Nara Palace Site Navigator: A Wearable Tour Guide System Based on Augmented Reality

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Abstract

This paper describes a wearable tour guide system using augmented reality techniques which can merge the real and virtual worlds. The proposed system is supported to be used in indoor and outdoor sightseeing sites which have some sightseeing spots. In the proposed system, the some user localization methods, which can be used both indoors and outdoors, are used to guide the user along the tour route and providing the user with multimedia contents stored in a networked shared database. Especially, the proposed system presents annotations and virtual objects to user using augmented reality techniques so as to be able to understand the augmented environment intuitively. In addition, we introduce a system by which virtual objects can be merged into a bird's eye view image acquired by an unmanned helicopter.

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 location-based 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]. Figure 1 shows an example of annotation overlay system which imposes annotations on the real scene using AR techniques with wearable computers. If the AR system can be realized with a wearable computer, user can get location-based information anyplace at any time. Therefore, the system is

Figure 1. A wearable AR application.

applicable to human navigation or tour guide systems which provide wearable computer users with location-based information such as sightseeing information or route guide.

To realize AR systems with wearable computers, we have to resolve some problems. The important two problems of them are user localization and management of location-based information provided user. The former means the registration problem which requires to estimate the relationship between the real and virtual worlds, to overlay virtual objects such as annotation and virtual buildings at the accurate position of the real scene. The later includes how to provide users with appropriate information and how to effectively visualize the information. Both of user localization and information management problems are more difficult and complex than the conventional AR, because wearable computer users move anyplace and try to get location-based information at any time.

Usually, to resolve the user localization problem, the position and orientation of user's viewpoint should be measured in real time. A number of methods have been proposed for localization in indoor and outdoor environments. For examples, Global Positioning System (GPS) is used

Figure 2. The aerial photograph of Nara palace site.

to measure the user's position outdoors. In AR systems which use GPS, a differential GPS or a real time kinematic GPS[10, 11] is often used to measure the user's position accurately. For indoor environments, several approaches which use fiducial markers or IR markers as positioning infrastructures are proposed. On the other hand, the problem of information management has not been investigated in detail yet. In general, a user's computer needs to hold user's location-based information to overlay annotations on the real scene image. Up to this time, since a database of annotation information is usually held in a wearable computer in advance, it is difficult for the database of annotation information to be easily updated or added by information providers.

This paper introduces new approaches which overcome both of the user localization and information management problems. We selected Nara palace site as a platform of experiment environment. Nara Palace Site Navigator which is a wearable tour guide system using augmented reality techniques is constructed. Nara palace site is the remains of Japanese ancient capital palace which existed 1300 years ago. Nara palace site shown Figure 2 has 2 square kilometers and locates in the west of Nara city. It has museums which exhibit hangover and an outdoor archaeological site which has scattered sightseeing spots such as ancient building excavation sites. We propose user localization methods for this experiment environment which includes indoor and outdoor scenes. In addition, we attempt to generate an augmented scene which is captured from bird's eye view. Finally, we describe a networked shared database of location-based information and view management method for effective visualization management.

2. Framework of Nara Palace Site Navigator

Some navigation systems using a wearable computer or mobile device have already been proposed until now[12, 13, 14]. ARCHEOGUIDE system is a mobile system for guiding tourists[15, 16]. This system is intended to present archaeological information to the user at cultural-heritage sites. The archaeological information in this system includes virtually reconstructed buildings which are overlaid on ruins of buildings using augmented reality techniques. This system demonstrates that augmented reality provides an effective method for guiding tourists. We try to establish a wearable AR system which can provide the user with augmented scene in several experiment environments.

