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# A Localization System Using Invisible Retro-reflective Markers

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**Abstract**

*This paper describes a method for localizing wearable computer users. To realize applications of wearable computers like a human navigation system, the position of a user is required for location-based services. Many localization methods in indoor environments have been proposed. One of the methods estimates user's position using IR beacons or visual markers. However, these methods have some problems concerning power supply and/or undesirable visual effects. In order to avoid the problems, we propose a new localization method which is based on using an IR camera and invisible markers consisting of translucent retro-reflectors. In the proposed method, to extract the regions of the markers from the captured images stably, the camera captures the reflection of IR LEDs which are flashed on and off synchronously.*

## 1 Introduction

Since computers have made remarkable progress in resent years, a wearable computer can be realized. At the same time, the augmented reality (AR) technique which merges the real and virtual worlds has received a great deal of attention as a new method for displaying location-based information in the real world[1, 2]. Therefore, AR systems using wearable computers like navigation systems[3, 4] are proposed. To realize an AR system using wearable computer, the exact position and orientation of a user are required. Especially in indoor environments, since a GPS cannot be used, many localization methods have been proposed[5, 6]. One of the methods estimates the user's position using infrared markers[7, 8]. The methods specify the user's position using the position IDs received from IrDA markers which compose positioning infrastructures. Tenmoku, et al[7] have estimated user's position using infrared markers and pedometer, and the orientation of the user by gyro sensor. Maeda, et al[8] have developed a hybrid tracking system that estimates the position and orientation of the user by combining a gyro sensor with a stereo camera which captures infrared markers. Another type of methods estimates the user's position by recognizing visual markers pasted up on the ceilings or walls[9, 10]. For example, Baratoff, et al[9] used ARToolKit[11] square markers, and Naimark, et al[10] have developed a system that stably estimates the position and orientation of the user by combining an accelerometer with a camera which captures circular markers. However, these methods have some problems concerning power supply of positioning infrastructure and/or undesirable visual effects.

In order not to impair the scenery, we propose a new localization method which is based on using invisible markers that consist of translucent retro-reflectors. In the proposed method, translucent retro-reflective markers, which are invisible and do not need power supply, are captured by an IR camera. In order to avoid the influence of infrared other than the reflection from retro-reflective markers, infrared LEDs are flashed on and off continuously. Thus, the images containing the markers are captured synchronized with the flash. The regions of the markers are robustly extracted from the difference between images as LED on and off. Herewith, the position of a user can be estimated without power supply of infrastructures and undesirable visual effects in the real scene.

This paper is structured as follows. Section 2 describes a localization system using invisible markers and IR camera. In Section 3, experimental results with a prototype system are described. Finally, Section 4 gives conclusion and future work.

## 2 User Localization Using Invisible Markers

In this section, our proposed localization system is described in detail. In Section 2.1, invisible markers are described. Section 2.2 discusses marker patterns, and finally Section 2.3 explains a method for estimating user's position and orientation.

### 2.1 Invisible Markers

The markers are set up on the ceilings or walls in indoor environments as infrastructures. When visual markers are set up on the ceilings, the markers impair the scenery as shown in Figure 1(a). Figure 1(b) shows the scene where invisible markers consisting of translucent retro-reflectors are set up. Since the markers are translucent, it is difficult for a user to observe the markers. However, when the image is captured with a flash, the markers can be clearly observed as shown in Figure 1(c). Because the retro-reflector reflects a light toward a light source, its reflection can be captured clearly by the camera which is located near the flashing light.

(a) Standard visual markers. (b) Invisible markers. (c) Invisible markers with a flash.

Figure 1: Markers as positioning infrastructures.

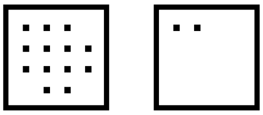


Figure 2: Instances of markers ($N = 4$) (the black part illustrates a retro-reflector).

