Real-time Estimation of Light Source Environment for Photorealistic Augmented Reality

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Abstract

This paper proposes a vision-based augmented reality system with correct representation of attached and cast shadows. To realize a seamless augmented reality system, we need to resolve a number of problems. Especially, the geometric and photometric registration problems are important. These problems require to estimate the positions of light sources and user's viewpoint. The proposed system resolves the problems using a 3D marker which combines a 2D square marker and a mirror ball. The 2D marker and the mirror ball are used to estimate the relationship between the real and virtual worlds and the positions of light sources in the real world, respectively.

1. Introduction

Augmented reality produces an environment in which virtual objects are superimposed seamlessly on user's view of the real environment. Augmented reality has received a great deal of attention as a new method for displaying location-based information or increasing the reality of virtual environments [1, 2, 3]. To implement an augmented reality system, we must solve a number of problems. When virtual objects should be superimposed on a certain place as if they really exist in the real world, the geometric and photometric registration problems are especially important.

The geometric registration is especially the most important problem because the problem is a principal factor which provides a user with a sense of incongruity. The registration includes a problem of geometric alignment of the real and virtual coordinates in real time. The problem is considered as one of acquiring the position and orientation of the user's viewpoint in a world coordinate system. One of the major approaches to the geometric registration between the real and virtual worlds is a vision-based method [4, 5]. The methods, which are sometimes referred to as vision-based tracking or registration, estimate the position and orientation of user's viewpoint from images captured by a camera attached at the user's viewpoint. Some methods use square markers[2].

On the other hand, the photometric registration problem requires the consistency between light sources in the virtual world and those in the real world. Therefore, to resolve the photometric problem, the positions of light sources in the real world should be estimated in real time[6]. Debevec has acquired a lighting environment by photographing a mirror ball[7]. Another methods estimates the illumination distribution in the real world using cast shadow regions[8]. However, this method cannot estimate the lighting environment in real time.

Matsuoka has proposed a method which resolves geometric and photometric registration by using a square marker which is combined with sensors for estimating a lighting environment [9]. However, since the photodiodes sensors are used to estimate the position of light sources, the hardware configuration of the system is complex.

This paper describes an augmented reality system which resolves both the geometric and photometric registration problems using a 3D marker consisting of a 2D square marker and a mirror ball which is painted black as shown in Figure 1. The 2D marker is used to estimate the relationship between the real and virtual worlds. We estimate a simple light source map observing a mirror ball. Since it needs to estimate position, color and intensity of only light sources, the mirror is painted black to resolve a dynamic range problem.

This paper is structured as follows. Section 2 describes the algorithms to calculate camera parameters and to estimate the position of light sources in real world as well as an

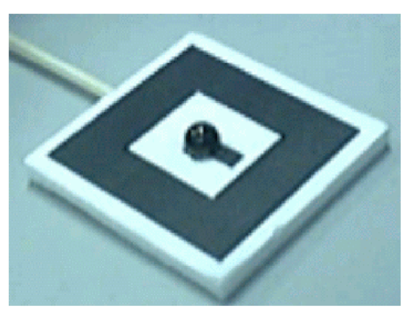

Figure 1. A 3D Marker.

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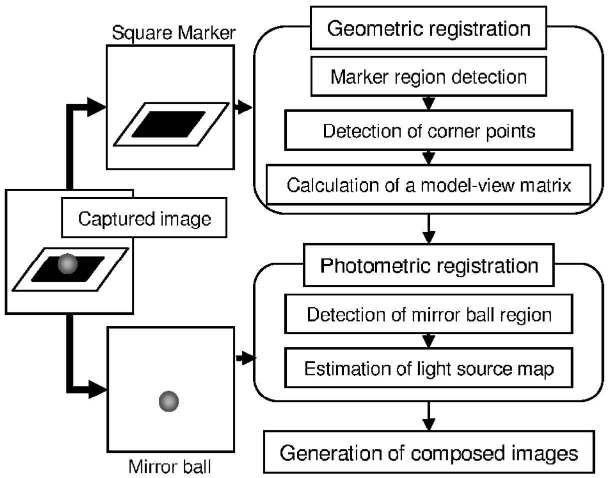

Figure 2. Flow diagram of the registration method.

image composition method. In Section 3, the experimental results with a proposed method and the discussion about the prototype system are described. Finally, Section 4 summarizes the present work.