Figure 3 shows an overview of Nara palace site navigator. The user can acquire generated augmented scene as guide information under three kinds of environments including indoor and outdoor scenes and bird's eye view. In outdoor environments, to estimate user's position widely, the position is measured by combining the user's absolute position acquired by GPS and infrared marker and dead reckoning data. In indoor environments, to measure the user's position accurately, the infrared marker and fiducial marker set up on the ceiling of building are used as positioning infrastructure. On the other hand, the augmented scene from bird's eye view is generated by measuring the helicopter's position and orientation using GPS and gyroscope attached to the helicopter. We also propose a management method for location-based information. The proposed approaches are based on using a networked shared database, which can effectively provide the user with appropriate information and intuitive visualization.

This paper is structured as follows. Sections 3 and 4 describe the localization method in outdoor and indoor environments, respectively. Section 5 describes the method and experiments of bird's eye view augmentation. In Section 6, the approaches of networked shared database and view management are described in detail. Finally, Section 7 summarizes the present work and also describes future work.

3 Outdoor user localization

To acquire the user's position in wide outdoor environments, the position is measured by combining specification of the user's absolute position and dead reckoning data as shown in Figure 4[17]. In the proposed method, the user's position is measured by combining the user's absolute position which is measured by the GPS and the user's relative movement which is measured by the pedometer.

3.1 Specification of user's absolute position

The user's absolute position is measured using a handheld GPS in outdoor environments. When the GPS is used solely for specifying the position in outdoor environments, the error fluctuates between 5 meters and 50 meters which

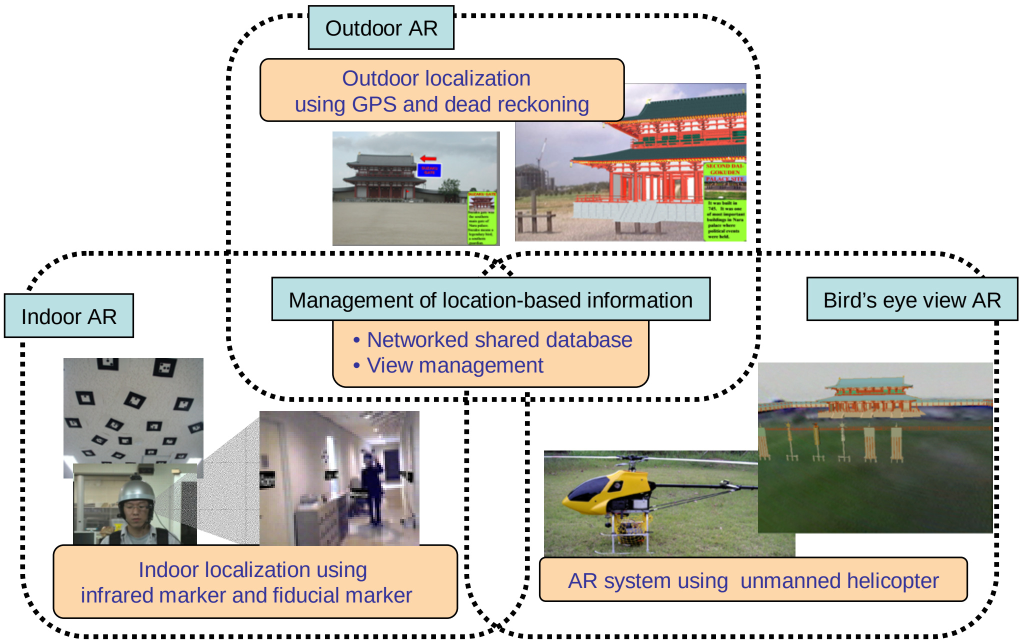


Figure 3. Overview of Nara Palace Site Navigator.

