Dynamic Depth-of-Field Projection for 3D Projection Mapping

Lihui Wang
University of Tokyo
Bunkyo-ku, Tokyo, Japan
wang_lihui@ipc.i.u-tokyo.ac.jp

Hongjin Xu
University of Tokyo
Bunkyo-ku, Tokyo, Japan
hongjin_xu@k2.t.u-tokyo.ac.jp

Yunpu Hu
University of Tokyo
Bunkyo-ku, Tokyo, Japan
yunpu_hu@ipc.i.u-tokyo.ac.jp

Satoshi Tabata
University of Tokyo
Bunkyo-ku, Tokyo, Japan
satoshi_tabata@ipc.i.u-tokyo.ac.jp

Masatoshi Ishikawa
University of Tokyo
Bunkyo-ku, Tokyo, Japan
masatoshi_ishikawa@ipc.i.u-tokyo.ac.jp

ABSTRACT

Demonstration for a dynamic depth-of-field projection mapping on a 3D moving object would be performed. Conventional projection mapping was limited on 2D space, due to their narrow depth-of-field projection range. Our system included a high-speed projector, a high-speed variable focus lens, a depth sensor by a stereo camera, so that the depth information would be detected and then served as feedback to correct the focal length of the projection. As a result, a projection mapping would be well-focused projected on a 3D dynamic moving object.

CHI'19 Extended Abstracts, May 4–9, 2019, Glasgow, Scotland Uk

ACM ISBN 978-1-4503-5971-9/19/05…$15.00
https://doi.org/10.1145/3290607.3313246

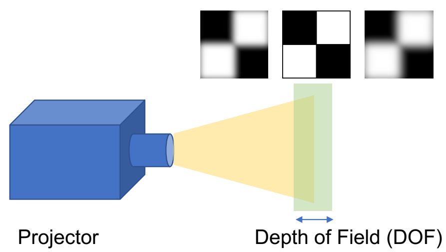

Figure 1: A conventional projector has a fixed focal length and a narrow depth of field (DOF), so the objected within its DOF could be well-focused, but when the ones are out of its DOF the projcion become blurry.

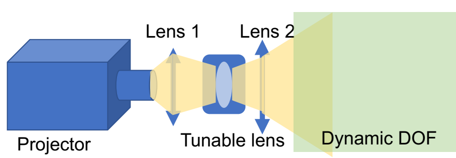

Figure 2: A sketch of the dynamic focal tracker projection system was illustrated. A variable focus lens was employed to realize a dynamic DOF in the optics unit.

CCS CONCEPTS

• **Human-centered computing** → *Displays and imagers.*

KEYWORDS

Projection mapping; depth of field; variable focus lens.

ACM Reference Format:
Lihui Wang, Hongjin Xu, Yunpu Hu, Satoshi Tabata, and Masatoshi Ishikawa. 2019. Dynamic Depth-of-Field Projection for 3D Projection Mapping. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI'19 Extended Abstracts), May 4–9, 2019, Glasgow, Scotland Uk.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3290607.3313246

INTRODUCTION

Projection mapping continues to be one of the hottest research fields. Projection mapping includes a projection unit, image generation unit, and projection target. The projection target is traditionally a fixed object, like a projection screen, as shown in Fig.1. Nowadays projection mapping includes the human-machine interaction entertainments, and the projection targets are not to be limited as a static object or a dynamic object in 2D [3, 4]. The projected targets tend to be dynamically moved in three-dimensional space, but it becomes challenge to traditional projection unit. Conventional projector is designed with a large-open aperture so that the project information could address a high resolution. However, the depth of field (DOF) of the projection system becomes narrow. As a result, when the target moves out of the projection DOF, the information becomes blurry.

One method for dynamiclly changing the projector's DOF could be changing the focus status in a very high-speed. However, traditional lenses are made by solid materials, such as glass or plastic, and they have fixed focal lengths. To change the focal length of an optical system, the conventional approach is to employ two or more lenses, which are mechanically moved over specific distances. However, the traditional solid lenses are too heavy to move fast, so the typical response time is around 1.0 second. It is not suitable to be used in real-time projection mapping and human-machine interaction. In recent years, compact optical systems using variable focus lenses have become popular[1, 2], which is a term given to a single lens whose focal length can be changed dynamically[5–7].

