A Method for Wearable Projector Selection that Considers the Viewability of Projected Images

SHUHEI OTA, YOSHINARI TAKEGAWA,
TSUTOMU TERADA, and MASAHIKO TSUKAMOTO
Kobe University

Many projects and practices can now support user tasks by presenting images on the floor or wall using a mobile projector. However, unstable images make communication and task support difficult. The viewability of a projected image depends on several factors; the position of the wearable projector, user contexts such as whether he/she is walking or standing, and the type of presentation content. We describe a method for selecting a projector from multiple wearable projectors, wherein the method considers these factors. We investigated the characteristics of viewability by changing various factors in various contexts and with different content. We also investigated the appropriate position for a wearable mobile projector in various situations and with different content in subjective evaluations. The results indicated that our system dynamically changes the characteristics of a projector for presenting content. We implemented a prototype system that selects the appropriate projector dynamically in response to the situation.

Categories and Subject Descriptors: H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Evaluation/methodology; Ergonomics; Interaction styles*

General Terms: Human Factors, Experimentation

Additional Key Words and Phrases: Wearable projector, viewability

ACM Reference Format:
Ota, S., Takegawa, Y., Terada, T., and Tsukamoto, M. 2010. A method for wearable projector selection that considers the viewability of projected images. ACM Comput. Entertain. 8, 3, Article 17 (December 2010), 16 pages. DOI = 10.1145/1902593.1902596.
http://doi.acm.org/10.1145/1902593.1902596.

This research was supported in part by JST PRESTO and a Grant-in-Aid for Scientific Research (A)(20240009) and Priority Areas (21013034) made available by the Japanese Ministry of Education, Culture, Sports, Science and Technology.
Authors' address: S. Ota, Grad. Sch. of Engineering, Kobe University, 1-1 Rokkoudaichou Nadaku, Kobe, 657-8501, Japan, shuhei@stu.kobe-u.ac.jp.

1. INTRODUCTION

A mobile projector enables us to show information anywhere. A wearable projector supports various kinds of research work by projecting and controlling images on a floor or a wall to support his/her tasks. The projectors include a system to manipulate several kinds of content such as photos, maps, and analog clocks by using a camera-based image-processing method [Mistry et al. 2009], Interactive Dirt [McFarlane and Wilder 2009] which supports military activities such as briefings for missions. The viewability of a projected image depends on various kinds of factors, such as the stabiliity of the projected image, the size and location of the projected image, and the wearability of the device. These factors have not been considered yet. The effects on these factors change according to the user contexts and the type of projected content. To achieve high viewability in projected images, we need to consider various aspects. For example, when a user views a navigation content while walking, the system can use a projector on the chest whose image is the most stable. In addition, when a user views photo content while standing, the system can use a projector on the shoulder where image is the widest. However, achieving high viewability in all these situations with only a projector is difficult.

Therefore, we describe a situation where a user can wear multiple projectors, and we describe a method for selecting a projector from multiple wearable projectors wherein the method considers various aspects of viewability. We investigated the characteristics of the viewability by changing various factors in various contexts and with different content. We also investigated the appropriate position for a wearable mobile projector in various situations and with different content by subjective evaluations. The evaluation results indicated that our system dynamically changes the projector to be used for presenting content. We implemented a prototype system that selects the appropriate projector dynamically in response to the current situation. The remainder of this article is organized as follows. Section 2 outlines the related work; Section 3 describes the design of our system; Section 4 explains its implementation; and Section 5 presents our conclusions and our planned future studies.

2. RELATED WORK

Much research has been conducted on presenting various kinds of information using a mobile projector. For example, iLamps [Raskar et al. 2003] is a technique for adaptive projection on nonplanar surfaces using conformal texture mapping. It has some characteristics for operating a mounted camera and angular velocity sensor; for correcting a keystone and a projected direction; for automatically adjusting the projected brightness, zoom, and focus; and for capturing three-dimensional textures. CoGAME [Hosoi et al. 2007] is a cooperative game that allows players to control a robot with a mobile projector visually and intuitively. Players interchangeably move and connect the load in their projected images to create a path that leads the robot to its goal. Kanbara et al. [2010] proposed a projection-based augmented reality system for sharing guide information among multiple users during a tour. These studies utilize the characteristics of a mobile projector; the information presentation on real space; the sharing of information; and the change in a projected location. However, they do not take into account the viewability, such as the usability of a projected image.