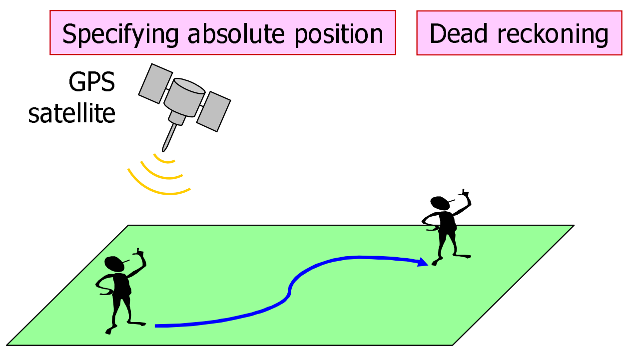
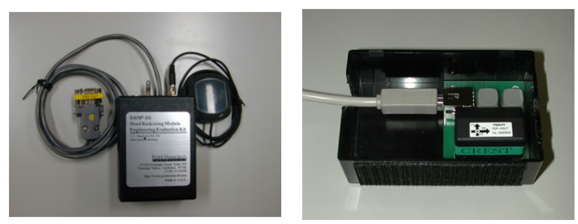


Figure 4. The proposed positioning method.



(a) DRM-III. (b) MDP-A3U9.

Figure 5. Dead reckoning sensors.

is caused by various reasons: the number of captured GPS satellites, the weather, and so on. In environments which have no high-rise buildings, the error of the standard GPS is within 20 meters. The GPS can specify the user's position at 1Hz.

3.2 Estimation of user's relative movement

We can estimate the user's relative movement using a pedometer represented by the dead reckoning module, "DRM-III (Point Research Corporation)" as shown in Figure 5 (a) both indoors and outdoors. The "DRM-III" estimates the user's relative movement by integrating these three data: the user's average pace which is input beforehand, the detection of the user's walking action, and the user's walking direction. However, the sensor just like "MDP-A3U9 (NEC-TOKIN)" (Figure 5 (b)) which is composed by acceleration sensors and a digital compass also can estimate the user's relative movement. The "MDP-A3U9" can measure the acceleration of the user's waist to detect the user's walking action using the acceleration sensor and measure the user's walking direction using the digital compass.

3.3 Combining the absolute position and dead reckoning

In our method, even when the accuracy of the GPS drops temporarily, the user's current position is measured by using past GPS data and dead reckoning data. Thus the positioning accuracy is defined as the sum of the GPS accuracy which is included the standard GPS data, NMEA data and 5% of the distance traveled. The system calculates the value for GPS data at every moment and adopts the position

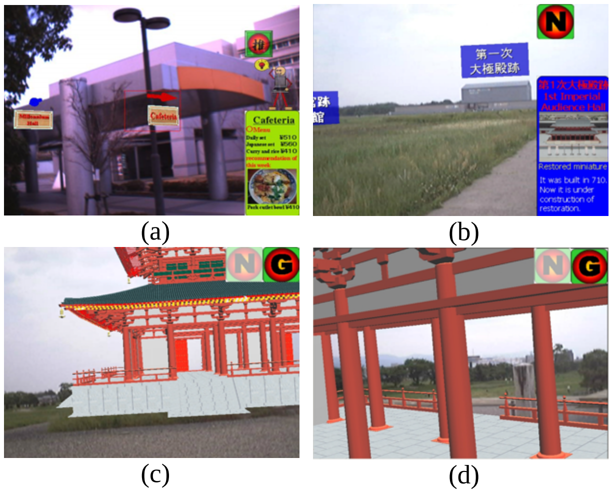


Figure 6. Examples of generated images.

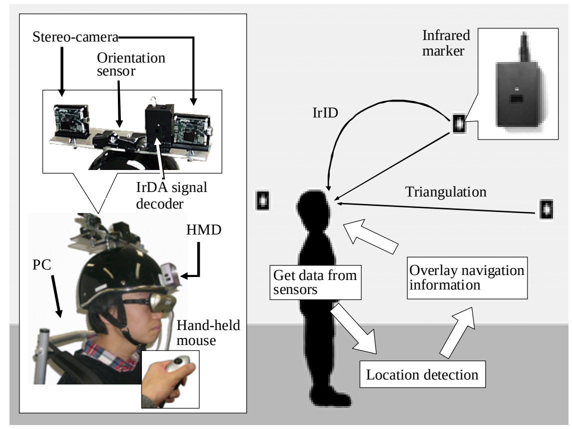


Figure 7. Infrared marker based indoor tracking technique.

data whose value of positioning accuracy is minimum as the user's position.