We would like to demonstrate a dynamic DOF projector, as shown in Fig.2, which could detect the depth information of the target in real-time and feedback to adjust a best projection focal length, in turn, a well-focused high-resolution projection could be realized. The system includes a high-speed projector, a high-speed variable focus lens, a depth sensor by a stereo camera, and an image processing and control. The demonstration showed that our system could project well-focused image on the target from 0.5 m to 2.0m. The system potentially improved the feasibility of the 3D projection mapping.

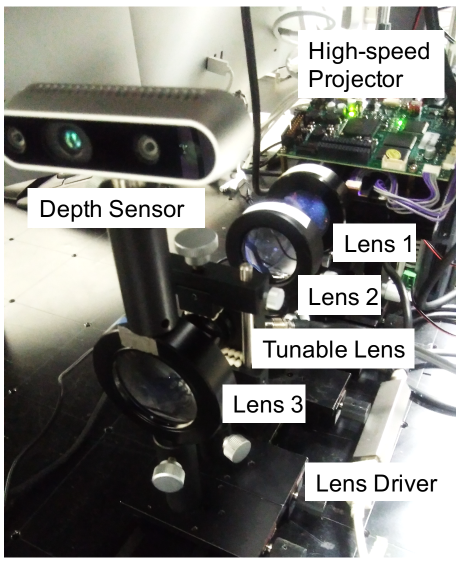

Figure 3: A photo of the experimental setup was shown above. A high-speed projector, three solid lenses and a variable focus lens was placed along the optical axis. A stereo camera was placed on the side-by-side position with the last lens.

DESIGN PRINCIPLE

A conventional projector has a fixed focal length, but it could be tunable by adjusting the lens. However, due to the limitation of the response speed of the traditional lenses, it cannot meet the needs of the dynamic interaction environment. Flicker fusion threshold shows that the response speed would be higher than 60 Hz, so that the display flicker can be un-noticeable. A liquid-filled variable focus lens was employed in the optics unit of the projector. It could control its focal length by adjusting the bending curvature of its lens body. Instead of the back and forth motion of the solid lens, the focus changing is realized by changing the curvature of one lens cell. The response speed is over than 100 FPS, according to the technical data. A light beam of a projector was collected by the first lens (focal length = 50 mm), converged by the second lens (focal length = 60 mm) to form the beam and pass through the variable focus lens, and then expend by the third lens (focal length = 100 mm). A sketch of the system setup was shown in Fig. 2 and a photo of the experimental setup was shown in Fig. 3.

To recognize the depth changing of the target, a depth sensor was employed and realized by a stereo camera. The dynamic changing of the depth information would be detected, and the feedback speed should be higher than the flicker fusion threshold (60 Hz). As long as the depth information was updated, two functions of the projection would be conducted. The optics system would control the variable focus lens to modify the projection focal length, so as to project an well-focused projection image. On the other side, the contents of the projection information should be updated so that it could be used as an interactive device in the future.

PROTOTYPE

A photo of the experimental setup was shown in Fig.3. A high-speed projector (TI DLP, LightCrafter 4500) was employed and placed tilt-up to align the optical axis. As shown in the sketch in Fig. 1 three solid lens (Focal Length = 50 mm, Focal Length = 60 mm, and Focal Length = 100 mm) and a variable focus lens (Optoune, EL-10-30) was used. The variable focus lens was driven by a lens driver (Optoune, Lens Driver 4i), which was controllable by the external voltage. A stereo camera (Intel, Real Sense D435) was placed on the side-by-side position, and it could provide a sampling rate at 90 FPS. The depth information was acquired by the camera, the control command was computed by PC, and then the command sent to the lens unit. The dynamic DOF projection range was from 0.5 m to 2.0 m.

EXPERIMENT AND DEMONSTRATION

A target screen, a whiteboard, was used as a target and moved back and forth along the projection depth. Because our dynamic depth tracker would recognize the variation of the depth changing, the focal length of the projection would be controlled in high-speed around 10 milliseconds. A 2*2 monochrome chessboard was projected so that the edge boundary would be used to analyze the

