A Wearable Augmented Reality System Using Positioning Infrastructures and a Pedometer

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Abstract

This paper describes a wearable augmented reality system using positioning infrastructures and a pedometer. To realize augmented reality systems, the position and orientation of user's viewpoint should be obtained in real time. The proposed system measures the orientation of user's viewpoint by an inertial sensor and the user's position using positioning infrastructures in environments and a pedometer. The system specifies the user's position using the position ID received from RFID tags or IrDA markers which are the components of positioning infrastructures. When the user goes away from them, the user's position is alternatively estimated by using a pedometer. We have developed a navigation system using the proposed techniques and have proven the feasibility of the system with experiments.

1. Introduction

Since computers have made remarkable progress in resent years, a wearable computer can be realized[1, 2]. At the same time, Augmented Reality (AR) which merges the real and virtual worlds has received a great deal of attention as a new method for displaying information[3, 4, 5]. If we construct an annotation overlay system for real scene using an AR technique with a wearable computer, it can be applied for many applications[6, 7, 8, 9, 10]. Figure 1 shows an example of the annotation overlay system which imposes annotations on the real scene using AR techniques with wearable computers.

Figure 1. An example of a wearable AR application.

To realize AR systems, the position and orientation of user's viewpoint are needed for acquiring the relationship between the real and virtual coordinate systems. Usually, Global Positioning System (GPS) is used to measure the user's position outdoors[11]. In AR systems which use GPS, a differential GPS[12] or a real time kinematic GPS is used to measure the user's position accurately. However, since both of them need radio communication to correct GPS data, the hardware configuration of the system will be complicated. Moreover, GPS cannot be used indoors. Therefore, if we construct a wearable AR system which can be used both indoors and outdoors, we must combine other positioning methods which can be used indoors such as an electro-magnetic sensor[13] or image markers. Thomas et.al. constructed a wearable AR system which can be used both indoors and outdoors combining a differential GPS and image markers[14]. However, there remain some problems such that the hardware configuration of the system is complicated and the system needs to switch the sensors between indoors and outdoors.

The purpose of the present work is to construct a wearable annotation overlay system which can be used both indoors and outdoors seamlessly. In this paper, we propose a wearable annotation overlay system using positioning infrastructures and a pedometer. Positioning infrastructures are used for specifying the user's position at appointed points, and the pedometer is used for estimating the user's position by measuring the user's movement. Moreover, an