The user's position can be measured at user's step rate by using the dead reckoning method with specifying the user's absolute position. Therefore, the user's position can be measured with the same timing as the user's movement. However, the accumulative error occurs according to the user's walking distance when we use the proposed dead reckoning method. The accumulative error 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 method, the accumulative error of dead reckoning is canceled whenever the system receives the GPS data.

3.4 Examples of outdoor augmented scene

We have developed a prototype wearable augmented reality system which presents location-based information in outdoor environments. The user's position is measured by using the proposed method. Figure 6 shows examples of generated images which are presented to the user. Figures 6(a) and (b) show a position-based annotation overlay image. Figure 6(c) and (d) show images on which a virtual building is overlaid.

4 Indoor user localization

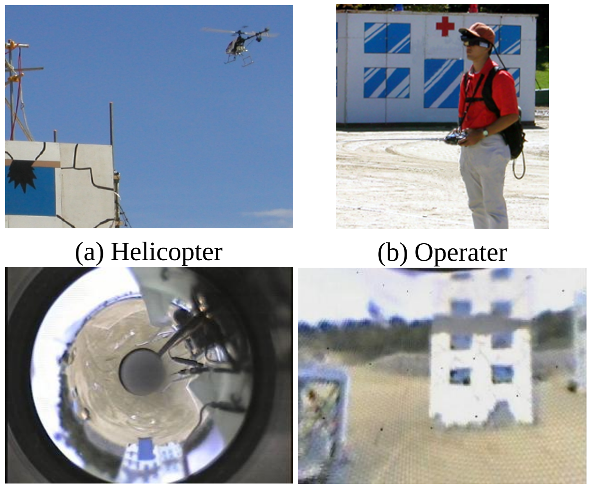
We have developed two kinds of indoor position and orientation tracking systems[18]. We explain the proposed systems in detail in the following sections.

4.1 Infrared marker based hybrid tracking

We have developed an indoor position and orientation tracking system, which combines infrared markers with a head-mounted stereo camera and an orientation sensor as shown in Figure 7. In this system, most markers can be casually placed without the need for calibration, as unknown markers in the workspace are automatically mapped. The proposed method is robust with respect to lighting conditions, also working in complete darkness, and is less obtrusive in terms of aesthetics compared with conventional marker-based approaches. An extended Kalman filter is employed to reduce triangulation and orientation errors by integrating the signals acquired by multiple sensors. The location accuracy of the system was evaluated through a series of experiments that showed that the error for a stationary subject is less than about 10 cm, while that for a moving subject is within 10% of the movement distance.

4.2 Fiducial marker based technique

We have developed another indoor user positioning technique, which is inexpensive, easy to setup, and available in a wide area. This technique uses many fiducial markers casually stuck on the ceiling with a camera looking upward. In the technique, an arbitrary small number of fiducial markers have to be calibrated, while the rest of them can be roughly placed. Positions of uncalibrated markers are propagatively estimated based on adjacent markers. User's global position is then detected based on the estimated marker positions. Experimental results have shown that jittering is a few millimeter and accumulative error is not critical. This approach is applicable to a large scale indoor environments since a marker can be roughly placed in a short time.



(a) Helicopter (b) Operater

(c) Omnidirectional image (d) Perspective image

Figure 8. Immersive teleoperating system.

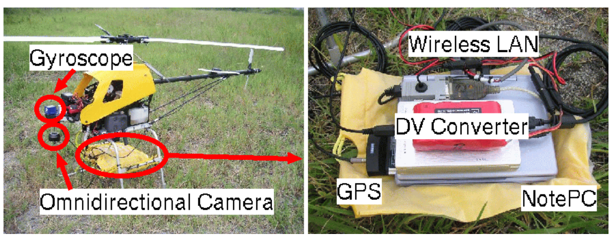


Figure 9. Bird's eye view AR system overview.

