Invisible Marker Based Augmented Reality System

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ABSTRACT

Augmented reality (AR) has recently gained significant attention. The previous AR techniques usually need a fiducial marker with known geometry or objects of which the structure can be easily estimated such as cube. Placing a marker in the workspace of the user can be intrusive. To overcome this limitation, we present an AR system using invisible markers which are created/drawn with an infrared (IR) fluorescent pen. Two cameras are used: an IR camera and a visible camera, which are positioned in each side of a cold mirror so that their optical centers coincide with each other. We track the invisible markers using IR camera and visualize AR in the view of visible camera. Additional algorithms are employed for the system to have a reliable performance in the cluttered background. Experimental results are given to demonstrate the viability of the proposed system. As an application of the proposed system, the invisible marker can act as a Vision-Based Identity and Geometry (VBIG) tag, which can significantly extend the functionality of RFID. The invisible tag is the same as RFID in that it is not perceivable while more powerful in that the tag information can be presented to the user by direct projection using a mobile projector or by visualizing AR on the screen of mobile PDA.

Keywords: Invisible marker, infrared, augmented reality, VBIG

1. INTRODUCTION

Augmented Reality (AR) is a technology in which a user’s perception of the real world is enhanced with additional information generated by a computer. In a typical AR system, a user’s view of a real scene is augmented with virtual objects. Thus, accurate measurements of the camera pose relative to the real world are required for the proper registration of virtual objects. Many tracking methods have been used in AR applications. These include mechanical, magnetic, ultrasound, inertial, vision-based and so on. The augmentation results based on vision-based methods are more accurate as they are directly computed from features extracted from the images to be augmented. For this reason, many vision-based methods have been proposed and their performance has been improved. The previous methods can be classified into two categories: marker-based\cite{1,13} and marker-less (or marker-free)\cite{3,4,5}. Each of the approaches has its own advantages and disadvantages, respectively. Placing a physical marker in the workspace of the user is intrusive while the use of the fiducial marker increases robustness and reduces computation requirement. Using natural features instead of an intrusive physical marker requires user’s intervention or initial offline calibration. The marker-less methods are useful only when there are lots of rigid and unchanging features in a scene. If this condition is not satisfied, their performance significantly degrades. In particular, if there should be no features to be tracked in a scene, they do not work any more. In particular, if there should be no features to be tracked in a scene, they do not work any more. To trade the pros and cons, hybrid methods have been recently proposed\cite{14}. However, no method seems to completely resolve the problems.

We present a novel method for augmented reality that uses an invisible fiducial marker which is drawn with infrared (IR) fluorescent ink. We call this invisible marker based augmented reality (IMAR). The method has the advantages of the conventional marker-based methods and marker-less methods at the same time: The marker is not intrusive while the use of the fiducial marker increases robustness and reduces computation requirement. Using natural features instead of an intrusive physical marker requires user’s intervention or initial offline calibration. The marker-less methods are useful only when there are lots of rigid and unchanging features in a scene. If this condition is not satisfied, their performance significantly degrades. In particular, if there should be no features to be tracked in a scene, they do not work any more. To trade the pros and cons, hybrid methods have been recently proposed\cite{14}. However, no method seems to completely resolve the problems.

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To achieve IMAR, two cameras are used: an IR camera for tracking an invisible marker and a visible camera for capturing a scene. The two cameras are positioned in each side of a cold-mirror so that their optical centers coincide with each other. We track the invisible markers using the IR camera and visualize AR in the view of the visible camera. From a viewpoint of the visible camera, the system works as an invisible marker based augmented reality system.

Similar works\cite{2,10,11,12} using IR markers for AR have been proposed. Sauer et al.\cite{2} have implemented a tabletop setup to explore augmented reality (AR) visualization, which is called an “augmented workspace”. The user sits at the table and performs a manual task, guided by computer graphics overlaid on to his view. The method is not a marker-based
method and tracks natural features of which the geometry is known. The features are detected in the visible range. Thus, their method has the problem that the features are still intrusive. In the field of wearable computer, Tenmoku et al.\textsuperscript{10} have estimated user’s position using IR markers and pedometer, and the orientation of the user by gyro sensor. Maeda et al.\textsuperscript{11} developed a hybrid tracking system that estimates more exactly the position and orientation of the user by combining a gyro sensor with a stereo camera which captured infrared markers. Those methods require an additional sensor to estimate user’s orientation. Nakazato et al.\textsuperscript{12} proposed a fully vision-based localization method using invisible markers consisting of translucent retro-reflectors, which is most similar to our method. Their markers are not invisible in the visible range and the performance is quite good. However, their markers are tape-typed ones unlike ours and IR LEDs should be flashed on to capture the markers.