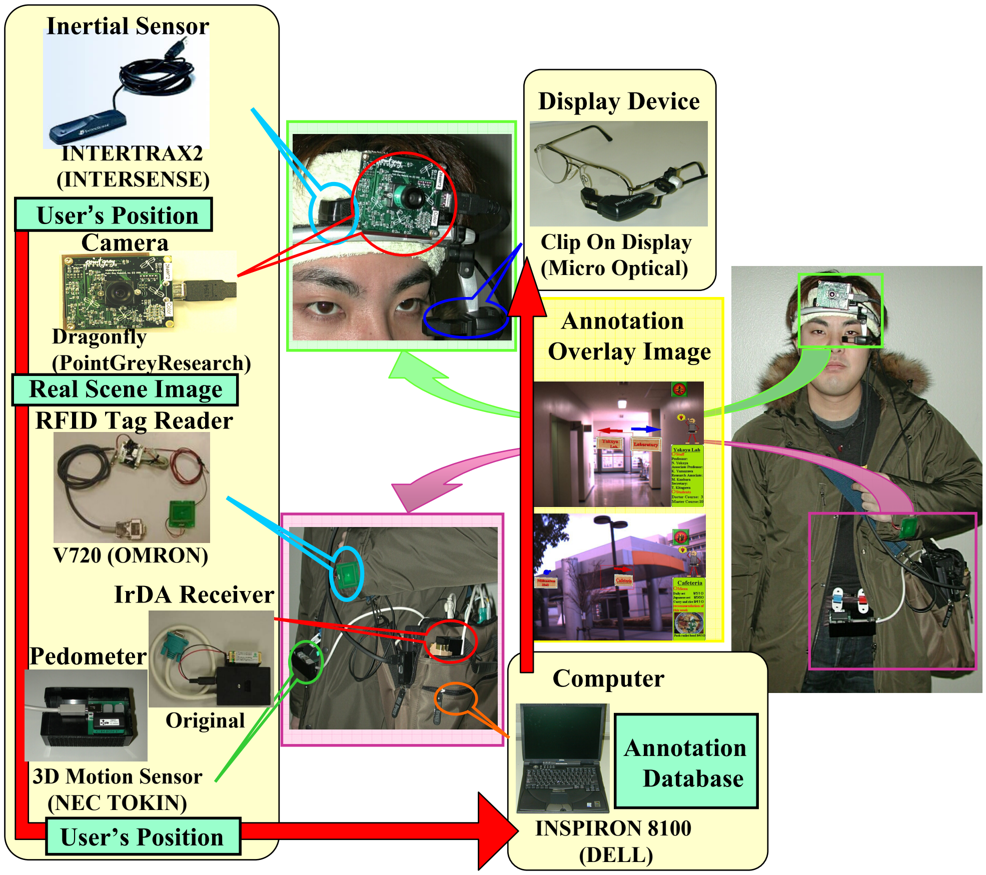


Figure 2. Hardware configuration of the proposed system.

inertial sensor which is attached to the headset detects the orientation of the user's viewpoint. The system generates annotation overlay images from information such as the position, the orientation, and the database of annotations that are held in a wearable computer, and shows annotation overlay images to the user in real time through a display device attached to the headset.

This paper is structured as follows. Section 2 describes the proposed wearable AR system using positioning infrastructures and the pedometer. In Section 3, experimental results with a prototype system are described. Finally, Section 4 describes summary and future work.

2. Wearable Annotation Overlay System

In this chapter, our proposed wearable annotation overlay system is described in detail. In Section 2.1, the hardware configuration of the proposed system is described. Section 2.2 and 2.3 describe how the system measures the user's position and orientation respectively. Section 2.4 describes the method of generating annotation overlay images.

2.1 Hardware Configuration of Prototype System

Figure.2 shows a hardware configuration and data flow of the proposed wearable augmented reality system. The user equips five sensors, a notebook PC and a display device. Five sensors can obtain the position and orientation of the user's viewpoint and the real scene image. These data are sent to a notebook PC. The notebook PC generates annotation overlay images from these data and a database of annotations stored in the PC. The notebook PC sends annotation overlay images to a display device which is attached to the user's headset. The user can see it through the display device. Components of the proposed system are described in more detail in the following.

Sensors The user equips following five sensors. Electric power of them is supplied from the notebook PC or a 9V battery. The data is transmitted to the computer through USB, IEEE1394, or serial connection.

Inertial sensor (Intersense: InterTrax^2) An inertial sensor is attached to the user's headset and measures the orientation of the user's viewpoint. The inertial sensor can obtain data at 256Hz.

Camera (Point Grey Research: Dragonfly) A camera is attached to the user's headset and captures the real scene image from the user's viewpoint. It can capture RGB 24bit color image of 640×480 pixels. The camera can capture the image at 30 frames per second.

IrDA receiver (Original) An IrDA receiver is attached to the user's bag as shown in Figure 2. The IrDA receiver can receive infrared ray including position IDs.

RFID tag reader (OMRON: V720): An RFID tag reader is attached to the user's wrist as shown in Figure 2. The RFID tag reader can read the position IDs recorded in RFID tags.

Pedometer (NEC TOKIN: 3D motion sensor) A pedometer can measure pitch, roll, and yaw. It can also measure accelerations in the horizontal directions. The pedometer can obtain data at 125Hz.

