Direct-Projected Augmented Reality Considering User's Viewpoint

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Abstract
In direct-projected augmented reality, different position of user requires different projection on 3-D display surface. The problem is caused by the difference between the direction of projector-to-object and the direction of user-to-object. In this paper, it is demonstrated that the graphical contents are properly pre-warped according to user's viewpoint and projected onto 3-D display surface without geometric distortion.

1. Introduction
Augmented Reality (AR) is a technology in which a user's perception of the real world is enhanced with addition information generated by a computer. Up to now, AR techniques have been primarily accomplished in the desktop environments [10]. By using head-mounted display (HMD), portability was provided. Recently, projection-based approaches have been presented for enhancing the face of an actor or changing the color and texture of real objects [8]. Projection made it possible to use 3-D real and large objects as displays [7] and freed from discomforts incidental to wearing a device such as HMD.

For instance, surgeons schedule the operation and check up the state of patient while seeing magnetic resonance imaging (MRI) or computed tomography (CT) images. Although it has become more effective since the methods for 3-D reconstruction and visualization of the MRI or CT images have been presented recently [1], it is still stressful for surgeons to keep peering at the CRT display or wearing HMD to see the information while operating. By directly projecting the 3-D reconstructed MRI or CT images onto the patient's body, surgeons can be visually assisted to operate and monitor the patient's state simultaneously.

Because the position of the projector is not same as that of user's viewpoint, the projection cannot be seen to user just as designed. This problem has not been coped with by the previous projection-based AR methods. In this paper, the projection is properly changed in advance considering user's viewpoint and projected onto 3-D display surface without geometric distortion.

Similar work to our research had been done by Yasumuro et al. [2] on which ultrasonic images were directly projected on the human body *without considering user's viewpoints*. Unlike our method, they used a magnetic tracker for tracking the probe and employed structured lights for 3-D shape measurement of the human body. They employed near-infrared pattern projection for coping with dynamic geometrical changes of the display surface although the geometrical change is not as large as the complicated is required.

The rest of this paper is as follows. In Section 2, the proposed method is explained in detail. In Section 3, experimental results are given. Conclusion is drawn in Section 4.

2. Method
The concept of the proposed method is depicted in Fig. 1. Graphical contents are directly projected onto 3-D display surface which are reconstructed using a modified Zhang's calibration method [6] and a linear triangulation method [4]. An optical tracker [9], which is more suitable compared to magnetic tracker because it is less sensitive to electromagnetic devices, is used for coping with the dynamic change of user's viewpoint as shown in Fig. 1. The corrected position of the graphical contents conforming to the changing user's viewpoint is estimated using a ray/triangle intersection algorithm [3]. The graphical contents are properly pre-warped and projected onto the corrected position.

2.1 3-D Surface Modeling
In the field of computer vision, at least two images are required to compute the 3-D coordinates of an object [4]. In this paper, the image captured by a camera (*camera image*) and the image projected by a projector onto the object (*projector image*) are used. First of all, the projector and camera should be calibrated. For calibrating a camera, the Zhang's calibration method [6] is used as it is. For calibrating a projector, a modified one of Zhang's calibration

method is used.

A modified Zhang's calibration method: For robust calibration, the points on 3-D real pattern and their corresponding 2-D image points are required. In Zhang's calibration, the points on a real planar pattern correspond to 3-D points and their projected points to 2-D points. On the contrary, the projected points correspond to 3-D points and the points on a source pattern of a projector to 2-D points in our method. The coordinates of the projected points can be computed from the image captured by a camera (see Figure 2). Given the 3-D and 2-D points, optimization algorithms of Zhang's method are used as it is.

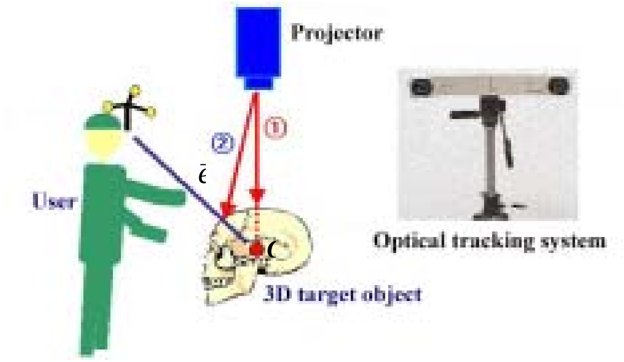

Figure 1. Projection considering the user's viewpoint which is tracked using the optical tracking system. The graphical contents should be projected to not ① but ②.