2. Geometric and Photometric Registration

2.1. Outline of the proposed method

Figure 2 illustrates the outline of the proposed method. First, a camera captures a 3D marker which is composed of a 2D square marker and a mirror ball and is placed in the real scene. The relationship between the 2D marker and the mirror ball and their size are known. The method consists of three processes. In the following, each process is briefly described.

1. Geometric registration

   The relationship between the marker and the camera coordinate system is estimated by detecting the region of the 2D square marker using an existing method.

2. Photometric registration

   Using the result of the first process, a region of the mirror ball in the image is detected. To avoid the dynamic range problem, the mirror ball is painted black. Next, a simple light source map which represents a distribution of light sources in the real scene is estimated from the region of the mirror ball.

3. Generation of composed images

   Finally, a virtual object is rendered with correct attached and cast shadows by using the estimated light source map.

The rest of the section describes the geometric registration and the estimation of light source map in some more detail.

2.2. Geometric registration

In the geometric registration process, a 2D square region is detected based on the size, color and shape of the maker. The model-view matrix, which represents the relationship between the marker and the camera, is estimated by identifying the corners of the markers[2]. In addition, to detect the marker region stably, a threshold of the binarization process is changed dynamically.

Step1 Marker region detection

First, candidate regions of the square marker are detected by using standard binarization and segmentation techniques from the captured image. When the multiple regions are detected from the captured image, the biggest region is selected as the square marker region. To detect the marker for changing the light environment, a threshold of the process of binarization is determined by a mean intensity value of the marker region in the previous frame.

Step2 Detection of corner points

The four points of marker's corners are detected from results of segmentation process in Step 1.

Step3 Calculation of a model-view matrix

A model-view matrix, which represents relationship between the real and virtual coordinate systems, is calculated by using the positions of the four points of marker's corners as well as [2].

2.3. Photometric registration: Estimation of lighting environment

The region of the mirror ball in the captured image can be easily determined by using the model-view matrix estimated in Section 2.2 and the known relationship between the 2D square marker and the mirror ball. Next, the directions of light sources are estimated by using the camera pose and surface normals of the mirror ball points corresponding to the detected pixels as shown in Figure 3. The direction $\mathbf{V_r}$ of light source can be calculated by using the viewing vector $\mathbf{V_{ray}}$ and the normal vector $\mathbf{V_N}$ of the mirror ball point as follows:

$$\mathbf{V_r} = -\mathbf{2}(\mathbf{V_N} \cdot \mathbf{V_{ray}})\mathbf{V_N} + \mathbf{V_{ray}}. \quad (1)$$

In this method, to decrease calculation cost, all viewing vectors are approximately set to the direction parallel to the optical axis of the camera. When the size of the region of mirror ball is assumed to be 20×20 pixels, directions of

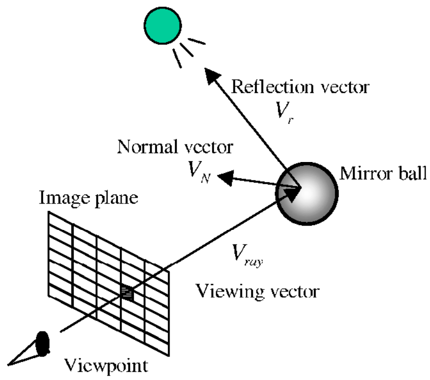

Figure 3. Relationship between a viewpoint and a light source.

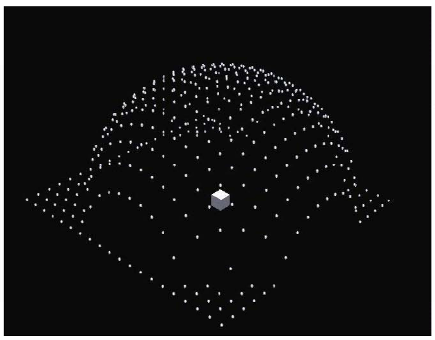

Figure 4. An example of light source map.

the light sources are discretized as shown in Figure 4. The brightness and color of a light source in the real world are determined by intensities and color of pixels in the region of the mirror ball, respectively.