Computer (DELL: Inspiron8100, PentiumIII 1.2GHz, 512Mbytes memory) A computer is carried in the user's shoulder bag. It has a database of annotation information for generating annotation overlay images.

Display device (MicroOptical: Clip On Display) A display device is a video see-through display device. It is attached to headset as shown in Figure 2. It can present a 640×480 color image to the user. Power is supplied from a control box which is carried in the user's shoulder bag.

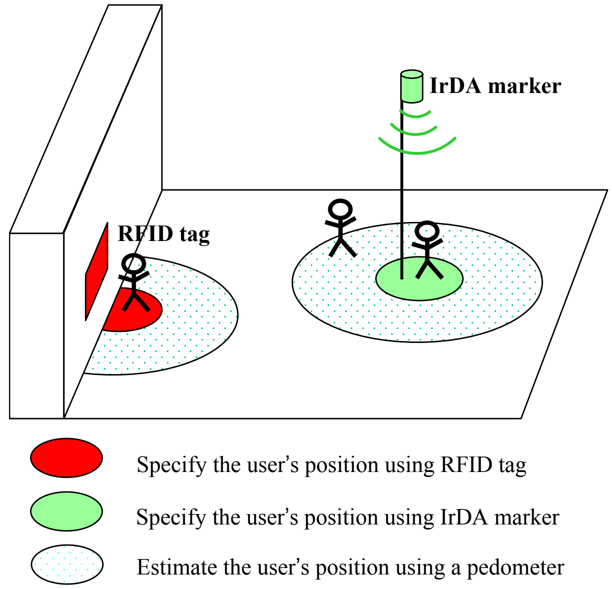


Figure 3. Method for measuring the user's position.

(a) RFID tags.

(b) RFID tag reader.

Figure 4. RFID tags and a tag reader.

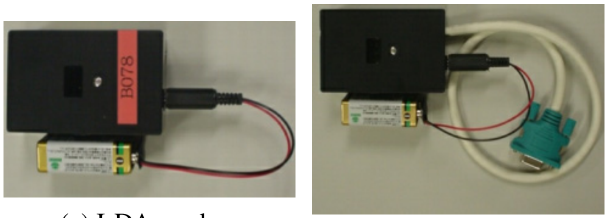
2.2 Measurement of User's Position

The proposed system measures the user's position indoors and outdoors using positioning infrastructures and a pedometer as illustrated in Figure 3. The system identifies the user's accurate position using positioning infrastructures when the user is near the components of positioning infrastructures. If the user goes away from them, the user's position is estimated by using a pedometer. An accumulative error of the pedometer is corrected when the system receives the position ID again.

2.2.1 Identification of User's Position Using Positioning Infrastructures

In this paper, RFID tags and IrDA markers are used as the components of positioning infrastructures. The components of positioning infrastructures have their own position IDs, and the user equips the sensors which can receive position IDs. The position ID which is recorded in a RFID tag shown in Figure 4(a) can be read by bringing a tag reader shown in Figure 4(b) to the RFID tag. It is also possible to transmit the position ID by receiving infrared ray from IrDA markers shown in Figure 5(a) with an IrDA receiver in Figure 5(b). In our approach, RFID tags and IrDA markers are set up to the appointed points as components of positioning infrastructures, and the system can specify the user's position receiving position IDs with the RFID tag reader or the IrDA receiver that are put on the user.In the following, characteristics of these two devices are explained in detail.

IrDA device : Figure 6 shows an example of arranging IrDA markers. The user equips an IrDA receiver which can identify IrDA markers on the shoulder bag as shown in Figure 2. IrDA markers always send their unique position IDs. When the user comes into the in-



(a) IrDA marker.

(b) IrDA receiver.

Figure 5. IrDA receiver and marker.