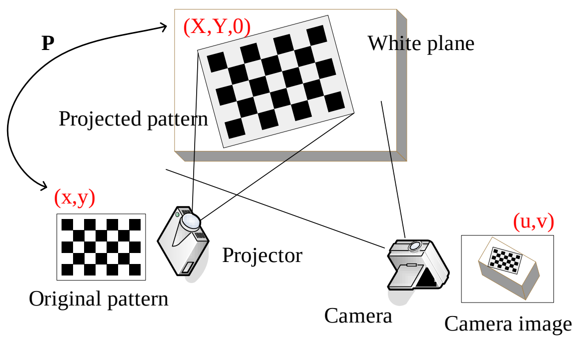

Figure 2. Projector calibration. The relationship (correspondence) between (x,y) and (X,Y) is defined by homography.

If the projector and camera are calibrated and the correspondence between the points in the two images (camera image and projector image) is given, the 3-D coordinates of the object can be easily computed using a linear triangulation method [4]. Finally, the 3D display surface can be polygonally represented based on the recovered points on surface [5] because the surface is piece-wise planar.

2.2 Projection Considering the Viewpoint

For coping with the user's viewpoint which is tracked using an optical tracker [9], it is assumed that the geometric transformation between user, projectors, and display surface is recovered and 3-D coordinates of the display surface is known. This problem has already been addressed in the previous section.

In Fig. 1, it is clear that the graphical contents should be projected to not ① but ② considering user's viewpoint. To do so, the intersection point between $\vec{e}$ and the 3-D display surface should be estimated. In this paper, a ray/triangle intersection algorithm is used [3]. The algorithm is divided into 2 steps. First, it is estimated if a ray is intersected with a certain triangle. Next, the coordinates of the intersection point is computed.

Step 1: Let V_i for $i \in 0,1,2$ be the coordinates of the three vertices of the triangle. The normal vector of the triangle is represented by

$$\vec{n} = (V_1 - V_0) \times (V_2 - V_0).$$

Any point V in the triangle's plane satisfies $V \cdot \vec{n}$ + *constant* = 0. The constant d is computed by

$$d = -V_0 \cdot \vec{n}.$$

If a ray parameterized by $O + \vec{e}\, t$ is intersected with a triangle, t parameter is computed by

$$t = \frac{d - \vec{n} \cdot O}{\vec{n} \cdot \vec{e}}.$$

When $0 \le t \le 1$, the ray intersects with the triangle.

Step 2: A point V in the triangle plane is defined by

$$\overrightarrow{V_0V} = \alpha \overrightarrow{V_0V_1} \times \beta \overrightarrow{V_0V_2}$$
$$where \quad \alpha \ge 0, \beta \ge 0, \alpha + \beta \le 1.$$

In the image plane, this can be written as

$$\overrightarrow{v_0v}(u,v) = \alpha \overrightarrow{v_0v_1}(u_1,v_1) \times \beta \overrightarrow{v_0v_2}(u_2,v_2)$$
$$where \quad v_i : \text{image point of } V_i$$

Therefore, α and β are computed by

$$\alpha = \frac{\det\begin{pmatrix} u_0 & u_2 \\ v_0 & v_2 \end{pmatrix}}{\det\begin{pmatrix} u_1 & u_2 \\ v_1 & v_2 \end{pmatrix}}, \quad \beta = \frac{\det\begin{pmatrix} u_1 & u_0 \\ v_1 & v_0 \end{pmatrix}}{\det\begin{pmatrix} u_1 & u_2 \\ v_1 & v_2 \end{pmatrix}}..$$

After computing the intersection point, the graphical contents are properly pre-warped and projected onto the polygon including the point without geometric distortion.

3. Experimental Results and Discussion

As shown in Fig. 3 and Fig. 4, the 3-D display surface was successfully reconstructed using the proposed calibration method and the graphical contents were accurately projected onto the object without geometric distortion. Through a variety of experiments, we computed that the average projection-errors were less than 2-mm.

As shown in Fig. 5(a), it was intended to project the information of the target object onto 3-D display surface using a projector. If not considering the user's viewpoint in Fig. 5(a), the graphical contents were wrongly projected. It was corrected to be projected as shown in Fig. 5(c) using the ray/triangle intersection algorithm which was explained Section 2.2.