Spotlight [Khan et al. 2005], which uses multiple projectors, gets the attention of the audience using spotlights in the environment with large wall-sized displays. Moreover, multiple projectors use an immersive projection technology display with multiple screens such as CAVE [Cruz-Neira et al. 1993]. These studies utilize multiple projectors for the amount of projected information and the projected size. They differ from my research, where multiple projectors are used to maintain viewability. As research using multiple projectors related to the viewability, this technique [Brown et al. 2005] achieves a large-size image display to a project tiled and calibrated by multiple projectors. Another method [Damera-Venkata and Chang 2007] achieves a super-resolution image by superimposing multiple projector images. This method utilizes multiple projectors for the viewability and the projected size. They differ from my research, which takes into account the viewability with a wearable mobile projector.

As for research on wearing a mobile projector, WUW-wear [Mistry et al. 2009] and BOWL Procama [Kurata et al. 2006] can control a projected image with a user's hand motions, which are recognized by the camera. Interactive Dirt [McFarlane and Wilder 2009] demonstrated that a mobile projector is useful to support military activities such as a meeting for missions and communications with foreign civilians. Helicopter Boyz In Yomiuri Land [2010] is an example of using multiple projectors. It is a dance performance where images projected to the back screen are controlled by the motions of children who wear multiple cameras. These works utilize the characteristics of a mobile projector. However, they do not consider the viewability of a projected image.

One example of stability in a projected image is Konishi's study [Konishi et al. 2009], which proposed a method to stabilize an image projected from the shoulder or the chest to a palm, even if the user is walking and running. The system tracks the palm with a camera, and detects the motion of the hand with an acceleration sensor and an angular velocity sensor. [Tajimi et al. 2010] proposed a method to stabilize an image projected from the lumbar to the floor.

It recognizes the movement of the lumbar using a gyroscope. The main goal of these studies is the same as that of our research. However, they consider only the stability of a projected image. This article focuses not only on the stability but also on the projected size, the projected location, and the wearability of the projector. Furthermore, our system dynamically selects a suitable projector from multiple wearable projectors.

3. SYSTEM DESIGN

3.1 Environmental Assumptions

A user wears mobile projectors, and views various kinds of useful content such as a navigation program, movies, and e-mails projected on a floor or a wall while he/she is walking, sitting, or standing, as described in Section 1. In these situations, projected images are not stable. Additionally, the appropriate size

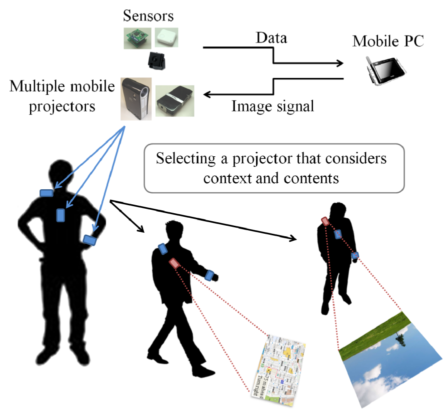

Fig. 1. The system structure.

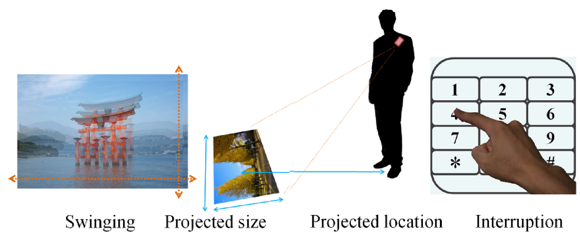

Fig. 2. Factors relating to the quality of projected image.

and location of the projected images depend on the situation and the content. Our method enables viewing a projected image comfortably in various situations and with different content.

3.2 System Structure

Figure 1 shows the system structure. It consists of a mobile PC, multiple mobile projectors, some sensors such as an acceleration sensor, an angular velocity sensor, and an image sensor. The system enables the user to receive high quality projected images that account for the projected size, location, and stability, as well as the wearability of the device by selecting the appropriate projector based on the user contexts and the content.

3.3 Examination of the Wearing Position

To decide the appropriate position of the projectors, we first investigated the factors that relate to the quality of a projected image. Second, we categorized the user contexts and the content. Third, we determined the appropriate positions of the wearable projectors from user evaluations.

3.3.1 *Factors that Affect the Quality of Images.* The factors that affect the quality of projected images are shown in Figure 2.

Table I. Classification of Content

	Text	Image	Text and Image
Still image	Next header	Photo	Cartoon
Animation	Ticker	Movie	Navigation content

—*Swinging*: the swinging of the projected image causes a user not to view the projected image comfortably.

—*Projected size*: if a projected size is small, it is difficult to read the letters.

