Expansion of the Free Form Projection Display Using a Hand-Held Projector

Kaoru Kenjo[1] and Ryugo Kijima[2]

[1] Gifu University Graduate School of Engineering, 1-1 Yanagido, Gifu 501-1193, Japan
[2] Gifu University Faculty of Engineering, 1-1 Yanagido, Gifu 501-1193, Japan

Abstract. We developed the multi projection system that supplement the free form projection display (FFPD) that virtual object image projected onto the real object with the projection of hand-held projector. This system enabled the users to expansion of projection area and look see the interesting area by covert to high-definition display. Furthermore, we investigated the effects of user's stereoscopy by visual gap of images projected each projector.

1 Introduction

One example of mixed reality technology is projection mapping, which displays a computer-generated (CG) image on a real object by projection. Moreover, the hand-held projector that the user can handle with one hand has been developed, and expected to be applied to various type of mixed reality application. We have developed a so called free form projection display (FFPD) technology[1] that merges virtual and real objects. The CG image is projected on the curved surface of a semitransparent real object. The virtual object is observed as if embedded inside this real object. The user's viewpoint is measured and reflected in the CG image to provide a sense of motion parallax. The position and orientation of the real object is also measured and used to fix the virtual object with respect to the real one and to cancel the distortion in the observed image caused by a projection on the curved surface. The virtual anatomical model (VAM)[2] is one of the applications of FFPD and is used for medical education. For this purpose, a movable white torso is used as the screen (real object). The internal organs, blood vessels, and bones are then embedded virtually in this torso.

There are three unresolved problems with the VAM system. The first is the resolution problem. Using the existing projector, the size of the pixel projected on the life-size human body is a couple of millimeters, which is not enough to represent the detailed texture of an organ's surface, for example. The second is the shadow problem. One projector cannot cover the whole surface of the torso; at least half of the torso cannot be used as screen. Further, the pixels are stretched in the boundary area between the projected and shadow area. The image becomes darker and the resolution, lower, in this area. For example, when the user looked into the side of the body, the lower half of the side is in the shadow area without image and the dissolving of organs is observed. The third

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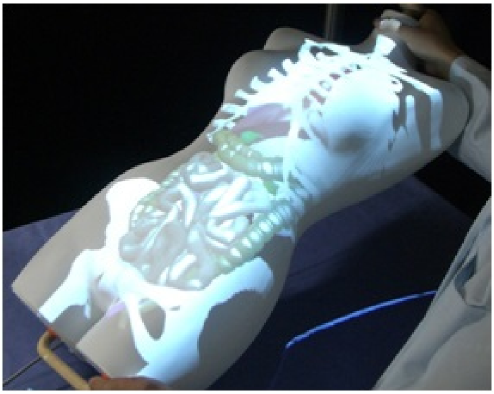

Fig. 1. Vitual Anatomical Model (VAM)

