Diminishable Visual Markers on Fabricated Projection Object for Dynamic Spatial Augmented Reality

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Figure 1: *Fabricated projection surfaces where visual markers are embedded and results of dynamic SAR by the proposed method.*

1 Introduction

Spatial augmented reality (SAR) is a projection technology to add optical illusion onto static objects. Generally, in SAR, images are projected on complex everyday surfaces other than a flat projection screen. Thus, geometric correction of images is essential. Many studies have examined geometric correction of projection images on nonplanar surfaces . If a projection surface shape is known, it is possible to correct images geometrically by calibrating intrinsic parameters of the projector and extrinsic parameters (position and pose relationships) between the projector and surfaces. However, it is difficult to directly apply previous geometric correction methods to dynamically moving surfaces, because these methods generally assumed only static surfaces.

Several techniques of online geometric correction of projected imagery have been proposed for dynamic SAR. The previous techniques fall into two categories: marker-less and marker-based techniques. As a marker-less approach, Molyneaux et al. proposed to track projection surfaces of complex shapes using depth images [Molyneaux et al. 2013]. Resch et al. proposed another method, which estimates the position and pose of a projection surface by detecting image features of projected results [Resch et al. 2014]. Sueishi et al. proposed to track projection surfaces using a high speed camera with simple set of computer vision algorithm [Sueishi et al. 2015]. However, obviously, such marker-less techniques cannot be applied to situations where projection surfaces have either invariant structures (e.g., flat, cylinder, and sphere surfaces) or periodic shapes (e.g., wavy surfaces), and where projection images do not have rich image features such as strong edges. In such cases, these techniques cannot estimate the position/pose of projection surfaces uniquely.

The use of visual markers can solve this limitation. In [Ehnes et al. 2004], standard square shaped AR toolkit marker is used for position/pose estimation. Akaoka et al. used retroreflective markers and vision-based motion capture system [Akaoka et al. 2010]. In the marker-based approach, users can use surfaces with any shapes and any projection images. However, it is hard to achieve a precise registration due to an inaccurate placement of visual markers on the projection object, which is generally done by manual operations in conventional systems (Figure 2).

This paper presents a novel visual markers for dynamic SAR, which are directly embedded on a 3D projection object printed out from a digital fabrication machine, in particular, full-color 3D printer. Since the markers are automatically embedded on a projection surface with mechanical accuracy, precise geometric registration is achieved. However, the shape of markers printed on a nonplanar surface is possibly deformed, which potentially decreases the performance of vision-based marker recognition. In addition, the marker itself is visually salient, and consequently, disturbs a user's sense of immersion. To solve the former issue, we apply a marker whose shape is topologically robust when being deformed. For the latter issue, we carefully decide the reflectance of the marker so that it can be visually canceled by projection using radiometric compensation technology while being detectable by cameras. We also proposed a novel marker placement method, which decides the positions of markers so that the position/pose of the object is accurately estimated from various viewpoints. In this demonstration, we show an accurate position/pose estimation and marker cancellation with the proposed visual markers.

2 Proposed Method

The system consists of a pair of infrared cameras for estimating position/pose of surfaces (stereocam), an RGB camera for radiometric compensation (colorcam), and a projector. The colorcam and projector are placed to be optically coaxial using a beam-splitter.

2.1 Marker Design

We design the shape of a marker so that its center is detected even when it is printed on nonplanar surface (Figure 1). To realize a robust center detection for marker shape deformation, we apply a checker corner for the center of the marker, which can be detected with sub-pixel accuracy even when being deformed. We also apply a donut-shaped frame to increase the robustness for image noise by which we regard a corner as the center of a marker only when the corner is inside of the frame. This topological relationship is not easily changed even when the marker is deformed. After detecting the marker center by stereocam, we measure the 3D position of the marker with a normal stereo measurement technique.

We decide each marker location so that the position/pose of a projection surface is accurately estimated from various viewpoints. Because the optimal marker placement is dependent on the shape of the surface, it is computed for each surface as follows. We generate a 3D computer graphics model of the projection surface, on which markers are mapped as a texture. We render this model from a viewpoint and regard it as a valid viewpoint if the position/pose of this model is estimated accurately from correctly detected marker centers. This process is performed from various predefined viewpoints. We used a genetic algorithm (GA) to search the optimal marker placement that maximizes the number of valid viewpoints, where a location of each marker represents a gene.