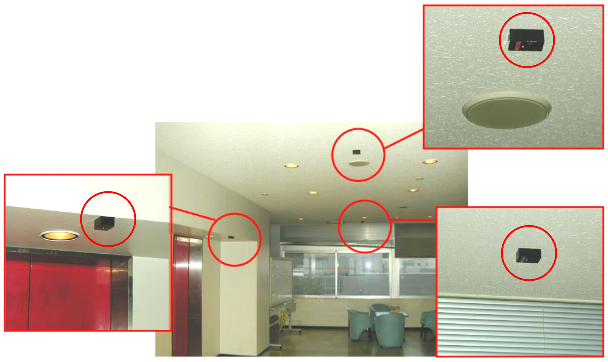


Figure 6. An example of arranging IrDA markers.

frared ray range of the IrDA marker, the user's position is identified by receiving the position ID with the IrDA receiver. The infrared ray range of an IrDA marker is a cone whose diameter is about 3 meters and height is about 5 meters since the infrared ray has the directivity. Therefore, when IrDA markers are set up to the ceiling in indoor environments as shown in Figure 6, the infrared ray range is a circle whose diameter is about 1.5 meter at floor level. Consequently, the system can specify the user's position automatically when passing under an IrDA marker.

RFID tag : RFID tags are set up to the appointed points as shown in Figure 7 and the RFID tag reader is set up to the user's wrist as shown in Figure.2. When the user brings the RFID tag reader close to the RFID tag, the system can receive the position ID and identifies the user's position. It is assumed that RFID tags are used in outdoor environments since they do not need electric power.

2.2.2 Estimation of User's Position Using a Pedometer

The pedometer consists of an electronic compass and acceleration sensors. The former can detect which direction the user walks toward. The latter can count how many steps the user walks[16]. These two data and the user's pace make it

Figure 7. An example of arranging RFID tags.

possible to estimate the user's position in the neighborhood of components of positioning infrastructures.

When the user walks, the periodic pattern appears in the user's waist acceleration in the back-and-forth direction. Figure 8 shows the typical relationship between user's walking actions and the user's waist acceleration in the back-and-forth direction. In Figure 8, a solid line shows the user's waist acceleration in the back-and-forth direction. Solid straight lines parallel to the vertical axis mean the time when the user walks one step which is measured manually. Considering these data, it is found that the user's waist acceleration in the back-and-forth direction changes rapidly within the fixed time while the user is walking one step. Our system finds the user's walking action by detecting these rapid changes of the user's waist acceleration. In Figure 8, dotted straight lines mean the time when the user walks one step detected from the user's waist acceleration. Comparing them with solid straight lines parallel to the vertical axis, their perfect correspondence can be found. Therefore, the user's walking action can be detected with sufficient accuracy. The system regards the user's waist direction measured with the compass when the user's walking action is detected as the user's walking direction.

In the proposed method above, thresholds for detecting rapid changes of the user's waist acceleration are decided from the user's waist acceleration of the past. Accordingly, the system can detect the user's walking action accurately. The accumulative error of the pedometer includes two kinds of errors mainly. One is the difference between the user's actual pace and the user's average pace estimated in advance, and the other is the difference between the actual walking direction and the user's waist direction. Both of them are accumulated according to the user's walking distance. In our system, the accumulative error of the pedometer is canceled whenever the system receives the position ID from the component of positioning infrastructures.

2.2.3 Evaluation of Measureing the User's Position

We have carried out an experiment for evaluating the measurement of the user's position using positioning infrastruc-