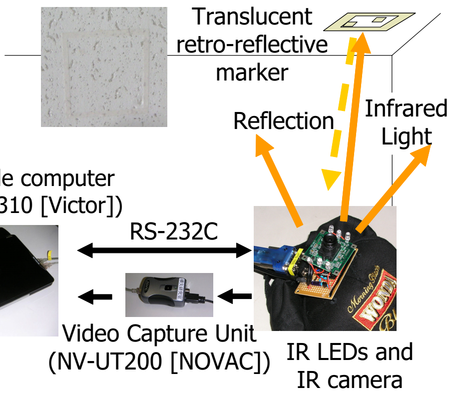



Figure 3: Overview of localization system.

## 2.2 Pattern of Markers

Figure 2 illustrates instances of marker patterns. In this figure, the black part represents the retro-reflector, and the marker has a square frame. To generate a marker pattern, the inside of the frame contains evenly spaced $N \times N$ grid points, and dots are allocated on the grids. To determine the direction of the marker uniquely, one dot is always allocated to one of four corners of $N \times N$ grids, and other three corners are blank. Therefore, the total number of IDs associated the patterns is $2^{N^2-4}$.

## 2.3 Estimation of Position and Orientation

Figure 3 illustrates the overview of the proposed localization system. Invisible markers consisting of translucent retro-reflectors are set up on the ceilings or walls. The user equips the head with an infrared camera upward for capturing images. The camera captures the reflection of the infrared LEDs that are attached to it. The reflection of retro-reflector can be captured clearly by the infrared camera.

However, the camera also captures lights other than the infrared LEDs; for example, fluorescent and sun light. To avoid such a problem, infrared LEDs are flashed on and off synchronously under control of a wearable computer as shown in Figure 4. In the image without infrared light from the infrared LEDs, invisible markers are not captured. On the other hand, in the image with infrared light from the infrared LEDs, these are clearly captured. By calculating the difference between the images with and without infrared light from the LEDs, the influence of infrared other than the reflection from retro-reflective markers can be eliminated. From the subtraction images, the regions of markers are extracted, and IDs associated with the markers are recognized. To extract the regions of markers, ARToolKit[11] can be used. In addition to identifying the received marker, it is possible to estimate the relative position and orientation of camera with respect to the marker coordinate system from four vertices of a square marker of known size using a standard computer vision technique.

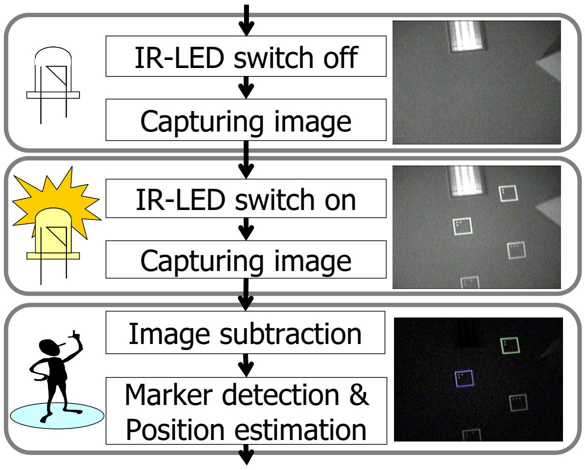
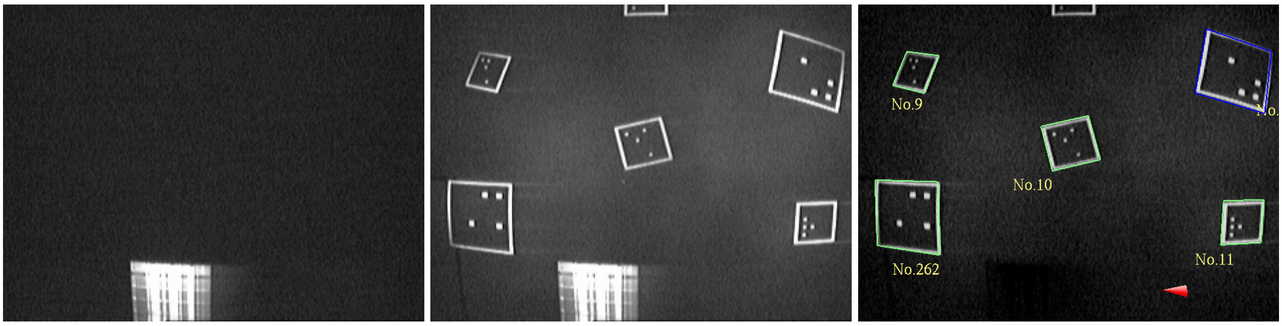



Figure 4: Flow diagram of capturing markers.