The rest of this paper is organized as follows. In Section 2, the concept and method of IMAR is explained in detail. Experimental results and discussion are given in Section 3. In Section 4, application areas of IMAR are exemplified. Conclusion is drawn in Section 5.

2. INVISIBLE MARKER BASED AUGMENTED REALITY

In this section, the concept and method of IMAR are described in detail. In Section 2.1, the invisible markers which are used in our system are described. Section 2.2 explains the method of IMAR. In Section 2.3, the method for tracking the invisible markers with cluttered background is presented.

2.1. Invisible marker

The markers are created/drawn with IR1PenSm (IR invisible ink writing pen of which the ink has the properties as shown in Table 1 and Figure 1)\textsuperscript{7}. Under normal light, the markers are completely invisible to the human eye (the human eye can see from about 400nm to about 700nm) yet can be seen by using a device which can see in the infrared range such as IR cameras. The invisible ink can be applied to paper, plastic, skin, wood and almost any substance. This property makes our system flexible to be used to various applications. Figure 1 shows the images of capturing an invisible marker using a visible camera and an invisible camera, respectively.

<table>
<thead>
<tr>
<th>Table 1. Properties of the invisible ink</th>
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<tr>
<td>Ink color</td>
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<td>Stimulation (absorption) frequency</td>
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<td>Emission frequency</td>
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<td>Ink solvent</td>
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![Figure 1. Visibility of the invisible marker in the visible (left) and infrared (right) range.](image)

2.2. IMAR

Marker-based methods require a space for a marker to be attached as shown in Figure 2(a) and suffer from an undesirable effect although using a marker makes them much more reliable. IMAR is a marker-based method in which the markers are invisible as shown in Figure 2(b). Therefore, IMAR does not suffer from the intrusiveness of markers
any more. We use a special-purpose library (ARToolkit) which is used to track a marker using a single camera and overlay a graphic object. In addition, an additional special camera is used to track an invisible marker unlike the general marker-based methods using ARToolkit. Therefore, two cameras are used: a camera which is equipped with an IR filter for tracking an invisible marker and the other camera which is equipped with a color correction filter for capturing a scene. The two cameras are positioned in each side of cold-mirror so that their optical centers coincide with each other as shown in Figure 3. The cold mirror reflects visible light while transmitting IR light.

(a) Using a visible marker

(b) Using an invisible marker.

Figure 2. Advantage of using invisible markers. Invisible markers are not intrusive.

Figure 3. Overview of IMAR system.

Camera calibration techniques might be used to make the optical centers of the cameras coincident. However, it is difficult to coincide the optical centers accurately and the resulting calibration error may significantly lower the tracking performance. In case of AR with the cluttered background, for instance, the calibration error significantly lowers the tracking performance because the result of the subtraction between the IR image and the visible image might not be

\[1\] Details are explained in Section 2.3.
useful for detecting or identifying the marker any more. We track the invisible markers using the IR camera internally and visualize AR in the view of the visible camera.

2.3. Invisible marker with cluttered background

For achieving IMAR, it is not required that the marker should be on the simple or solid surface. In this section, it is shown that the markers with cluttered background can be tracked using simple image processing algorithms. Notice that the image taken by the IR camera has different color or intensity from that by the visible camera but the difference is almost consistent in all the pixels of the images except the pixels occupied by the marker. Thus, if the image taken by the visible is subtracted from the image taken by the IR camera as follows,

$$I_{sub}^k = |I_{\mu}^k - I_{vis}^k| \quad k = r, g, b$$

where

$I_{\mu}$: IR image

$I_{vis}$: Visible image

the pixels occupied by the marker become noticeable while the background pixels become unnoticeable as shown in the middle-bottom and right-bottom images of Figure 4. The two images are obtained from applying a simple intensity-based cropping algorithm to the red- and green-channel of the subtraction image.

![Tracking an invisible marker with cluttered background. Visible image (left-top image) and IR image (right-top image) are discriminant from each other on the pixels occupied by a marker. The simply-cropped IR image (left-bottom image) is not useful for detecting and identifying the marker. The difference images (middle-bottom and right-bottom images) are not affected by the texture of background.](image)

Finally, the visible image ($I_{vis}$) is transformed into

$$I_{vis}' = AND(I_{vis}, Th(I_{sub}^k)),$$

where

$$Th(x) = \begin{cases} 1 & x > \text{const} \\ 0 & \text{otherwise} \end{cases}$$
The IMAR is applied to $I_{vis}'$ as it is. $I_{vis}'$ does not affected by the texture of background any more.

