaps with the probable position of the user (i.e., high probability area of position distribution) is the user able to point to that object. This way, objects which cannot be seen by the user are never estimated as candidates for specified objects. For example, consider the points 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

Direction measurements by a user include a certain degree of error, which are caused by user's pointing operation itself and geomagnetic field disturbance by metallic objects. Simply calculating the intersection of the half-lines is insufficient, because no accuracy information is acquired, and sometimes there is no intersection (e.g. two half-lines do not intersect, or there are three measurements). Thus, we model an error of azimuth measurement and calculate the user's probable position as a probability distribution.

The calculation of the position distribution can utilize the following various location-based information; first, influence of obstacles, such as off-limit areas where a user cannot go, and occlusions of objects or markers (see Sect. 2.6); second, rough position information by wireless-LAN base stations (see Sect. 2.4); third, by using pre-obtained magnetic-field distribution, robust measurements can be achieved even in environments of high geomagnetic disturbance.

In this section, we describe the details of the probabilistic approach for 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 Estimation

First, we present a calculation procedure for the probability distribution of a user's position. To formulate the problem, we introduce the following probabilities. Here *specified marker* refers to the marker that has been pointed to (at the ith 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 to which the user is actually pointing. 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), and repeats this procedure several times. Let n represent the total number of measurements; A_i, C_i, and M_i are results obtained from each measurement. Note that the system only directly knows A_i and C_i, but not M_i.

3.1.1 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. The standard deviation 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.

3.1.2 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:

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

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

3.1.3 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:

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

It will also be apparent from Equation (1) that

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

And,

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

Here, $f(c_i|a_i, m_i, p), f(a_i|m_i, p), f(m_i|p), f(p)$ are de-

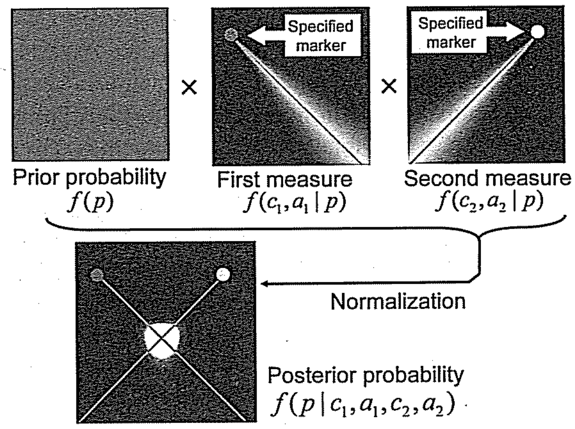

Fig. 5 Calculation of position distribution.

fined 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 Sect. 3.1.1.
- $f(m_i|p)$: This is the marker selection model of a user. In other words, it represents the probability function of the user selecting a particular marker when the user is at position p and performing the ith measurement. 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 Sect. 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 (see Sect. 2.4), or off-limits areas like obstacles where the user cannot go.

Figure 5 shows examples of calculations when azimuths toward 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 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 color represents the highest probability. As one can see from the posterior probability, it is estimated that the user is near the center of the area.

3.2 Calculation of Identifying Specified Objects

Then, we present a calculation procedure of identifying the object pointed to by a user. Here, 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*. The positions of objects are known. The specified object can be identified from the user's position distribution calculated by the method presented in Sect. 3.1 and the azimuth to the specified object. 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 to which the user is actually pointing. Each identifier corresponds to just one unique object.

The specified object is identified by calculating $f(s|a)$—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 Sect. 3.1.1).
- $f(s|p)$: This is the user's object selection model. In other words, this represents the probability of 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 Sect. 2.6).
- $f(p)$: This is the user's position probability, which is the position distribution acquired by the calculation in Sect. 3.1.

4. Implementation

We have implemented a prototype of the proposed direction-based service system [10]. For the azimuth measurements, we employed the *3DM* direction sensor manufactured by Microstrain [7] 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. Figure 6 shows several screenshots of the client terminal. The current pointing azimuth is displayed in the compass view like in Fig. 6(1). The user points in 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 or her position on the map view like in Fig. 6(2). The user then points in the direction of an object and presses the Find button (hand lens button), after which 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.