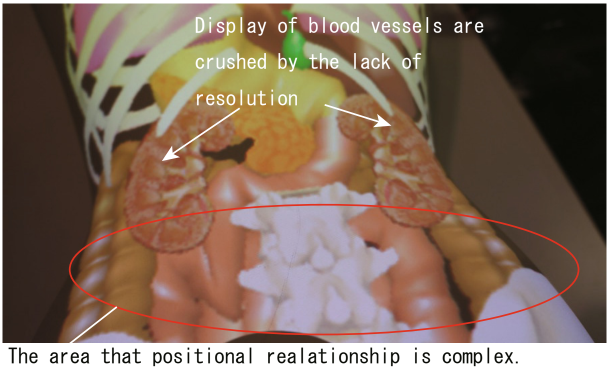

Fig. 2. Lack of resolution and the area that positional relationship is complex

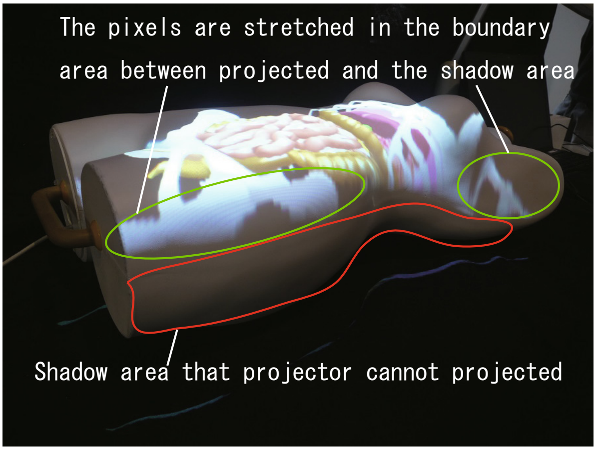

Fig. 3. Shadow area that projector cannot projected

problem is concerning the interface to control the content of the display. One important aim is to use the anatomical model in medical education to present the positional relationship of organs. However, since the internal organs hide each other, it is impossible to show all organs at once. There is hence a strong need to control which organ or which part of an organ is to be visible.

These problems could be reduced by adding a hand-held projector to the original VAM system. When the hand-held projector comes closer to the torso, the size of the pixel projected by it becomes smaller. The user can then achieve the necessary resolution by aiming the hand-held at the area of his/her interest. The hand-held projector can be used to cover the shadow area, simply by turning the line of projection to the shadow area where the user wants to observe the organs. In short, the primary projector covers the whole torso in relatively low resolution, and the hand-held projector is used to observe the area of interest. Further, it would be useful to feed the hand-held an image that is different from that for the primary projector. A simple example is to use the detailed model of organs for the image to the hand-held to produce the high density pixel area. Another aim is to use the different image to control the content of the image. When part of the image from the primary projector is erased to avoid overlap in the area of projection by the hand-held, the user feel as if the hand-held projector cuts a hole in the image from the primary projector and embeds the image from the hand-held inside this hole. By showing the whole organs with the primary projector and providing images of the organs deep inside the body to the hand-held, the user can cut a hole in a set of organs and unearth the hidden organs to be visible in this hole. The aim of this study was to solve the three problems in the VAM system and to validate a method of efficient stereoscopy.

2 Materials and Method

The original VAM system consists of a PC, a projector above the torso screen, a magnetic sensor on the torso to measure the position and orientation, and a sensor on the user's head to measure the viewpoint. The shape of the torso, and the relative position and orientation of the torso to the projector are considered both for embedding the virtual organ in the screen and for eliminating the distortion in the image caused by the projection onto the curved surface. The position of the user's eye is used for creating motion parallax by generating the organ's image as viewed from this viewpoint. Before starting the system, the projector's internal and external parameters are estimated by using a calibration tool[3]. A hand-held laser projector was added to this VAM system. Since the projection distance of the hand-held projector varies considerably with the user's manipulation, the laser projector has to forms a clear image at any distance. The internal parameters of the laser projector were measured in advance. A magnetic position/orientation sensor was attached to this projector. The data it produces are used to cancel the distortion in the image in the same manner as in the case of the primary projector. The projection frustum was also dynamically calculated for each frame based on the position and orientation data from the sensor and used to cut a hole in the content of the image from the primary projector.