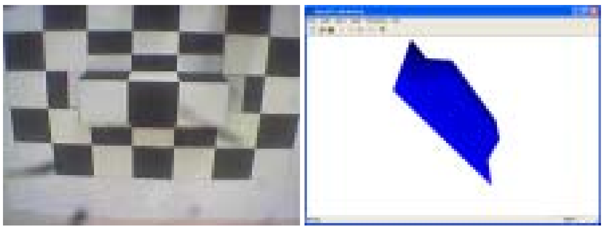

Figure 3. An example of 3-D surface modeling

4. Conclusion

A direct-projected augmented reality method considering user's viewpoint was presented, which is significant for providing the exact information to a user. This projection-based method made users free from discomforts incidental to keeping peering at the CRT display or wearing a device such as HMD.

5. Acknowledgements

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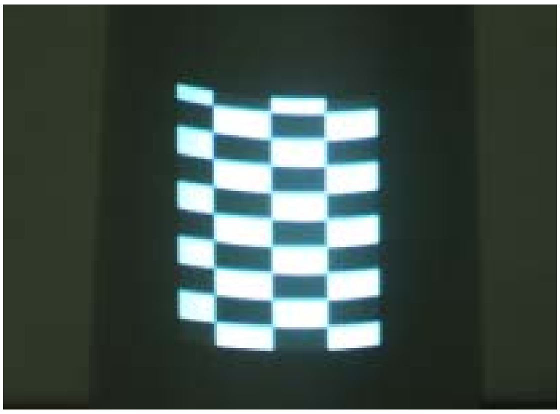
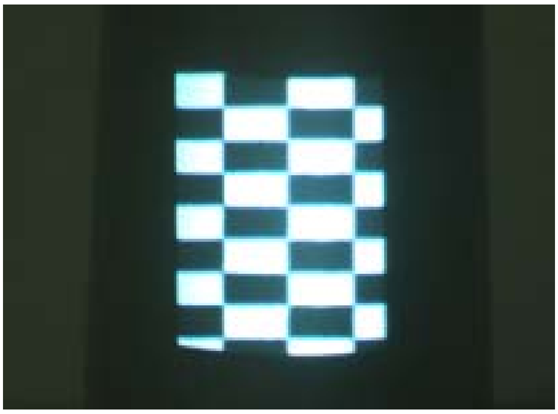


(a) Without correction



(b) Corrected

Figure 4. Correction of geometric distortion. The grid pattern was projected onto a convex surface.

6. References

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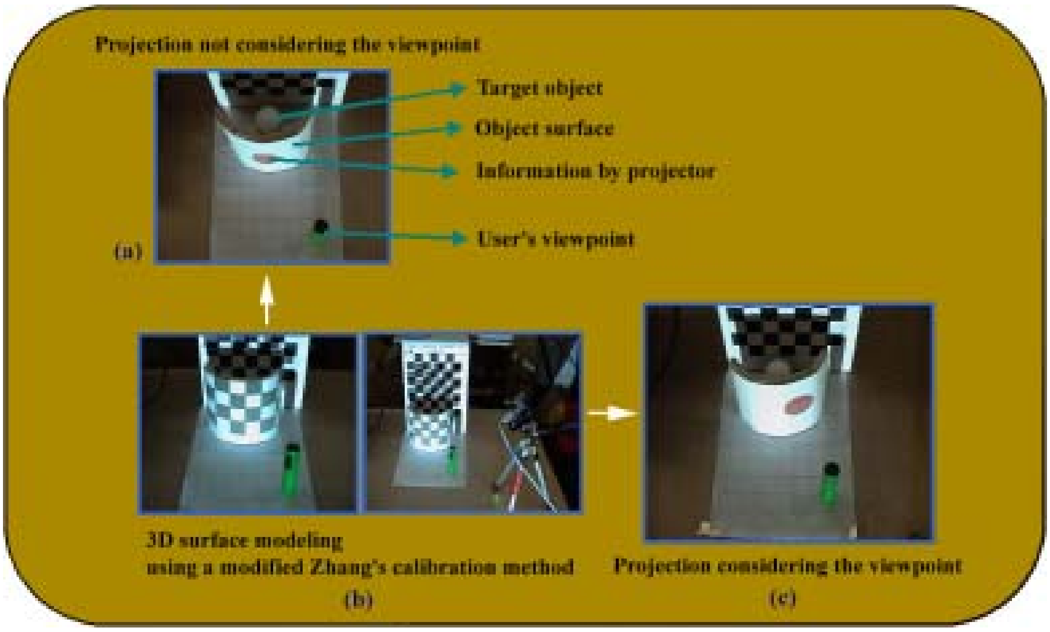

Figure 5. Results of projecting the graphical contents considering user's viewpoint.