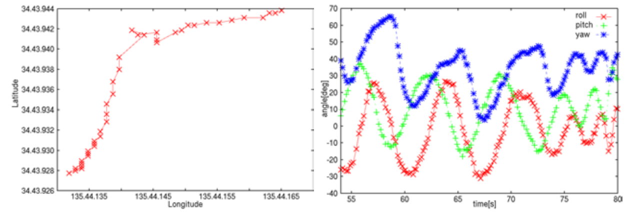


Figure 10. Measured GPS data and gyroscope data.

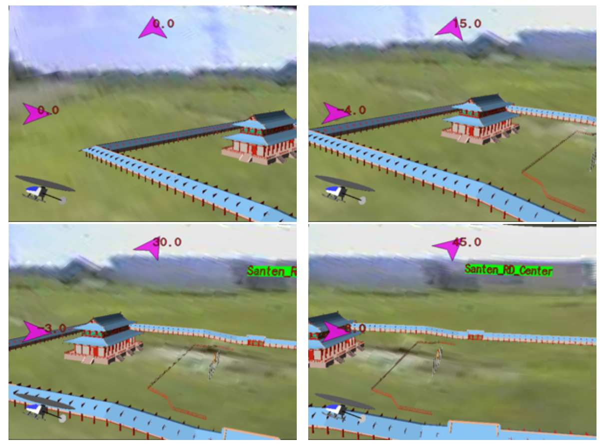


Figure 11. Annotation and virtual Nara palace overlaid on perspective images.

5 Augmented reality of bird's eye view scene

We have proposed an immersive teleoperating system[19] for unmanned helicopters using an omnidirectional camera as shown in Figure 8. We applied the developed system to an annotation-based guide system. User can see bird's eye view augmented scene at Nara palace site. Figure 9 shows the overview of this system. On the helicopter, an omnidirectional camera, a GPS, a gyroscope, and a PC are mounted. Position/attitude data and an omnidirectional image are transmitted to the operator during the flight via a wireless LAN. A perspective image is generated from a received omnidirectional image, and displayed on the Head Mounted Display(HMD) which the operator wears. Annotations to real objects and virtual objects are overlaid on the perspective image. The operator has a database of annotations which consists of the names and the position information of neighboring objects. The displayed image changes depending on the head direction which is measured by the gyroscope attached to the HMD. The operator holds a controller with both hands and controls the helicopter wearing a backpack which contains a laptop PC.

We have carried out an experiment using this system. Figure 10 indicates GPS and gyroscope data. Figure 11 shows examples of the annotation overlaid images. Using the current position and attitude of the helicopter, some annotations and virtual Nara palace site are overlaid on the perspective image. The attitude of the operator's head is displayed at upper side and left side of the image. Additionally, the attitude of the helicopter is indicated by a virtual helicopter at left below of the image. The position is measured correctly and annotations are overlaid on actual buildings generally.

6 Management of location-based information

In this session, we describe management methods for the location-based information in wearable AR system. In this section, as a first step, we handle only annotation information such as a name of building. To effectively manage the information, we propose some techniques: networked shared database for wearable AR, development toolkit for the shared database, and visualization method.

6.1 Shared database of annotation information

Figure 12 shows an overview of shared database system of annotation information[20]. In this study, the database is shared via a wireless network. The database of annotation information is stored in the server and is shared by multiple users of wearable AR systems and information providers. Consequently, users of wearable AR systems can obtain annotation information at anytime via a wireless network and can see the newest annotation overlay images without holding the database of annotation information in advance. On the other hand, information providers can provide efficiently the newest annotation information for users of wearable AR systems by updating and adding the database with a web browser. In Section 6.1.1, the construction of the database of annotation information is described. Section 6.1.2 describes how to update the database with a web browser. Section 6.1.3 describes how the user obtains annotation information.

6.1.1 Construction of annotation database

The database contains some kinds of location-based contents. Each annotation is composed of a pair of contents(name and detail) and their positions. Components of the annotation information are described in detail in the following.