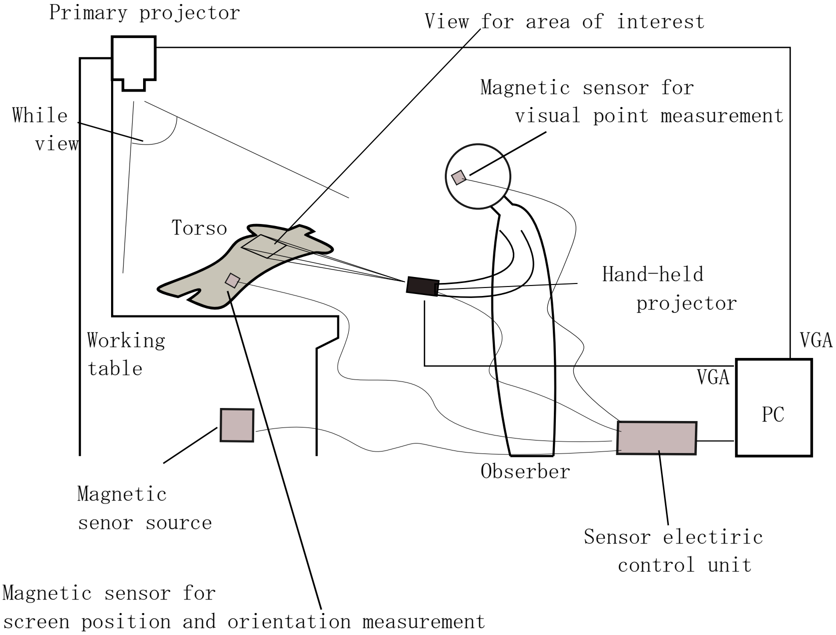

Fig. 4. Diagram of proposed system

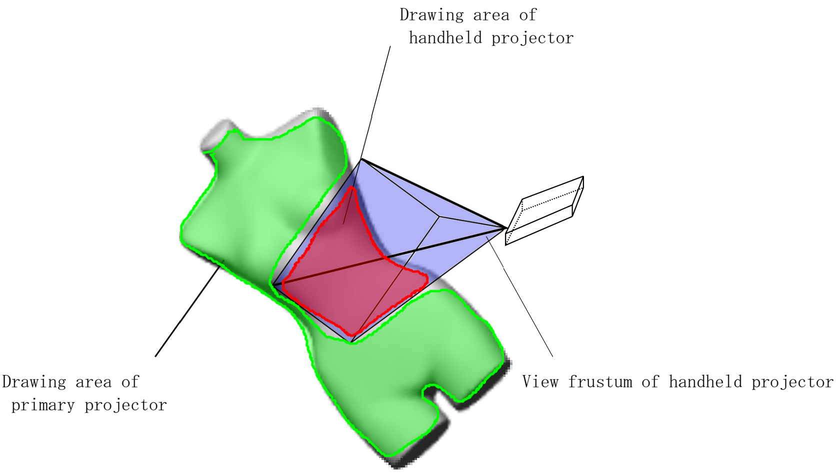

Fig. 5. Part of projection area is masked to avoid overlap

3 Result

In this section, the reduction of the three problems described in the first section is confirmed.

3.1 Improving the Resolution of the Display

The projection from the introduced hand-held projector helped achieve the necessary resolution to observe the detail of organs. It was easy and natural to choose the high-resolution area by facing the hand-held projector to the area of the user's interest. It was also possible to control the pixel density by changing the distance between the projector and the screen's surface. However, it seemed like there was more improvement in the size of the projection area than in the resolution. On the other hand, the image became brighter as the hand-held projector came close to the screen's surface, and the large difference in brightness between the two projection areas broke the constancy of the content's appearance. This defect was eliminated by adding a brightness control to the hand-held projector based on the projection distance. The table below shows the relation between the projection distance and pixel density. In our current system, the resolution of the primary projector was 1920 by 1080 pixels and the projection distance was set to 180 centimeters. This configuration provided 323 pixels per square centimeter. In contrast, although the resolution of the hand-held projector was only 848 by 480 pixels, the density of pixels was 1146 pixels per square centimeter when the projection distance was 30 centimeters.

