Visual Perception With Dynamic Projection Mapping

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ABSTRACT

Dynamic projection mapping is an emerging technology to augment the real-world surface by projecting images even in the dynamic scene. In such a technology, the augmented appearance needs to be highly realistic. However, there is some technical limitations to reproduce the physically same appearance with complete correspondence as the one in the real world. To overcome this gap, we explore the reality which is perceptually consistent in our vision. This paper shows our research results showing that such strategy is effective for dynamic projection mapping.

1 INTRODUCTION

Dynamic projection mapping achieves high-speed sensing of dynamically-changing environment in real time, generates graphics, and projects them onto the target. In this application, the misalignment between the target and the projected target needs to be avoided. In order to meet this requirement completely in physical sense, the system latency from the sensing to projection needs to be zero millisecond (ms). However, it is technologically impossible.

On the other hand, dynamic projection mapping is the application for human. We can design the system to explore not the physical strict reality but the reality in the visual perception.

Such strategy allows us to set the above latency requirement as around 6 ms. This clue can be found in [1]. They have developed a projection-based touch-input device which responds with 1 ms latency. In their user experiment, a white square is displayed on a freely moving user's hand while changing the projection latency. The results showed that participants perceived a difference when the projection latency was greater than 6.04 ms on average. This means that in order to realize dynamic projection mapping without any perceivable misalignment, we do not need zero-ms latency, although 6-ms latency is hard to realize in the conventional technologies and requires high-speed projection and high-speed image sensing [2].

Dynamic projection mapping is a challenging technology. There are various problems hard to be solved. However, if we efficiently combine the system design with the characteristics of the human visual perception, we can find novel solutions. This paper introduces some examples and how human visual perception is effectively combined with them.

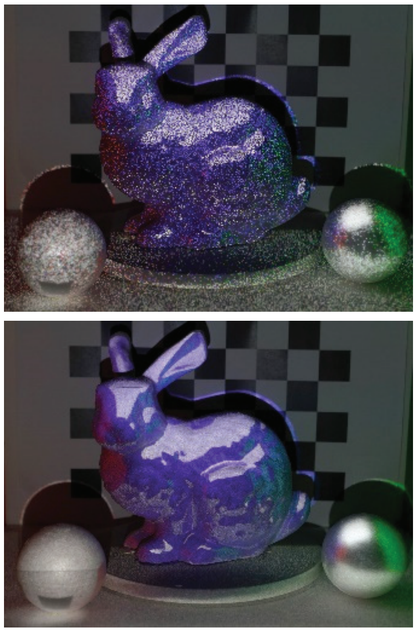

Fig. 1 Realistic dynamic projection mapping using real-time ray tracing. (Top) 1-fps projection of 2-spp image. (Bottom) 947-fps projection of 2-spp image [5].

2 REALISTIC DYNAMIC PROJECTION MAPPING USING REAL-TIME RAY TRACING

One of the important challenges for dynamic projection mapping is to enhance the sense of reality, which would require the projection of highly realistic graphics.

In the computer graphics field, such an image can be rendered via ray tracing. In particular, path tracing, which is one of the techniques for ray tracing, is effective. Path tracing can create a highly realistic image.

However, such rendering takes a considerable amount of time because it requires many ray samples and integration of the traced results for each pixel of the rendered image. In contrast, as described in Section 1, dynamic projection mapping inherently requires high-frame-rate rendering, e.g., 500-1000 fps, for low-latency projection. Although the latest GPU technology accelerates the path-tracing rendering drastically, images rendered within several milliseconds are highly noisy because the number of sampled rays is insufficient.

The key to solving this issue is persistence of vision. If the refresh rate of the displayed images is higher than the critical flicker frequency, our vision integrates them.

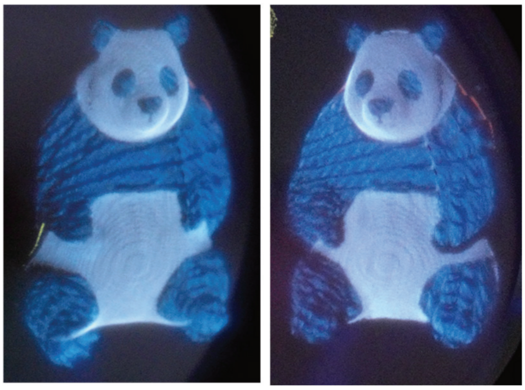

Fig. 2 Realistic volumetric 3D display using physical materials [7]

Additionally, our vision integrates spatial pattern information along the trajectory of pattern movement for clear perception [3][4]. This perception characteristic is also effective for realistic dynamic projection mapping based on path tracing.

The proposed method projects the path-traced intermediate noisy images at a high frame rate onto the dynamic scene and induces their visual integration on the perceptual space [5]. This approach can reduce the noise owing to path tracing via perceptual integration. In addition, it allows the alignment between the projected image and the moving target to be consistent via high-frame-rate intermediate image projection.

Fig. 1 compares the two different projection speeds. The projected image was rendered with 2 samplings per pixel (spp). We confirmed that noise was drastically reduced by high-frame-rate projection. This technique allows dynamic projection mapping to reproduce various realistic effects such as the complicated reflection, refraction, soft shadows, and so on. It achieves a level of realism that surpasses the level achievable by conventional techniques, while meeting the low-latency requirement.