Position: Three-dimensional position of an annotation in the real world. Three parameters (latitude, longitude, height) are stored in the database.

Name: The name of the object which is overlaid in the real scene as annotation information.

Detail: Detailed information about the object to be annotated. When user's eyes are fixed on the object, the detail about the object is shown in the lower part of the user's view.

6.1.2 Updating the shared database

The annotation information can be corrected, added and deleted by information providers with a web browser. An interface for information providers to update the database is a web browser as shown in Figure 13. Information providers can easily update the database by accessing a prepared web page and by transmitting the data of annotation information. The annotation updating procedure is described below.

1. **Specification of position**

   Information providers can zoom in and out to maps (Figure 13: C, D) using buttons (Figure 13: A). Besides, the providers can move in the map by clicking any point on the map. In this way, the providers can specify the position of a new annotation to be added. It should be noted that position parameters such as latitude, longitude and height are automatically determined based on the specified position on the map.

2. **Input of name**

   Information providers input the object name to web page. The name is sent to the server and the picture of annotation is automatically generated in the server.

3. **Input of details**

   Using the same method as in the input of the name, information providers send details of objects. The providers also can send a picture, a sound file and a movie file as details.

The providers can efficiently send the newest annotation information using a web browser. Note that users of wearable AR systems can also update the database. In this case, the server shows the user a map of his neighborhood according to the user's position acquired by positioning sensors. Since the user is able to update the database, the user can immediately correct the position error of annotations by confirming the overlaid image.

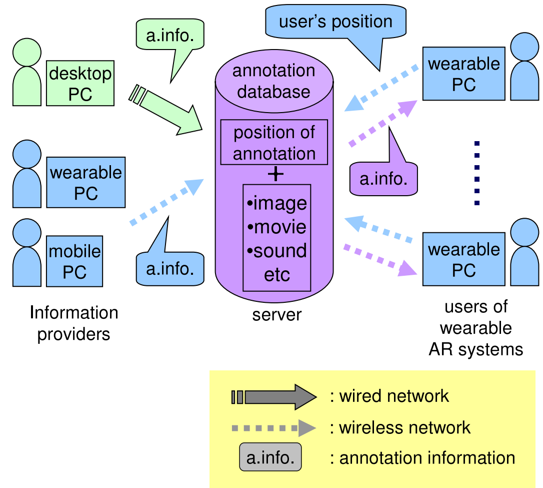


Figure 12. Overview of a networked annotation database shared by users.

6.1.3 Getting annotation information

In this work, the database server is prepared assuming that the user's wearable computer can access the database via a wireless network. Annotations to be presented to the user are determined based on the user's current position. First, the user's position is measured by some positioning sensors such as GPS which are equipped by the user. The user's

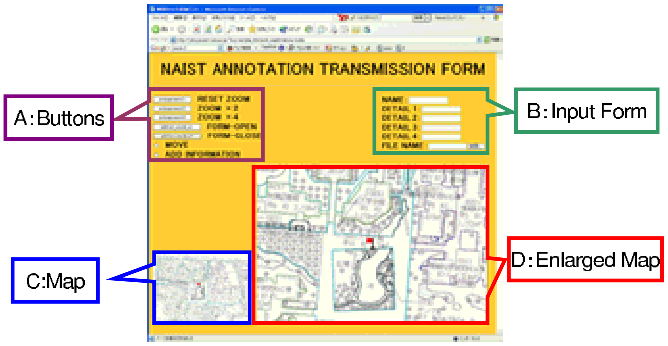


Figure 13. Input form of annotation information.