Table 1. Pixel number per unit area of primary projector

Projection distance(cm)	Area(cm^2)	Resolution(px)	Pixel number per unit area(px/cm^2)
180	6420	848×480	63.40
180	6420	1024×768	122.5
180	6420	1920×1080	323.0

Table 2. Pixel number per unit area of hand-held projector

Projection distance(cm)	Area(cm^2)	Pixel number per unit area(px/cm^2)
10	50	8141
15	112	3634
20	185	2200
25	268.75	1515
30	355.25	1146
35	470.25	865.6
40	612	665.1

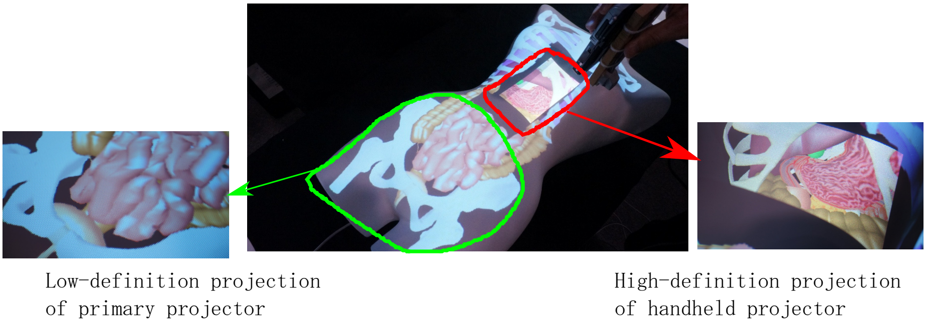

Fig. 6. Projected images by primary and hand-held projector

3.2 Extending the Field of View

As shown in Fig.7, the hand-held projector could fill part of the shadow area where the primary projector was not able to create an image. The operation of facing the projector to the area of the user's interest was easy and natural, and this ability of adding a new visible part was felt to be effective. When the hand-held was turned to the boundary area between clear projection and shadow, the accuracy of stitching the images from the two projectors together was not enough. Sometimes this improper connection made a bad impression on the user. When a gap between the images from the hand-held and primary projector was introduced, this error in image alignment was not disturbing, though the unity of two images was lost.

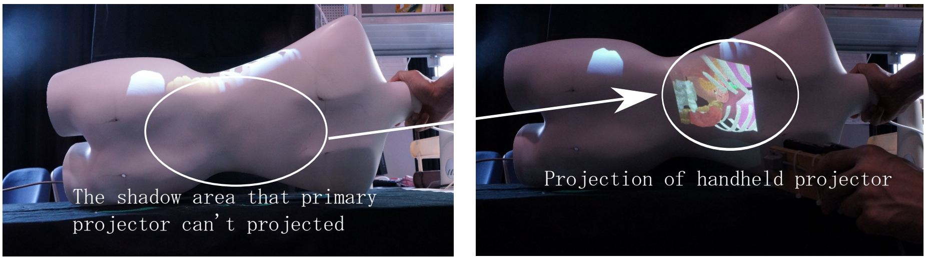

Fig. 7. Expansion of projection area

3.3 Switching Image Content by Hand-Held Projector

It is not easy to understand the positional relationship between organs in compacted shape in three dimensions. A typical example is the digestive organs that are layered in the stomach, such as the gastric organ, duodenum, pancreas, liver, and the blood vessels around them. As described above, our approach is to provide the image of the organs in upper layer to the primary projector and the

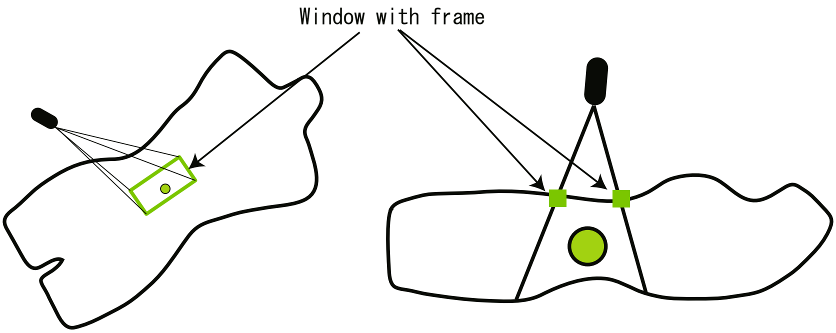

Fig. 8. The method that window with frame on surface to show boundary between projection areas