- 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 Sect. 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 Sect. 3.1.1).

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*.

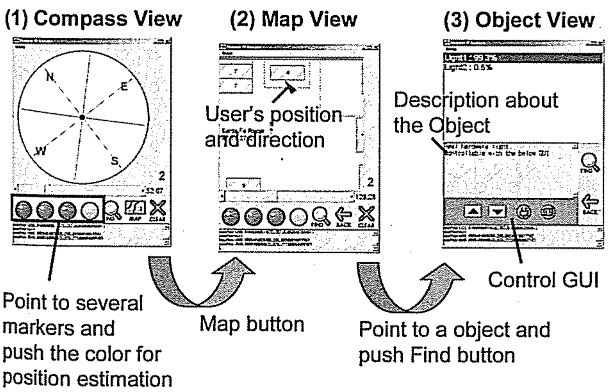

Fig. 6 Screenshots of the client terminal.

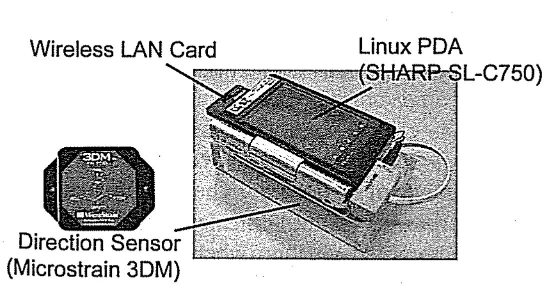

Fig. 7 LocPointer: portable client terminal using a Linux PDA.

5. Evaluation

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

5.1 Experiment 1 (Outdoors)

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

Markers were set up in two locations (Markers A and B in the figure) 30 meters apart. The proposed method was used to estimate the positions of 14 different points scattered in the vicinity of the markers. The subject pointed at each of the two makers and measured the azimuths by the LocPointer (described in Sect. 4). 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, while the 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. 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 fell within 2.8 meters). We think that this positioning accuracy is precise enough for

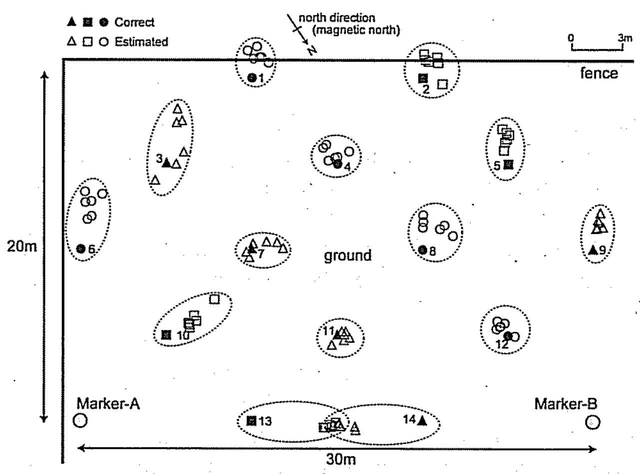

Fig. 8 Estimated positions. (outdoors; 2 markers)

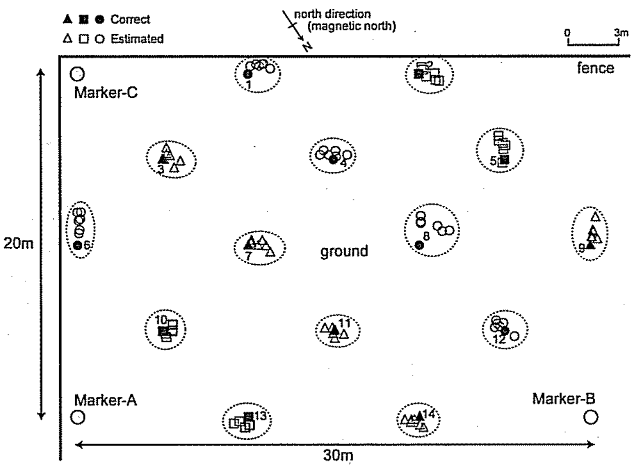

Fig. 9 Estimated positions. (outdoors; 3 markers)

the direction-based service where a user specifies objects by pointing in outdoor environments. We 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 points 13 and 14 in Fig. 8, the estimation accuracy was relatively inferior, though if the relative angle between the two specified markers was close to a right angle (90 degrees), the estimation accuracy was relatively good. Thus it is a good idea to deploy more than two markers in the service field, and a user can select two desirable markers, or simply measure the azimuths of all markers.