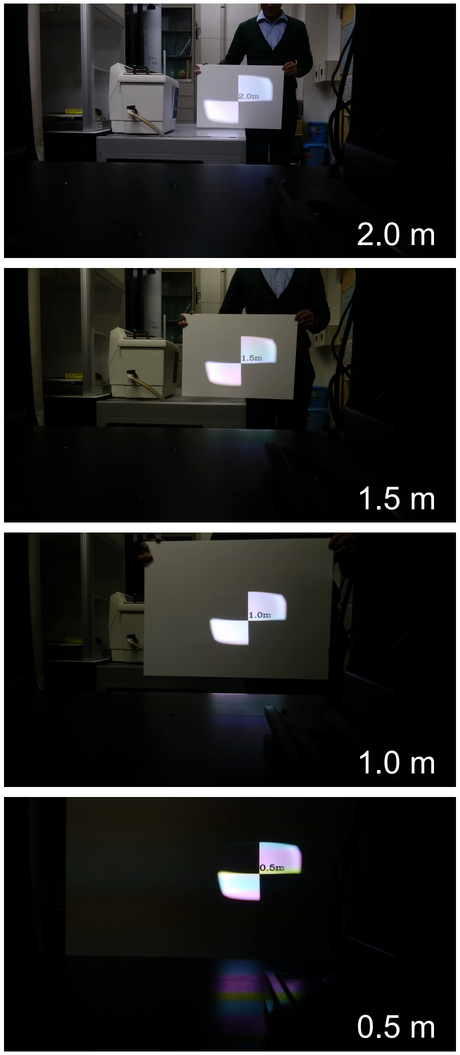

Figure 4: Four screen-shots of the demonstration video were taken and shown. It showed that the dynamic focal tracker projection could track the depth changing of the target and projected a well-focused image between 0.5 m to 2.0 m.

focusing status. At the same time, in the middle of the projection image, the depth information content was shown and update in real-time on the screen as an example of animation.

The experiment result shows that with the help of our dynamic DOF projection, when the target moved from 0.5 m to 2.0 m, the projection information formed a focused image on the screen, and the varies distance information as an animation content updated in real-time. As shown in Fig.4 that four screen-shots of the demonstration video were taken and shown. It showed that the dynamic focal tracker projection could track the depth changing of the target and projected a well-focused image.

DISCUSSION

To conduct a projection mapping on a 3D movement object, especially the one moves along the depth, is a challenging job, because of the limitation of the response speed by moving the solid optics of the projector. This work showed a possible solution for 3D projection mapping by employing a high-speed liquid-filled variable focus lens and a depth-senor module. The dynamic projection range covered from 0.5 m to 2.0 m. The demonstration illustrated that a well-focused projection was confirmed when a target moved gradually from 0.5 m to 2.0 m, and it was also suitable for the target that suddenly flew into the project area at a random distance.

The main of the projection center area was focused, but the boundary area was blurry. However, this optical performance can be improved by employing an optical design to correct that aberration. On the other side, some other depth sensors are still available for this application to improve the response speed and increase the recognition.

REFERENCES

[1] Jen-Hao Rick Chang, BVK Kumar, and Aswin C Sankaranarayanan. 2018. Towards Multifocal Displays with Dense Focal Stacks. *arXiv preprint arXiv:1805.10664* (2018).

[2] Daisuke Iwai, Shoichiro Mihara, and Kosuke Sato. 2015. Extended depth-of-field projector by fast focal sweep projection. *IEEE transactions on visualization and computer graphics* 21, 4 (2015), 462–470.

[3] Yuri Mikawa, Tomohiro Sueishi, Yoshihiro Watanabe, and Masatoshi Ishikawa. 2018. VarioLight: Hybrid Dynamic Projection Mapping Using High-speed Projector and Optical Axis Controller. In *SIGGRAPH Asia 2018 Emerging Technologies (SA '18)*. ACM, New York, NY, USA, Article 17, 2 pages. https://doi.org/10.1145/3275476.3275481

[4] Leo Miyashita, Yoshihiro Watanabe, and Masatoshi Ishikawa. 2018. MIDAS Projection: Markerless and Modelless Dynamic Projection Mapping for Material Representation. In *SIGGRAPH Asia 2018 Technical Papers (SIGGRAPH Asia '18)*. ACM, New York, NY, USA, Article 196, 12 pages. https://doi.org/10.1145/3272127.3275045

[5] Hongwen Ren and Shin-Tson Wu. 2012. *Introduction to adaptive lenses*. Vol. 75. John Wiley & Sons.

[6] Lihui Wang, Hiromasa Oku, and Masatoshi Ishikawa. 2013. Variable-focus lens with 30 mm optical aperture based on liquid–membrane–liquid structure. *Applied Physics Letters* 102, 13 (2013), 131111.

[7] Lihui Wang, Hiromasa Oku, and Masatoshi Ishikawa. 2014. An improved low-optical-power variable focus lens with a large aperture. *Optics express* 22, 16 (2014), 19448–19456.