The problem associated with cluttered background happens to all the marker-based methods. However, no solution seems to be proposed because they use only a single camera. We use an additional camera (it might be a weakness of our system) to track an invisible marker but the additional camera is a good solution for coping with the cluttered background.

3. EXPERIMENTAL RESULTS

To realize the system described in Figure 3, the followings are exploited in the experiments. Two Sony CCD-TRV 128 camcorders with IR functionality are used. One is equipped with X-Nite 715nm infrared filter for tracking an invisible marker and the other is equipped with X-Nite color correction filter (visible light cutoff filter) for capturing a real scene. A marker is created/drawn with IR1PenSm (IR invisible ink writing pen – 840nm peak) on a paper. Some details about our cameras, filters, and ink are found in the website. A cold mirror is used to coincide the optical centers of two cameras with each other. The cold mirror reflects 90% of visible light while transmitting over 80% of IR light. Intel OpenCV library is used to handle an image and ARToolkit library to track a marker and overlay a graphic object.

The experimental results are shown in Figure 5. No marker is observable in the scene but virtual kettle appeared rigidly anchored in the scene. It would not be possible unless IR camera tracked the invisible marker internally. IR images may be sensitive to environmental noise because their brightness gets decreased when they are filtered. However, the noise can be easily removed using a suppression filter and intensity-based enhancement algorithm. We applied the median filter and histogram equalization to the images.

![Figure 5. Experimental results of IMAR with solid-colored background (top images) and cluttered background (bottom images). The middle image of each row represents the transformed visible images using the algorithm explained in Section 2.3. The marker is clearly visible on the transformed images.](image)

4. APPLICATION

As an application of the proposed system, the invisible marker can be used as a Vision-Based Identity and Geometry (VBIG) tag, which can significantly extend the functionality of RFID. The invisible tag is the same as RFID in that it is not perceivable. However, it is much more powerful because the tag information can be presented to the user by direct projection using a mobile projector or by visualizing AR on the screen of mobile PDA. A few examples are introduced in the section.
Figure 6 shows an experimental result of using the proposed system for inventorying in the warehouse. There is an invisible-tagged package. A user can obtain the information about the inner things without unwrapping the package.

The proposed system can also be used as a virtual advertisement system. Most of commercial virtual advertisement systems have been based on a physical sensor which is quite expensive. Some sensor-free systems have been proposed but their performance is still unreliable. The proposed system is suitable for achieving cheap but reliable one. Figure 7 shows an example of providing the preview (it can be considered as a kind of advertisement) of a movie using the proposed system. Although the marker is not explicitly visible, the user can see the preview.

Figure 6. Inventorying using an invisible marker. Left image: IR camera image, middle image: visible camera image, right image: augmented visible camera image.

Figure 7. Providing the preview of a movie ("Mulan 2") using an invisible marker. Left image: IR camera image, middle image: visible camera image, right image: augmented visible camera image.

The method of tracking invisible markers can be used as a novel localization method in a navigation system such as "building scanner" which recognizes and visualizes an area and information of building equipment using visible marker-based AR techniques.

Figure 8. "Building scanner" system (courtesy of Park et al.). Left image: original system which uses an artistic visible marker. Right image: improved one to which our system is applied.

2 It is not implemented but still in the blueprint stage.
Park et al. tried to make the visible marker artistic for alleviating the intrusiveness but not resolved completely. The problems of the previous localization methods such as power supply and undesirable visual effects are completely resolved by using invisible markers. Figure 8 shows an example of applying our system to “building scanner”.

5. CONCLUSION

We proposed a kind of marker-based AR system (called IMAR) using invisible markers. Then, the IMAR method was extended to be applied to a scene with cluttered background. The system with the algorithms given in this paper showed a reliable performance even in the cluttered background and thus was applicable to various fields.

The area of IMAR has been hardly explored and thus there are still a lot of things to be explored. First of all, providing a quantitative measure for estimating the performance of our system would be helpful for one to be interested in the system.

As mentioned in Section 4, it is much more powerful to use a projector for visualizing AR because the tag information can be presented to the user by direct projection. However, the projected contents may be mixed with the scene and thus unreadable or distorted. It would be interesting to employ radiometric calibration techniques for resolving this problem.

There is something debatable about using an IR ink although IMAR system based on IR ink shows quite a good performance. IR ink is not permanent and sensitive to thermal noise. Ultraviolet (UV) ink is also invisible. Moreover, UV ink is permanent and less sensitive to thermal noise. Only the special light such as a UV flashlight is required to make UV ink visible while no device is required to make IR ink visible. Therefore, using an UV marker may be more suitable in the applications such as inventorying in which permanency or accuracy is more significant than the requirement (special light). For these reasons, we are now considering using UV marker instead of IR marker for achieving IMAR.

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