By measuring azimuths of more than two markers, the positioning accuracy and robustness improve. Figure 9 shows estimated positions when the subject points to the three markers (Markers 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 fell within 1.1 meters). Note that positioning accuracy was stable at all the positions, even between the markers.

5.2 Experiment 2 (Indoors)

Second, we conducted a trial in an indoor environment, which is our test-bed room for the ubiquitous computing environment named Cogma Room. In this room, there are four markers (Markers 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 suffer geomagnetic disturbance. To correct a azimuth measurement disparities, we obtained a spatial distribution of the magnetic field by sampling a magnetic vector at some points in the room. Figure 11 shows the interpolated magnetic field information (abbreviated as

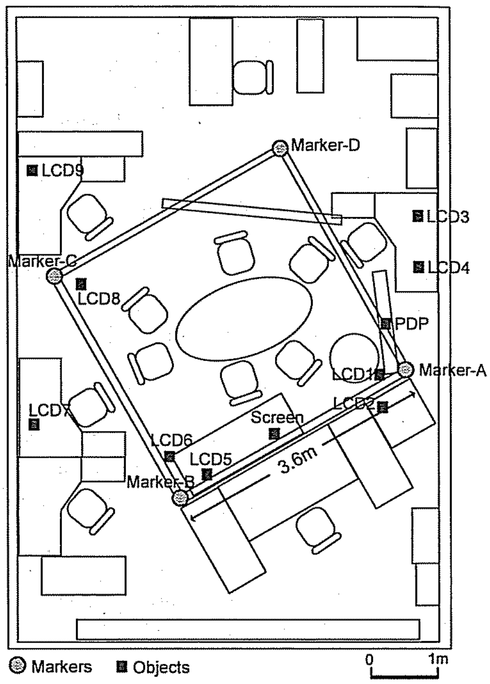

Fig. 10 Map of objects in the indoor environment.

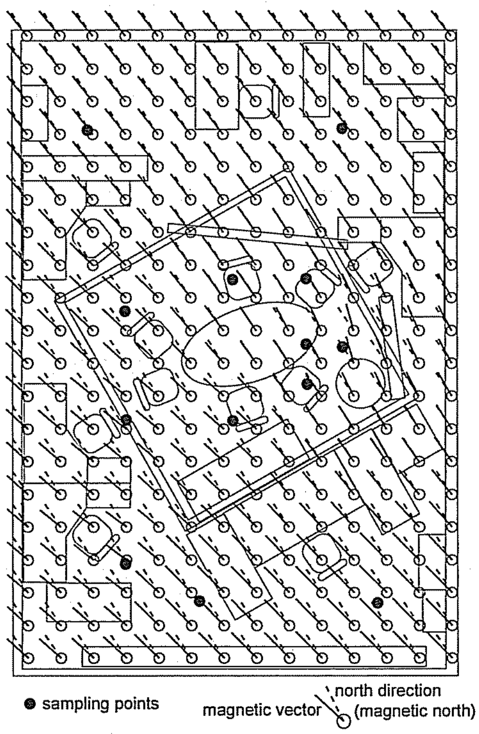

Fig. 11 Pre-obtained magnetic field information. (MFI)

MFI hereon), 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 was used to correct the azimuth measurement (a_i of

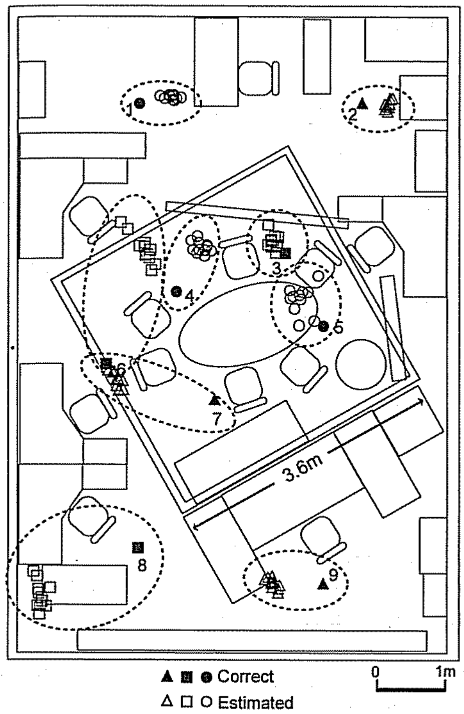

Fig. 12 Estimated positions without the MFI.