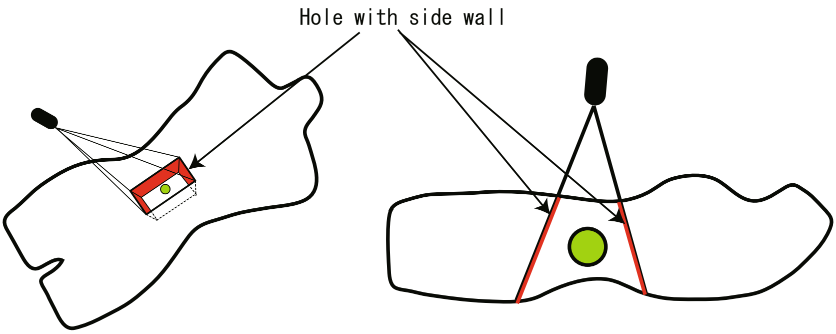

Fig. 9. The method that hole with side wall in torso to show boundary between projection areas

image of the lower layer to the hand-held projector. The image from the hand-held projector had priority over that from the primary projector, avoiding an overwrap between them. As a result, by using the hand-held projector user cuts a hole in the surrounding organs projected by the primary projector, and could watch the organs inside this hole displayed by the hand-held projector. Since this situation was still visually complicated, we added a cue to show the boundary between organs from different projectors. Two different cues were used and compared in experiments with the subjects: (1) a window frame on the surface of the torso and (2) side walls of the hole in the torso. The subjects were asked to try the system with the two types of cues and evaluate the result by choosing one among five answers about the easiness to understand the positional relationship between organs inside and outside the hole. The subjects were also asked to write freely about their impressions of the two types of cues. The subjects were 13 men and women, 20 - 24 years old. The duration of experiment was about 5 minutes for each case.