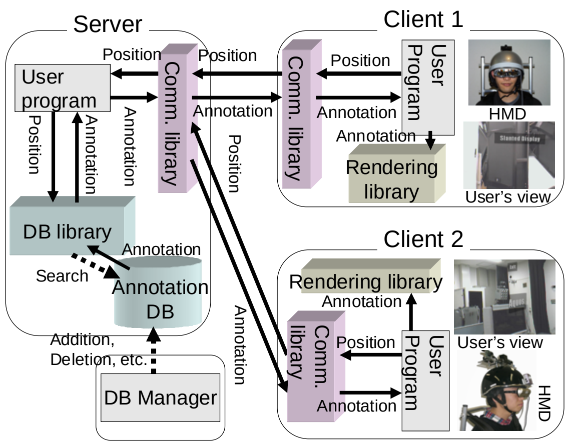


Figure 14. A data flow diagram of a networked wearable AR system architecture.

wearable computer then obtains proper annotation information based on the measured user's position. The server automatically decides which annotation should be provided. Consequently, the user's wearable system can obtain the newest annotation information at anytime.

6.2 Development toolkit for networked wearable AR systems

We have also developed a development toolkit for a networked wearable AR system. Our toolkit is designed with consideration of annotation data volume, ease of annotation updates and hardware architecture diversity. In particular, the toolkit hierarchically manages annotation data based on a geographic distribution of clients and annotation. The system transmits annotations to clients using dedicated priority management architecture. Specifically, user preference, location, viewing direction, and levels of details etc. are

Figure 15. Clients' view in the experiment.

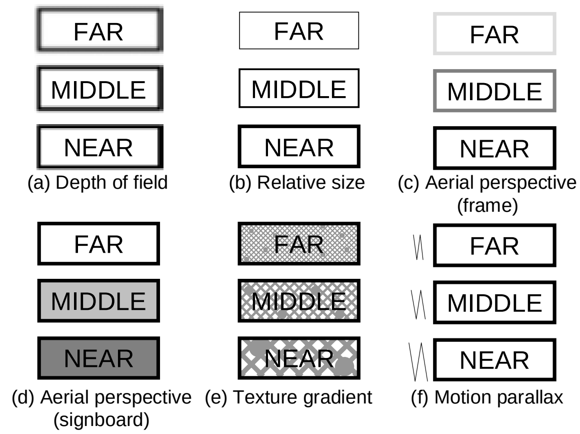


Figure 16. Metaphors of monocular depth cues for depth visualization.

taken into consideration for fast and effective data transfer. An experiment shows that annotation information was properly transmitted from the server to two clients that use the proposed toolkit and different position detection techniques, based on their position information (see Figures 14 and 15).

6.3 Annotation visualization techniques

We have proposed a number of depth visualization techniques for virtual object annotations. It is often difficult to perceive the depth of virtual objects in an augmented reality (AR) environment due to poor depth cues and visual congestion. Existing techniques are intended primarily for normal objects having 3D geometry. Our techniques dynamically modify visual attributes of each annotation, such as color or line-style of the frame, based on its distance to the user or occlusion relationship between the annotation and the real environment to facilitate perception of annotations' location and spatial relationship (see Figure 15). Preliminary experiments indicate that three representative depth visualization methods are effective for reducing response time, depth recognition error, and head moving distance. These approaches should be particularly effective for wearable AR systems that use a monocular HMD.

7 Summary

This paper has described wearable tour guide systems and related augmented reality for Nara palace site which is the remains of Japanese ancient capital palace. In particular, we proposed the techniques of indoor and outdoor user localization, bird's eye view augmentation and management methods of location-based information for wearable computer users. The user can acquire the guide information in three environments: outdoor, indoor and bird's eye view scenes. We also have proposed the management method of overlaid information. The proposed methods are the networked shared database for effectively providing the user with the annotation information, and the visualization method of overlaid information. For future work, we plan to improve the Nara palace site navigator as a guide tour application and to integrate the proposed localization methods.

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References

[1] S. Mann: "Wearable computing: A first step toward personal imaging," IEEE Computer, 30, 2, 1999.

[2] R. D. Vaul, M. Sung, J. Gips and A. S. Pentland: "Mithril 2003: Applications and architecture," Proc. of Int. Symp. on Wearable Computers 2003, pp. 4–11, 2003.