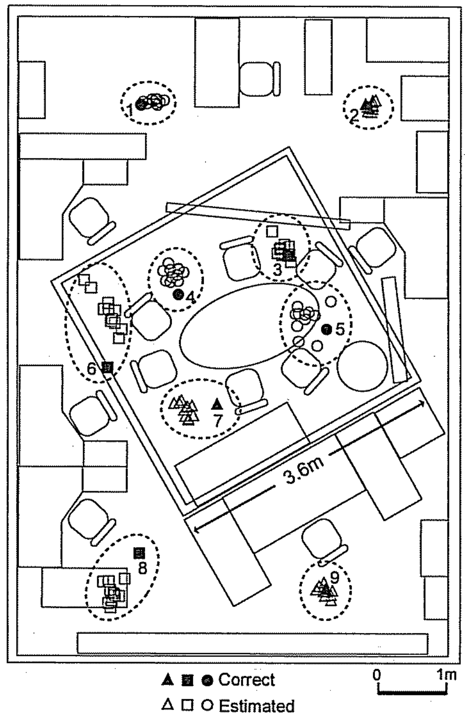

Fig. 13 Estimated positions using the MFI.

$f(a_i|m_i, p)$ in Sect. 3.1.3, and a of $f(a|s, p)$ in Sect. 3.2). To evaluate the advantage of using the MFI, we compared the two estimations—*without the MFI*, in which magnetic vectors are assumed to be parallel to the magnetic north direction anywhere, and *using the MFI*.

We conducted a trial at nine points in the room, shown as Points 1 – 9 in Fig. 12. At each point, the hand-operated position estimation based on the proposed method was conducted eleven times by pointing to two markers with the LocPointer. The two used markers were Markers A and B at Points 3, 4, 6, 9; B and C at Points 5, 8; C and D at Points 1, 7; D and A at Points 2.

The estimated positions without the MFI are shown in Fig. 12. Just like in Experiment 1, the solid black symbols show the correct positions of the measurement points, while the 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 fell within 1.51 meters). On the other hand, the estimated positions using the MFI are shown in the Fig. 13. Here, the estimated positions diverged from the correct positions by 0.35 meters on average (80 percent of measurements fell within 0.60 meters). The two estimations (without and with the MFI) are based on the same measurement data. These results means that the accuracy of the estimated positions is improved by using the MFI. Consequently, the proposed position estimation method is also useful even in indoor environments when the MFI is employed.

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

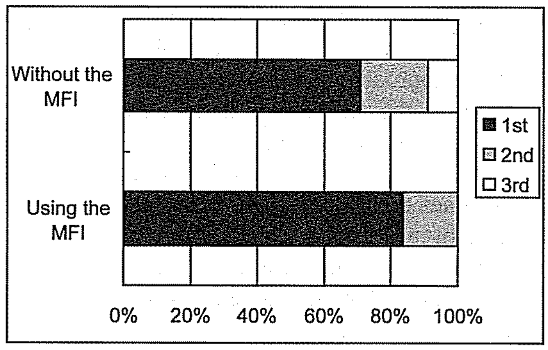

Fig. 14 Order of the specified object in the estimated list.

identifies the specified display using the position distribution and the display direction (described in Sect. 3.2). The result of the estimation is a list of the estimated objects in order of probability from highest to lowest. The measurements were conducted only on Points 3–7, because the displays were out of sight from the other points. Figure 14 shows the proportion of the order of the specified object in the estimated list. Using the MFI, the specified object is at the top of the estimated list in 84 percent of the measurements, whereas the value is 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 will be improved by the use of three-dimensional information such as the altitudes of objects and the elevation angle (pitch) of the pointing device, since some of the objects overlap at an azimuth angle but not at an elevation angle. We will consider this in our future work.