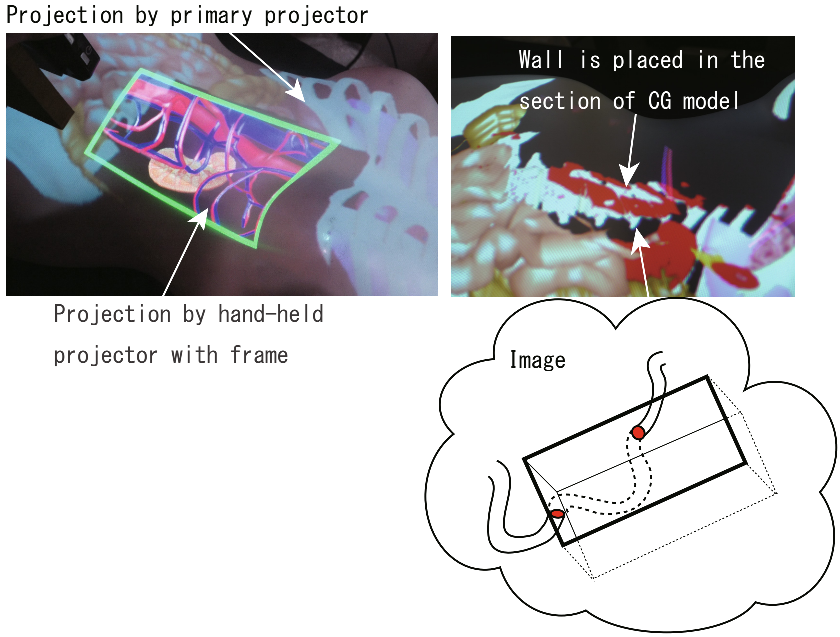

Fig. 10. Two method in actual projection

The results are shown in Fig. 11. The frame type cue was preferred as being easier to observe the organs. One opinion was that the "Sense that you are looking into the cut in the frame has increased" and "I felt that the frame was always closest to viewpoint and on the torso's surface, and the organs are present in it". The result score and the opinions suggested that the frame worked to help the users distinguish organs inside the hole from outside the hole, avoiding visual confusion. This could be considered as an indirect help to understand the positional relationship between the organs. However, there were subjects who complained that the presence of frame confused some part of the three dimensional visual perception. A typical opinion was "When the frame exists, the organs in the frame is no longer appeared to be buried inside". The wall type cue generates a relatively complicated image on the screen's surface as compared to the frame type cue, since the former is three-dimensional inside the torso and the latter is two-dimensional on the torso's surface. The wall sometimes overlaps other organs displayed by the hand-held projector and this overwrap varies in each frame. Opinions from the subjects such as "the wall was visually disturbing" would be caused by this phenomenon. On the other hand, opinions such as "I felt like I was looking into the hole by recognize the cutting surface" suggested that the presence of the property placed walls improved the three dimensional perception. Our interpretations of this user test are; (1) the frame on the torso's surface was visually simpler and easier to understand, and worked to clearly

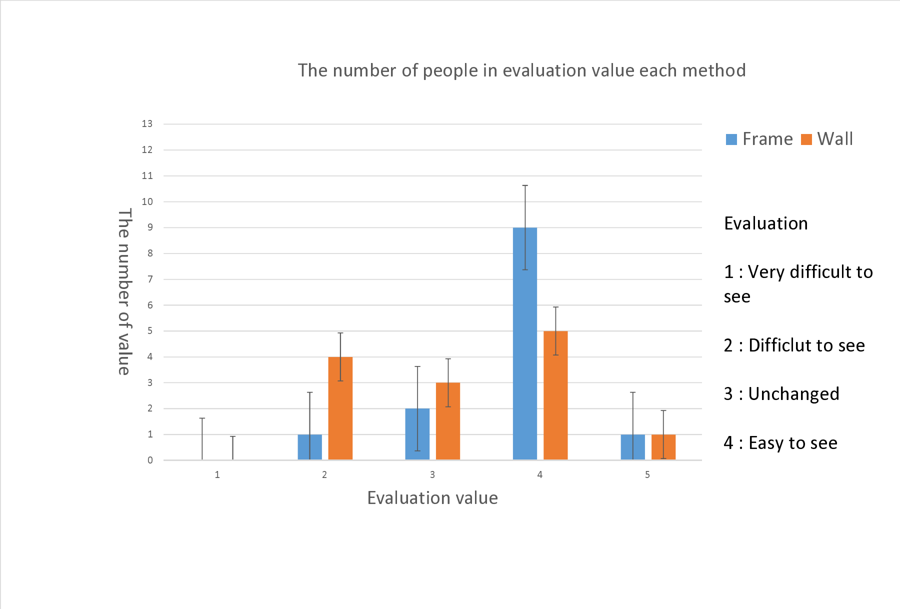

Fig. 11. The number of people in evaluation value each method

divide the organs displayed by the primary projector from that by the hand-held projector. (2) The sidewalls worked to connect the contents displayed by different projectors when the walls were perceived at the proper location in 3D space, but this was visually complicated and difficult to understand.

4 Conclusions

The improved image resolution and expanded visible projection area were successfully achieved by adding a hand-held projector to the existing VAM system. The hand-held projector was a natural tool to indicate the region of interest for the user. Furthermore, two types of cues were introduced to show the boundary between the contents from different projectors, i.e., a frame and sidewalls. These cues are expected to help reduce the difficulty in understanding the relationship between organs in different layers. The result of a user test suggested that the frame type cue promotes the division between layers and was preferred by the users. It was suggested that the wall type rather connects the layers and promotes an understanding of positional relation between organs in different layers, while the complexity in the projected image was magnified. Though the experiment with subjects described in this paper was preliminary, we suspect that the potential merit of the wall type cue would be to connect different layers by different projectors. The precise implementation to provide three-dimensional localization and improved visual appearance of the wall could draw on this potential merit.

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