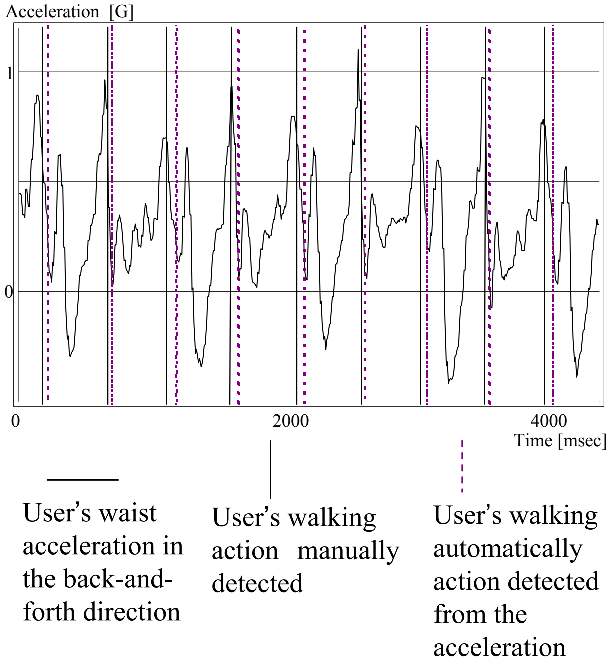
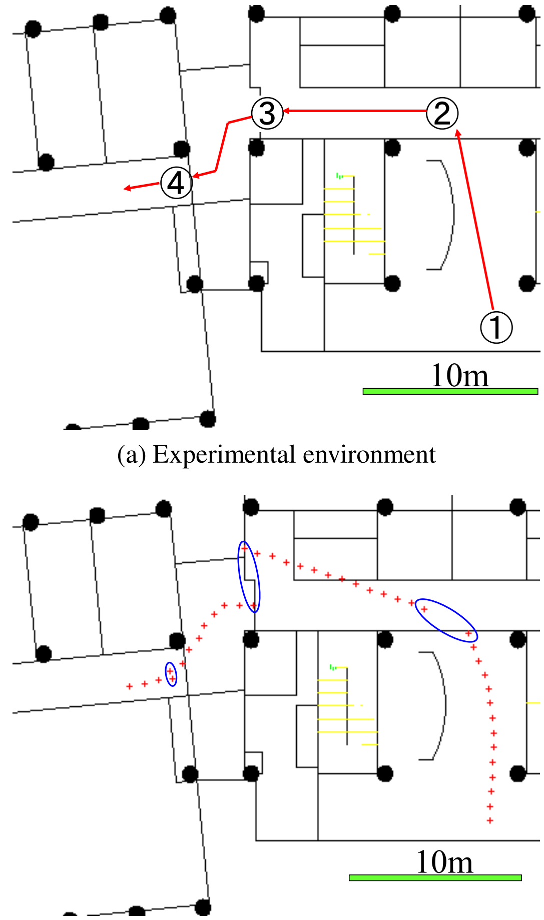


Figure 8. Relationship between the number of user's steps and the user's waist acceleration in the back-and-forth direction.

tures and a pedometer. In the experimental environment shown in Figure 9 (a), the user walked along arrows in the situation that IrDA markers were set up at ①, ②, ③, and ④. In Figure 9 (b), red crosses show the user's position at each step, blue circles show that the accumulative error of the pedometer was reset by using positioning infrastructures. This experiment shows that the accumulative error of pedometer is at most 20 or 30 percent of the user's walking distance from components of positioning infrastructures. Especially, when the user walks where the terrestrial magnetism is distorted (between ② and ③), the accumulative error of pedometer becomes larger. However, the accumulative error of pedometer can be bounded if components of positioning infrastructures are set up densely.

2.3 Measurement of User's Orientation

The direction of the user's viewpoint is measured with the inertial sensor attached to the user's headset. However, it is difficult to measure the user's direction correctly with only the inertial sensor since it has some kinds of errors generally. The errors of the inertial sensor include the drift error which is caused by the change of temperatures and the accumulative error which is caused by the high-speed rotation or being used for a long time. In our system, the drift error is estimated using input images from the camera, and



(a) Experimental environment

(b) Estimated user's position

Figure 9. Experiment for evaluating the measurement of the user's position.

the drift error is reduced[15]. As another issue of the inertial sensor, the data acquired from the inertial sensor are not synchronized with input images from the camera. The asynchronousness of two data is reduced by delaying the data of the inertial sensor. In our prototype system, the accumulative error of the inertial sensor is reset by the user manually. In the future, it is necessary to reduce the accumulative error of the inertial sensor combining an electronic compass and a gravity sensor.