# 3 Experiments

We have carried out experiments with the proposed localization system. View angle of the infrared camera shown in Figure 3 is 92.6°, and six infrared LEDs are attached around the camera. We made a circuit which controls the LEDs using RS-232C serial communication with a PC. The used PC is a mobile computer “InterLink MP-XP7310 (Pentium M




(a) Captured images when infrared LEDs are switch-off.

(b) Captured images when infrared LEDs are switch-on.

(c) Results of marker recognition.

Figure 5: Images obtained by infrared camera and results of marker recognition.

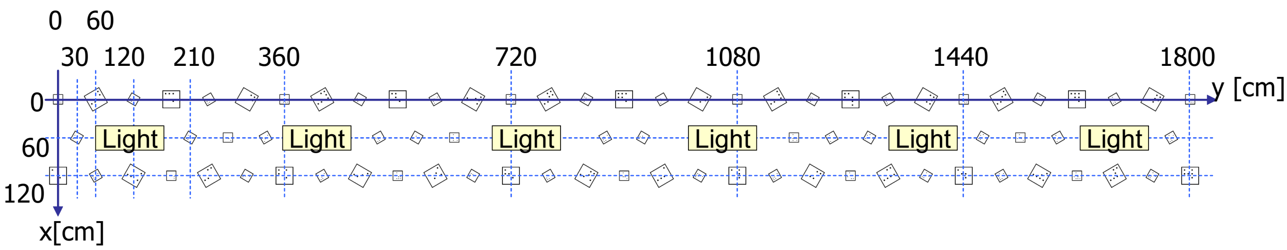



Figure 6: Layout of markers.

1GHz)," and the input image size is 320 × 240 pixels. The distance between the camera and the ceiling is about 120cm. In Section 3.1, recognition results of invisible markers are described. Section 3.2 gives experimental results about the accuracy of localization.

### 3.1 Results of Marker Recognition

In this experiment, we confirm that the proposed system can recognizes position IDs from markers without power supply of infrastructures and undesirable visual effects in the real scene. When the infrared LEDs are switch-off, retro-reflective markers are not captured as shown in Figure 5(a). On the other hand, when infrared LEDs are switch-on, the markers are clearly captured as shown in Figure 5(b). Figure 5(c) shows results of marker recognition. These images are generated by recognizing subtraction images between Figures 5(a) and 5(b). Note that the position IDs associated with the markers, and cones representing the direction of user are superimposed on the subtraction image. We confirm that marker IDs can be correctly recognized. The system can calculate the relative position and direction of camera with respect to the marker coordinate system. The processing rate is about 15 frames per second, because two images when the infrared LEDs are switch-on and switch-off are required for recognition.

### 3.2 Accuracy Evaluation of Localization Results

In this experiment, we evaluate the accuracy of the proposed system. The markers are set up on the ceiling, as shown in Figure 6. We employ two different size markers to recognize the markers even if the distance between a camera and markers is changed. The edge length of the small marker is 16cm and the size of its square element allocated on the grids is 1cm × 1cm. On the other hand, the large marker's edge length is 28cm, and the size of its square element is 2cm × 2cm. The both markers' frame width is 1cm. The number of grids $N$ in marker pattern is 4 as shown in Figure 2.