6. Related Research

In this section we differentiate the current research from other related studies with respect to several aspects.

6.1 Position Acquisition Technologies

GPS-based methods of position acquisition are now widely available [5]. In outdoor environments where there is an unobstructed line of sight, GPS enables positioning accuracy to within 10 meters. 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 a base station fixes on the GPS satellites and provides this information to cell phones to cut the time for a cold-start. Another location measurement technique for indoor environments is the Active-BAT location system [6], which uses ultrasound times-of-flight to ultrasonic receivers whose position are known. The major drawback of both these systems is that they tend to be quite costly to deploy 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 [2], [14]. In our proposal, this approarch can also be used to improve the accuracy of the pre-obtained 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. Ladd et al. [15] describe 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 produces position measurements that are robust against fluctuating RF signals. As described in Sect. 5, 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 hand-operated position estimation method in comparison with 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 as markers, then no dedicated markers need to be deployed at all. Moreover 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 indoors and outdoors.
- **Low-cost Client Terminal:** For the direction-based service, both the user's position and azimuth data are obtained from only a 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 after the mobile terminal is turned on.
- **Privacy:** As long as the user does not intentionally measure his own position, the user's precise 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 has been proposed. In the SpaceTag system [4], information can be accessed only from limited locations and for limited time periods. The Kokono Search service by 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 ultrasonic 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 it 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 or she is*. More specifically with direction data, the user can obtain information about *what he or she sees* or *points to*. We have also planned a direction-based search service, where the user can receive information about *in which direction the desired service exists* by sweeping around with the client terminal. When the service exists in the specified direction, the terminal informs the user by sound or vibration.

6.3 Identification of Specified Object Based on Image Recognition

Several methods using image recognition have been proposed for identifying specified objects. For example, InfoPoint [16] 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 [17], 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 cameras are already set up. 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

This paper described the design, implementation and evaluations of a direction-based service system named Azim, which is based on both the location and the direction of a user. In Azim, the user's position is estimated by having the user manually point to and measure azimuths of several markers whose positions are already known. Azim uses a wireless LAN to support these services. Finally, a prototype system was implemented using a direction sensor that combines a magnetic compass and a accelerometer, and we exemplified the utility of our approach through experiments in both indoor and outdoor environments. Using two markers outdoors separated by 30 meters, the positioning error was 1.9 meters on average. When using three markers, the error was 0.78 meters on average. Furthermore, using two markers indoors separated by 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 investigation. First, further study is required to develop an easy method for learning the MFI (see Sect. 5.2), for example, employing another positioning method, such as using only relative azimuths, in the beginning phase. Magnetic field information grows with daily use.

Second, although for simplicity we assumed that the position coordinate system was a two-dimensional plane, 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.

Third, the location information of objects is managed by a unique central server in the current system. However, when using the system in wide areas, the location information and client terminals management should be distributed for scalability.

Fourth, the usability of the hand-operated position estimation method should be evaluated, because a user may feel inconvenienced by having to point to several markers. The pointing operation consumes only a few seconds, thus we believe that the user will accept the operation once the variety of application services is rich enough.

Finally, we have proposed a direction-based service that is an advanced location-based service. Not only can a user intuitively specify the object by pointing, but the user can also expect the direction-based service system to produce many kinds of novel application. For example, a direction-based search service, where the user can find out in which direction the desired service exists by sweeping around with the client terminal.

Acknowledgments

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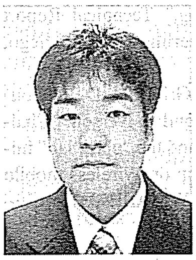

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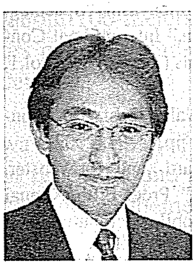

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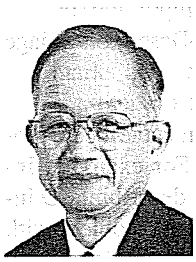

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