—*Projected location*: the location from the user to a projected image while he/she is walking should be farther than that while he/she is standing because a user looks forward while walking.

—*Interruption*: if a projected image is interrupted by the user's hand or leg, the user cannot view the image correctly.

3.3.2 *Type of Content.* We suppose that projected content can be classified into text, images, and their hybrids, as shown in Table I. They can also be classified into still-images and animation.

—*Text*: text-based content needs high stability and large projected size to be readable text. If the projected image is interrupted partially, the user cannot understand the content.

—*Image*: the projected size is important because users want to view the whole content. The influence on swinging is not very important compared with that for text. Furthermore, the animation needs higher stability than a still frame.

—*Text and Image*: the hybrid content of text and images have these two characteristics. We must consider all factors of text and images.

3.3.3 *User Contexts.* User contexts affect the viewability of projected content. We assume three contexts: walking, standing, and sitting.

—*Walking*: interruption of a projected image by arms and legs often occurs; moreover, we must consider swinging.

—*Standing*: swinging and interruption of projected images rarely occur.

—*Sitting*: swinging and interruption of a projected image also do not occur. The location from the projected image to the user while sitting becomes smaller than that while standing.

3.4 Evaluation on the Position of Projector

We investigated the appropriate position of wearing a projector based on the viewability with two kinds of content (navigation and photo-slide show), and two contexts (standing and walking). Figure 3 shows a snapshot of the experiment. Test subjects wear a PC, a mobile projector, an acceleration sensor, and an angular velocity sensor, as shown in Figure 4. We made a jacket that has a high stick hook-and-loop fastener on all parts of the jacket so that the projector could be attached there. We used the Optoma pocket projector PK101 for the projector on the Loas DCA-089GM to adjust the angle of the projector, and

Fig. 3. Photograph of the experiment.

Fig. 4. Photographs of a subject wearing the projector.

Wireless Technology WAA-006 was used as the acceleration and angular velocity sensor to detect swinging of the projector. We used a Sony VGN-SR94FS (CPU Core Duo 2.80 GHz x 2, RAM 1 GByte), with Windows 7 as the PC, and the Micomsoft XMOV-2 video was used as the scan converter unit to convert output PC images to input images for the projector.

3.4.1 *Evaluation Settings.* We conducted an evaluation experiment with 10 test subjects (nine men and one woman), whose ages were from 20 to 25 years. Figure 5 shows 16 candidates and the positions at which the projector was attached. These positions were the head (A), shoulders (B), sides (C), side-waist (D), chest (E - H), stomach (I - L), and waist (M - P). We decided on these positions based on related studies and preliminary evaluations [Konishi et al. 2009; Kurata et al. 2006; McFarlane and Wilder 2009; Mistry et al. 2009; Tajimi et al. 2010]. Because there is no difference in the results on the right side and that of left side in the preliminary evaluation, we investigated one side of the body. We used the content of a navigation and a photo-slide show. Figure 6 shows the navigation content, consisting of a map, starting point, destination, a route from a starting point to a destination, the present point, and an information sentence. As animation content, the present point on the map moves and the information sentence shown at the lower-right of Figure 7 was updated. The photo slide-show, shown in Figure 7, consists of 170 photos of scenery.

All test subjects conducted the evaluation in two contexts and with two kinds of content for 16 positions. They previously adjusted the angle of the projector to view optimum projected images in each context. We recorded the projected

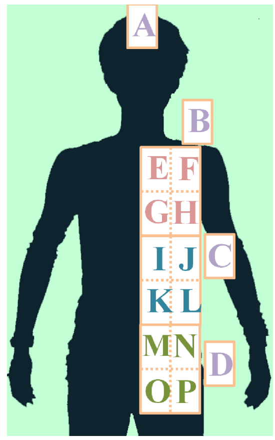

Fig. 5. Positions for wearing projector.

Fig. 6. Example of navigation content.

Fig. 7. Example presentation.

size and location, the body profile of the subjects (height, chest, and waist measurements, dominant hand, dominant leg, and dominant eye), the sensor data of the acceleration and the angular velocity.