2.4. Generation of composed images

By using the estimated model-view matrix and the light source map of the real world, CG images of virtual objects are mixed into the image of real world. First, a virtual object is registered geometrically by using the model-view matrix. Next, cast and attached shadows are rendered by the light source map. In the rendering process of attached shadows, a limited number of light sources are used in order to achieve real-time rendering (the brightest eight light sources are actually used in experiments). On the other hand, cast shadows are rendered using all the light sources that are obtained in the light source map assuming that the marker is put on a plane.

3. Experiment

We have developed a prototype of video see-through augmented reality system, for which an IEEE1394 camera (SONY: DFW-VL500) captures a 3D marker placed in the real world. The captured image is fed into a desktop PC (CPU P4 2GHz, Memory 256MB), and a composed image is generated.

Figure 5 (a) shows an input image. Figure 5 (b) shows a composed image in which a virtual object (teapot) is merged into the real world with only attached shadow. Figure 5 (c) shows a composed image in which the virtual object is merged with both attached and cast shadows. In Figure 5 (c), we can see that the virtual object really exists in real world. In the experiment, the frame rate is 20 frames per second. Figure 6 shows composed images with user's varying viewpoints. Figure 6(a) illustrates a region of mirror ball in the captured images,

The system can provide a user with a photorealistic augmented reality environment in the same lighting environment as the real scene. However, since the region size of mirror ball in the captured image is limited in the present experimented setup, the directions of light sources are estimated sparsely. Therefore, cast shadows are rendered with discontinuities, which can be observed in Figure 6.

4. Conclusion

This paper has described an augmented reality system which resolves both the geometric and photometric registration problems using a 3D marker composed of a 2D square marker and a mirror ball. The proposed method is mainly characterized by the estimation of a light source map in real time. The geometric registration problem is resolved by using an image of a square marker captured by a camera which is attached near user's viewpoint. The light source map is estimated by analysing a mirror ball region which is detected by using the result of geometric registration. Thereby, the proposed method can realize augmented reality environments which contain virtual objects in the same lighting environment as the real scene. As a pilot study, we also have developed a prototype of video see-through augmented reality system, which has resolved geometric and photometric registration at the same time. The prototype system can produce composite images of real and virtual objects nearly at video-rate, maintaining correct cast and attached shadows.

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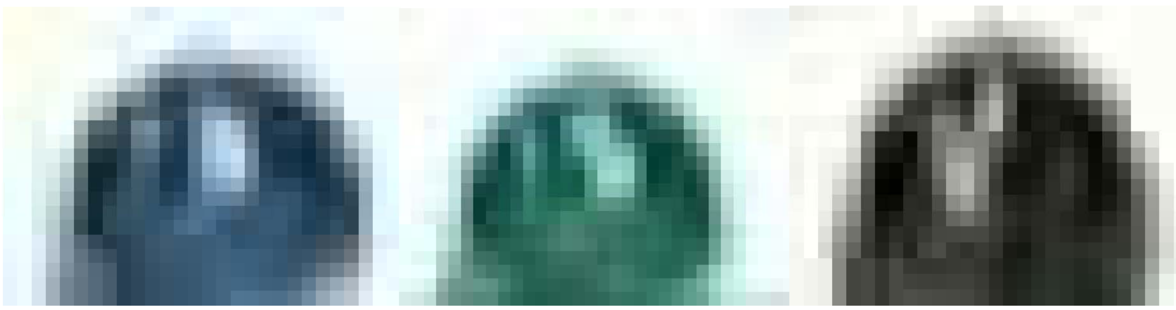
(a) Input image (b) Composed image with attached shadow (c) Composed image with attached and cast shadows

Figure 5. Results of geometric and photometric registration.



(a) Region of mirror ball

(b) Composed images

Figure 6. Augmented scenes with varying viewpoints and color of light sources.

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