3 REALISTIC VOLUMETRIC 3D DISPLAY USING PHYSICAL MATERIALS

Projection onto the dynamically-moving object can be used for swept volumetric 3D display [6]. In this display, patterns are projected to the swept screen at high speed so that the 3D image is perceived based on the persistence of vision. This type of 3D display can have advantages such as a wide-angle view and a glasses-free

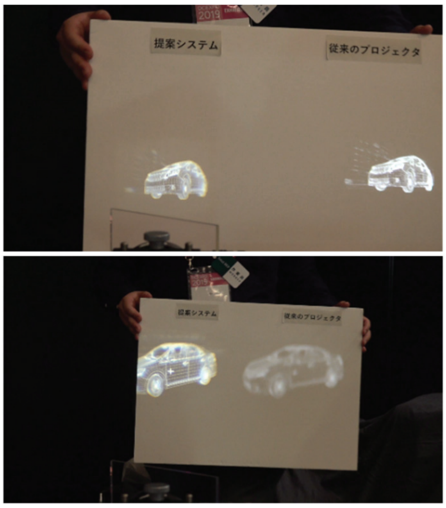

Fig. 4 High-speed focal tracking projection based on liquid lens [9]. Proposed projection (left) and the conventional projections (right) are compared

solution without accommodation–convergence. However, it presents limitations in reproducing realistic textures on 3D surfaces. This is because the swept volumetric display requires a high-speed projector, i.e., at least approximately 2,000 fps, and the resolution and bit depth of such a projector are limited.

A new configuration of a swept volumetric 3D display is proposed, in which physical materials are arranged on a swept screen to solve the aforementioned volumetric 3D displays' limitations [7]. This display retains the original advantages of the volumetric display mentioned above for shape reproduction. Additionally, the new configuration can contribute to realistic texture reproduction. In addition, the system can remove hidden surface in real time according to the observer's point of view.

Fig. 2 shows the displayed panda with blue wool and white felt. The images are observed from two viewpoints, respectively. The proposed display is expected to play an important role in the fields of design, education, and entertainment.

4 HIGH-SPEED HUMAN ARM PROJECTION MAPPING WITH SKIN DEFORMATION

Augmenting the human arm surface via projection mapping can have a great impact on our daily lives with regards to entertainment, human-computer interaction,

Fig. 3 High-speed human arm projection mapping with skin deformation [8]

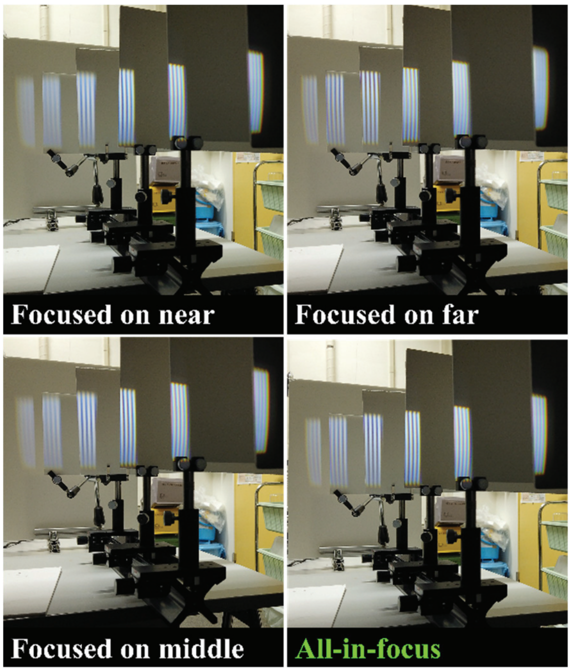

Fig. 5 An extended depth-of-field projection method using a high-speed projector with a synchronized oscillating variable focus lens [10]

and education. Skin deformation is an important factor to provide the immersive user experience in such applications. Skin deformation in arm is complicated and we normally don't care about its mechanism in our daily life. However, projection mapping ignoring such skin deformation largely degrades the user experience.

Based on this background, a high-speed human arm projection mapping capability that handles skin deformation is newly proposed [8]. Fig. 3 shows results that enabled digitally applied tattoos onto the arm.

5 EXTENDED DEPTH-OF-FIELD PROJECTION

In dynamic projection mapping, target can be moved freely. It can move closer and farther to the projection system. However, projector is traditionally designed to project information onto a flat screen on a fixed distance. The range of depth-of-focus (DOF) is narrow because the aperture is large to keep high intensity. This can be a limitation for dynamic projection mapping.

To solve this problem, a high-speed projection system with a dynamic focal tracking technology based on a variable focus lens is proposed [9]. The system corrects the focal length based on the feedback of the target position so that the projected image is focused on the target surface. The system shows that it is difficult to perceive the defocused image if the control speed of the lens is fast enough.

If the system utilizes the persistence of vision, another solution can also be provided. In the new solution, the system configuration is same as [9]. It consists of a variable focus lens and high-speed projector. However, the focal length of the lens is oscillated at high speed and synchronized with the projection [10]. If the system projects multiple images during its oscillation and the oscillation and projection speed is high enough, we perceive as the projector DOF is largely extended, even though the projected images with different focal lengths are projected at different timing. Fig. 5 shows the results. In the figure, the upper left and right images show the scenes, which are only focused at the near, and far positions, respectively. The lower left image shows the scene that is focused on middle position, and the lower right image is the result of the proposed system, which is focused at all the focal planes.

6 CONCLUSION

This paper introduces the latest work of dynamic projection mapping and explains how the human perception can contribute to break the limitation.

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