After each session, test subjects answered questionnaire entries, as shown in Table II. Note that the subjects were asked about the feeling of image swinging and the interruptions caused by hands and legs. The appropriateness of the

Table II. Questionnaire Entries

	1	3	5
Projected location	near	appropriate	far
Projected size	small	appropriate	large
Keystone distortion	bothering		don't care
Wearability	bad		good
Image swinging	bothering		don't care
Interruption	yes		no
Total	bad		good

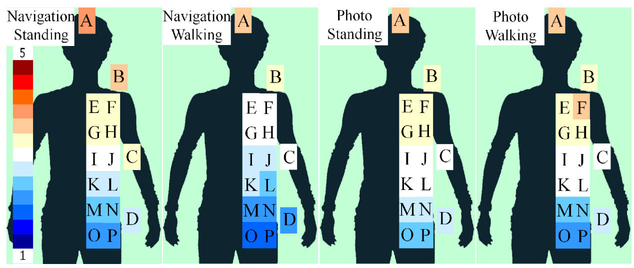

Fig. 8. Results of appropriateness of projected.

projected location and the projected size were evaluated on a three-point scale. Others were evaluated on a five- point scale.

3.4.2 *Results.* ***Projected location***. Figure 8 shows the results of the appropriateness of the projected location. The chest and the stomach (E - L) had good scores compared with the lower body. The appropriate projected location from the projected image to the subject of the navigation was 65 - 100cm while standing, and 140 - 160cm while walking. The appropriate projected location of the photo was 130 - 150cm for standing subjects, and 180 - 205cm for walking subjects. Because the line of sight of the subjects while they walked was farther than when standing, the projected location while walking was farther. Additionally, the projected location in the photo content was farther than that in the navigation content, because the subjects wanted to view the photo content in the large projected size.

Projected size. Figure 9 shows the results of the appropriateness of the projected size. The chest and the stomach (E - L) had better scores than the scores for the lower body.

The photo scores were better than navigation scores because the photos did not require as strict a projected size. The appropriate projected size for the navigation was 60 - 90 (W) x 40 - 60 (L) cm for standing subjects, and 98 - 123 (W) x 65 - 85 (L) cm for walking subjects. The appropriate projected size for the photo was 98 - 120 (W) x 65 - 80 (L) cm for standing subjects, and 135 - 180 (W) x 90 - 120 (L) cm for walking subjects. The large projected size was preferred for walking subjects. The subjects preferred a projected size where they could view the entire projected image in the navigation content, and preferred the larger-sized image in the photo content.

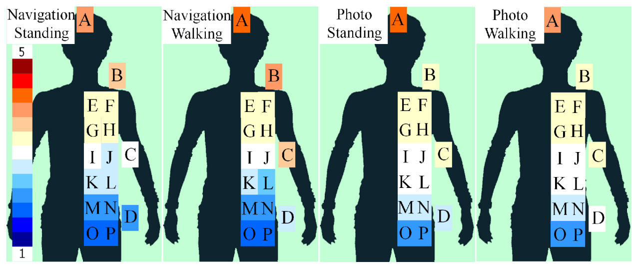

Fig. 9. Results of appropriateness of projected image.

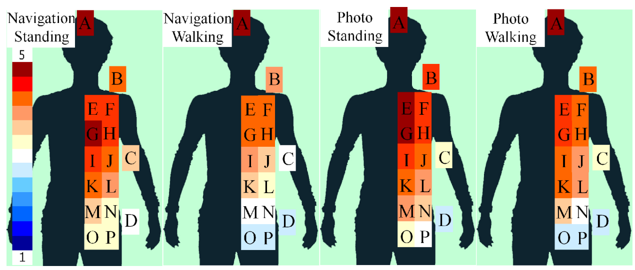

Fig. 10. Results of feeling the keystone.

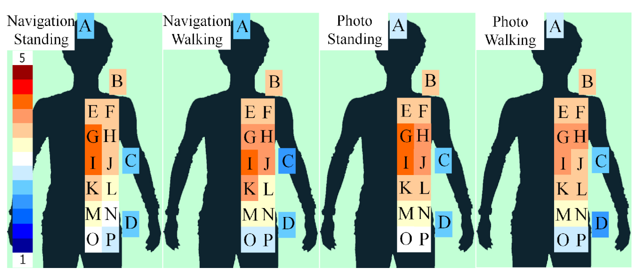

Fig. 11. Results of wearability.

Keystone. Figure 10 shows the results of feeling the keystone. Good scores were achieved for the upper body such as the head and shoulders (A, B). The lower side of the waist (O - P) had bad scores, and the side of the stomach and side of the waist (C, D) had bad scores due to adjusting the image that did not have a keystone. The score for standing subjects was better than that for walking subjects because the projected location for standing subjects was nearer to the subject. The smaller the location from the projected image to the subject was, the smaller the keystone distortion. The navigation scores were worse than photo scores, though the navigation image was nearer than the photo image. The reason is that the navigation needed high viewability and the subjects had trouble viewing the trapezoidal image.