We decide the reflectance of the marker by assuming that the markers are visually canceled by a radiometric compensation technique. We need to make the contrast between the marker and the background (white surface) as low as possible for this purpose, because the maximum intensity of a projector is limited. However, at the same time, we also need to consider that the contrast should be high so that the stereocam can successfully detect it. We empirically decide the reflectance. At first, we print an object on which markers with different reflectances are embedded. Then, we check for each marker if it can be visually canceled by projection as well as detected by the stereocam.

2.2 Position/Pose Estimation

In online process, marker center positions in each of the infrared camera coordinates are measured, from which 3D positions of the marker centers are computed. The position/pose of the surface is then estimated by matching between the measured positions and the original marker positions of the 3D model. The target appearance is represented as a texture of the model. Then, 6DOF geometric transformation is applied using the estimated position/pose information to generate the target appearance from the colorcam.

2.3 Radiometric Compensation

We use a closed-loop approach for radiometric compensation method similar to [Fujii et al. 2005]. Here, $\mathbf{P}(i,t)$ represents the RGB value of pixel i in projected image. $\mathbf{C}_{ref}(j,t)$ and $\mathbf{C}_{cap}(j,t)$ represent the RGB value of pixel j in the target appearance and captured image, respectively. The pixel j corresponds to the pixel i in the fixed pixel correspondence between captured image and projected image. In the proposed method, radiometric compensation/marker cancellation is computed as follows:

$$\mathbf{P}(i,t+1) = \mathbf{P}(i,t) + \alpha(\mathbf{C_{ref}}(j,t) - \mathbf{C_{cap}}(j,t)) \quad (1)$$

3 Experiment and Result

We made two projection surfaces by a 3D printer (Projet660Pro) from models of Cone and Bunny (Figure 1). The reflectance of markers was 0.3. Figure 3 shows experimental setup. We used PointGreyResearch FLEA 3 U3-12S2M-CS (1280×960 pixel) with IR pass filter as stereocam, U3-13S2C-CS (1280×960 pixel) as colorcam, and EMP1710 projector (1024×768 pixel). A beam-splitter was placed in front of colorcam and a projector, and two infrared light sources were placed around projection surface.

We evaluated position/pose estimation accuracy. As a result, the error of estimated translation and rotation was less than 2.6 mm and 3.2 deg, respectively. The average time from capturing projection surface by stereocam until generating the target appearance was 240 ms. We evaluated radiometric compensation accuracy while projection surface was static. It was able to cancel markers visually by projection in about 7 loop (Figure 4). The RGB (8 bit) error between the target appearance and captured image by colorocam was $(25, 32, 30)$ in the 1st loop and $(6, 6, 9)$ in the 7th loop. The average time of a loop of radiometric compensation was 160 ms.

4 Conclusion

We have presented a novel marker embedding method for position/pose estimation in dynamic SAR to 3D printed object. Experimental result shows that the proposed method estimated position/pose of projection surface accurately and canceled the markers visually by projection. In future, once a 3D printer using infrared ink is available, more correct pose estimation and marker cancellation will be achieved.

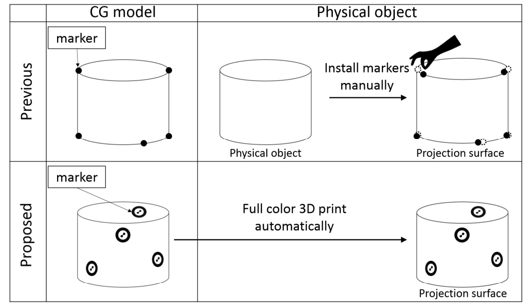

Figure 2: *Comparison of marker installing approaches.*

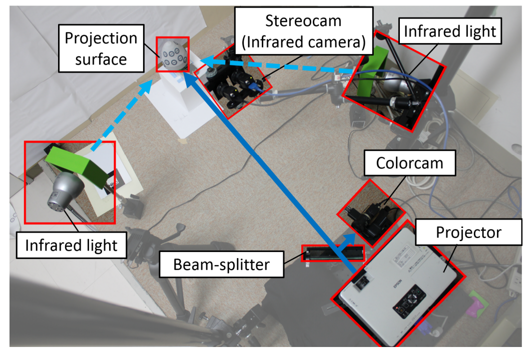

Figure 3: *Experimental setup.*

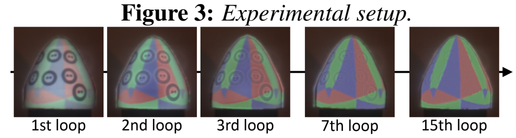

Figure 4: *Result of closed-loop radiometric compensation.*

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