[3] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Juiler and B. MacIntyre: "Recent advances in augmented reality," IEEE Computer Graphics and Applications, 21, 6, pp. 34–47, 2001.

[4] S. Feiner, B. MacIntyre and D. Seligmann: "Knowledge-based augmented reality," Communications of the ACM, 36, 7, pp. 52–62, 1993.

[5] M. Kanbara, N. Yokoya and H. Takemura: "Registration for stereo vision-based augmented reality based on extendible tracking of markers and natural features," Proc. of IAPR Int. Conf. on Pattern Recognition, II, pp. 1045–1048, 2002.

[6] T. Kurata, T. Kato, M. Kourogi, J. Keechul and K. Endo: "A functionally-distributed hand tracking method for wearable visual interfaces and its applications," Proc. of IAPR Workshop on Machine Vision Applications, pp. 84–89, 2002.

[7] M. Kourogi, T. Kurata and K. Sakaue: "A panorama-based method of personal positioning and orientation and its real-time applications for wearable computers," Proc. of Int. Symp. on Wearable Computers, pp. 107–114, 2001.

[8] W. Piekarski and B. Thomas: "Bread crumbs a technique for modelling large outdoor ground features," Proc. of Int. Symp. on Mixed and Augmented Reality, pp. 269–270, 2002.

[9] S. Feiner, B. MacIntyre, T. Höller, and A. Webster: "A touring machine: Prototyping 3d mobile augmented reality systems for exploring the urban environment," Proc. of Int. Symp. on Wearable Computers, pp. 74–81, 1997.

[10] T. Hollerer, S. Feiner and J. Pavlik: "Situated documentaries: Embedding multimedia presentations in the real world," Proc. of Int. Symp. on Wearable Computers '99, pp. 79–86, 1999.

[11] T. Hollerer, S. Feiner, T. Terauchi, G. Rashid and D. Hallaway: "Exploring mars: Developing indoor and outdoor user interfaces to a mobile augmented reality system," Computers and Graphics, 23, 6, pp. 779–785, 1999.

[12] R. Oppermann and M. Specht: "Adaptive mobile museum guide for information and learning on demand," Proc. of HCI International '99, pp. 642–646, 1999.

[13] J. Baus, A. Kruger and W. Wahlster: "A resorce-adaptive mobile navigation system," Proc. of Int. Conf. on Intelligent User Interfaces 2002, pp. 15–22, 2002.

[14] R. Malaka and A. Zipf: "Deep map - challenging it research in the framework of a tourist information system," Proc. of Int. Congress on Tourism and Comm. (ENTER2000), pp. 15–27, 2000.

[15] D. Stricker, J. Karigiannis, I. T. Christou, T. Gleue and N. Ioannidis: "Augmented reality for visitors of cultural heritage sites," Proc. of Int. Conf. on Cultural and Scientific Aspects of Experimental Media Spaces, pp. 89–93, 2001.

[16] T. Gleue and P. Dähne: "Design and implementation of a mobile device for outdoor augmented reality in the archeoguide project," Proc. of Archaeology, and Cultural Heritage Int. Symp., 2001.

[17] R. Tenmoku, M. Kanbara and N. Yokoya: "A wearable augmented reality system using positioning infrastructures and a pedometer," Proc. of Int. Symp. on Wearable Computers, pp. 110–117, 2003.

[18] M. Maeda, T. Ogawa, T. Machida, K. Kiyokawa and H. Takemura: "Indoor localization and navigation using ir markers for augmented reality," Proc. of Int. Conf. on Human-Computer Interaction, pp. 283–284, 2003.

[19] M. Koeda, Y. Matsumoto and T. Ogasawara: "Development of an immersive teleoperating system for unmanned helicopter," Proc. of Int. Workshop on Robot and Human Communication, pp. 47–52, 2002.

[20] K. Makita, M. Kanbara and N. Yokoya: "Shared database of annotation information for wearable augmented reality system," Proc. of SPIE Electronic Imaging, 5291, pp. 464–471, 2004.