2.4 Generation of Annotation Overlay Images

Figure 10 shows an example of annotation overlay images generated by the prototype system. Annotation overlay images are real scene images from the user's viewpoint with four kinds of information shown in Table1: pointing arrows, guiding annotations, indicators, and detailed information.

The pointing arrow and the guiding annotation are placed

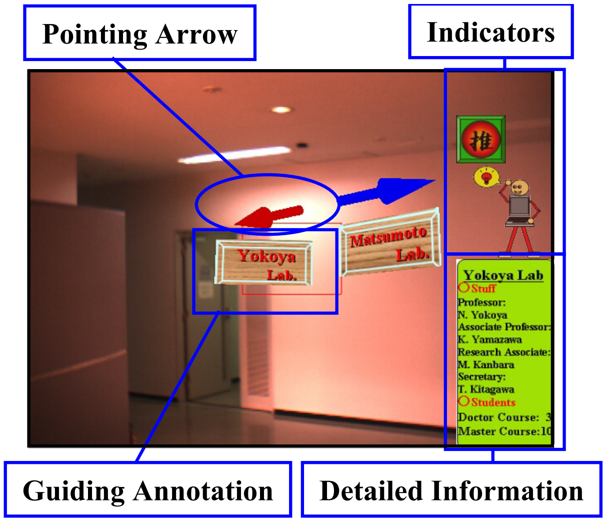


Figure 10. An example of annotation overlay image.

Table 1. Kinds of annotations.

Pointing arrows	Linking guiding annotations to the objects in the real scene
Guiding annotations	Showing the names of real objects
Indicators	Showing the state of the system to the user
Detailed annotation	Showing the detailed information of the real object

in the appointed points in the real scene. The closer the user walks to a guiding annotation, the larger it is shown to the user. Therefore, the user can intuitively link guiding annotations to real objects. Detailed annotations show the user detailed information about the real object. A detailed annotation appears on the lower right side of an image while the user notices the corresponding guiding annotations. The system recognizes that the user notices a guiding annotation when it is on the center of an annotation overlay image.

As mentioned above, the system needs the database of annotations to generate annotation overlay images that are presented to the user. The database of annotations consists of the following data:

- Image files of guiding annotations and detailed annotations,
- Directions of pointing arrows,
- Positions of annotations and IrDA markers.

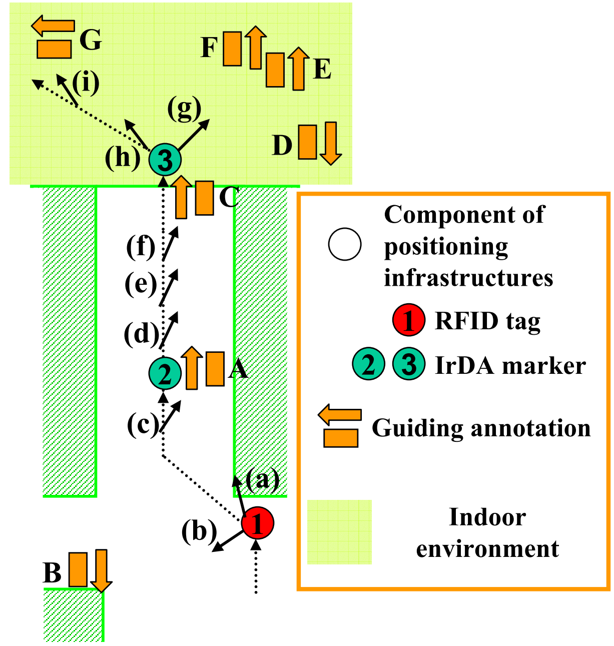


Figure 11. An experimental environment.