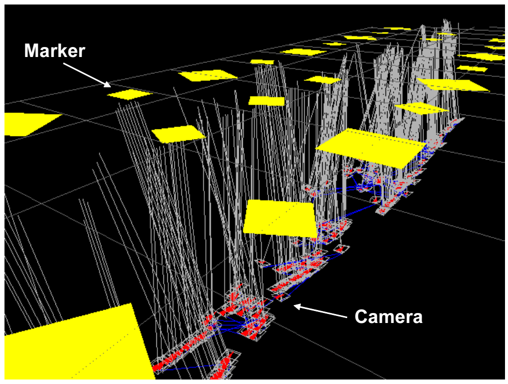



Figure 7: Estimated camera position and orientation.

In this experiment, $x$-$y$ plane represents the ceiling plane, and the $z$ axis corresponds to the vertical direction. The $pitch$ ,$roll$ and $yaw$ represent the rotation angles around $x$, $y$, and $z$ axes in the marker coordinate system, respectively. The distance between the camera and the ceiling is about 120cm, and the camera which looks toward the ceiling moves to (50,0,120) from (50,1800,120) in parallel to the ceiling. Figure 7 illustrates estimated camera positions and orientations

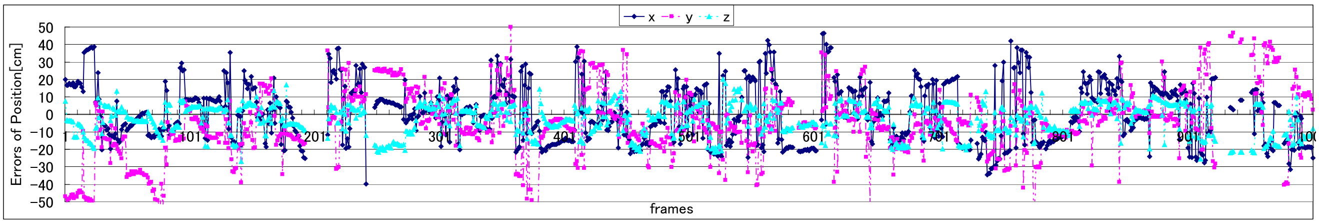



Figure 8: Errors of estimated camera position.

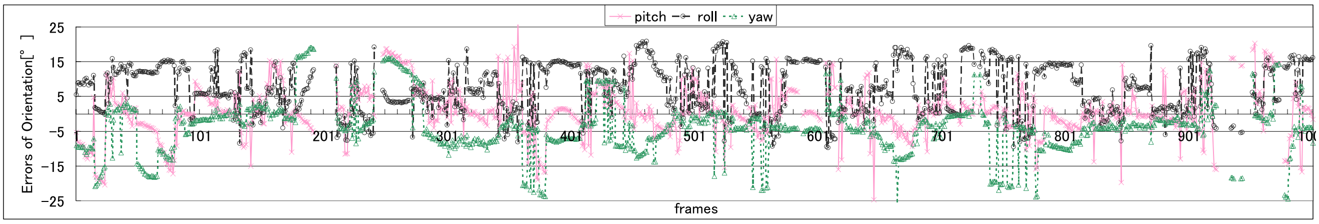



Figure 9: Errors of estimated camera orientation.

when the camera moves in parallel with the $y$ axis. Figures 8 and 9 show errors of estimated position and orientation, respectively. From the experiment, we can confirm that errors of estimated camera position and orientation are at most about 30cm and 15°, respectively. The averages of estimated position and orientation errors are about 15cm and 8°. We conclude that the accuracy of estimated camera position is comparable with the case of using conventional visual markers. However, the results of estimation are vibrated.

# 4 Conclusion

This paper has proposed a new localization method using invisible markers and infrared camera. In our method, user's position is identified by recognizing translucent retro-reflective markers which are illuminated from infrared LEDs. In order to eliminate the influence of infrared other than the reflection from retro-reflective markers, the infrared LEDs are flashed on and off synchronously with image capturing.

In experiments, we have confirmed that the accuracy of estimated camera position and orientation is comparable with the case of using conventional visual markers. In future work, we should carry out experiments at extensive indoor environments. We will also stabilize the result of position estimation in order to construct an AR system.

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