The system selects appropriate annotations from this database according to the user's estimated position and direction, and generates the annotation overlay images in real time.

3 Experiments with the Prototype System

We have carried out some experiments using the proposed wearable augmented reality system. We have developed a navigation system which works in our campus where IrDA markers and RFID tags are placed at appointed points in both indoor and outdoor environments.

Figure 11 illustrates a part of the experimental environment. In Figure 11, the point 1 means the position where the RFID tag is set up, 2 and 3 mean the positions where the IrDA markers are set up. The user walked along the dotted arrows from 1 to 3 in Figure 11. Seven guiding annotations are arranged at points A,...,G in Figure 11, and overlaid on the real scene image. Figure 12(a),...,(i) show annotation overlay images when the user was at the point (a),...,(i) in Figure 11, and the user's orientation was along the solid arrows at the point (a),...,(i) in Figure 11, respectively. Figure 12(a), (b), (d), (g), and (h) show the annotation overlay images when the system identified the user's position using positioning infrastructures, and (c), (e), (f), and (i) in Figure 12 are ones at the user's position estimated with the pedometer when the user walks some steps from components of positioning infrastructures.

Through this experiment, even if the user walks some

(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 12. Examples of annotation overlay images.

meters from components of positioning infrastructures in both outdoor and indoor environments, the system can estimate the user's position using the pedometer and the user can obtain the images on which annotations are correctly overlaid. The accumulative error of the pedometer is one or two meters at most when the user walks within ten meters. It does not affect overlaying annotations seriously. However, the accumulative error of the pedometer increases with the user's walking distance estimated with the pedometer. Thus components of positioning infrastructures should be arranged so well that the accumulative error of the pedometer does not amount so much. This experiment also shows that the system can be used indoors and outdoors seamlessly since the system measures the user's position indoors and outdoors seamlessly. The annotation overlay image can be presented to the user at 25fps. The weight of the user's headset is about 200g and the user's shoulder bag containing the notebook PC and batteries is about 5kg. The system can run with the battery more than three hours continuously. As shown in Figure 12(g), when there exist occlusions among objects in the scene, the system may overlay wrong annotations. Therefore, the user cannot intuitively link annotations to the correct real objects.

4 Summary

This paper has described a wearable augmented reality system which can be used in indoor and outdoor environments seamlessly using positioning infrastructures and a pedometer. RFID tags and IrDA markers are used as components of positioning infrastructures, and the system specifies the user's position at appointed points by receiving position IDs with RFID tag reader and an IrDA receiver. When the user goes away from components of positioning infrastructures, the user's position is alternatively estimated by using a pedometer constructed of an electronic compass and acceleration sensors. The direction of the user's viewpoint is measured with the inertial sensor. We also have shown the feasibility of the proposed system demonstrating with experiments in both indoor and outdoor environments. The proposed system can be extended to a navigation system for facilities or tourist attractions which cover both indoor and outdoor environments.

The issues for improving and extending the proposed system are listed below:

- Network sharing of the database of annotations
  The database of annotations held in a server computer can be obtained automatically using the wireless network. Therefore, it is not necessary to store the database of annotations in the user's computer in advance.

- Occlusions between real objects and annotations
  Using a simple 3D model of the real scene, the system could represent annotations with correct occlusion.

- Arrangement of the positioning infrastructures
  IrDA markers are set up to the ceiling in indoor environments with a 9v battery severally, since IrDA markers need the electric power. In the future, we will develop IrDA marker and fluorescent light lamp units in order to arrange and maintain them easily.

- Showing positions of components of positioning infrastructures
  It is necessary to let the user know positions of components of positioning infrastructures, if the proposed system is applied to a wide area. We will develop an interface to show the annotations at positions of components of positioning infrastructures.

Acknowledgments
This research is partially supported by Core Research for Evolutional Science and Technology (CREST) Program "Advanced Media Technology for Everyday Living" of Japan Science and Technology Corporation (JST) and also by the Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

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