Wearability. Figure 11 shows the results of wearability. The middle of the body (G, I) had good scores for wearability. The bony and muscled positions

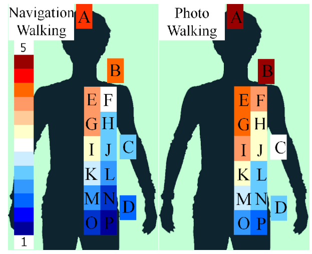

Fig. 12. Results of feeling of image swinging.

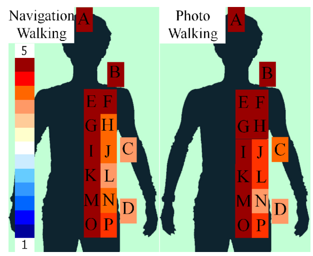

Fig. 13. Results of interruption.

were preferred. The upper-side of the chest (E, F) had bad scores because the position near the face and the projector came into the line of sight. The head and shoulders (A, B) had bad scores because they feel the weight of the projector more. The lower-side of the waist (O, P) had worse scores for walking subjects than for standing ones because the projectors often hit the legs. However, walking and standing scores were not too different. The variance values for wearability were very high too.

Image swinging. Figure 12 shows the results of image swinging. The feeling of swinging when walking produced optimum scores for the head (A), and the shoulders (B) had the second best scores. The side of the chest and the upper-side of the stomach (E, G, I) had good scores too. The waist (M - P) had bad scores because this area affected walking. The outside of the body (H, J, L, N, P) had bad scores because the subjects twisted their bodies when they stepped forward. The photo scores were all higher than those for navigation because they do not need high viewability and because image swinging is not a problem.

Interruption. Figure 13 shows the results of interruption by hands and legs. Five out of ten subjects said that the projected image was interrupted by their hands when they wore the projector around the sides of the stomach, the sides of the waist, and outside the body (C, D, H, J, L, N, P). The photos were more difficult to interrupt than navigation because the projected images of the photos were further away than those of navigation.

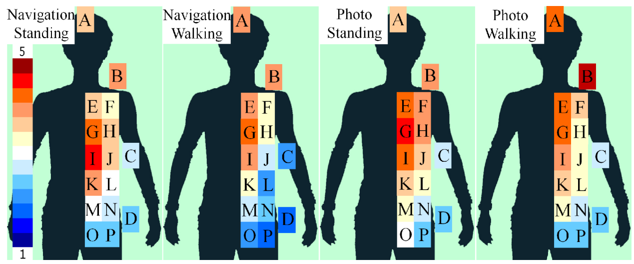

Fig. 14. Results of comprehensive evaluation.

Comprehensive evaluation. Figure 14 shows the results of the comprehensive evaluation. The evaluation differed for each context and type of content. The photo scores were optimal for the stomach (I) for standing subjects. This position got good scores in other questionnaire entries for the same situation. The photo scores were optimal for the outside of the chest (G) for walking subjects. The reason for this is high viewability, wherein the projected image does not swing and projects the appropriate size at the appropriate projected location. The navigation scores were optimal at the lower part of the chest (G) for standing subjects. The upper-side of the body (B, E - H) had good scores because large projected images were preferred in the photos. The navigation scores were optimal at the shoulders (B) for walking subjects. The reason for this is that the projected image did not swing and the position was able to project the appropriate projected size on the appropriate projected location. The average values for standing subjects were all better than those for walking subjects. The comprehensive evaluation of the photo was better than that of navigation because the photo content did not need high viewability. The side of the stomach, the side of the waist, and the waist (C, D, M - P) had bad scores on the questionnaire, so they had bad scores on the comprehensive evaluation too.

Categorical regression. We investigated the degree of dependence between the comprehensive evaluation and other questionnaire entries for each context and each type of content by the subjects via a categorical regression analysis.

One analysis method can quantify the categorical data; write the appropriate linear regression equation for the exchanged variables; and can predict the relationships between the independent and dependent variables. The results of the analysis were as follows. When the subjects viewed navigation while standing, wearability affected the comprehensive evaluation. Equally, when they viewed the photos while standing, wearability depended on the comprehensive evaluation. However, when they viewed navigation while standing, the feeling the keystone depended on it, too. When the subjects viewed navigation while walking, it was less affected by wearability; instead, the feeling of swinging influenced the comprehensive evaluation heavily. When they viewed the photo while walking, the comprehensive evaluation was optimal when also reliant on the feeling of image swinging. However, the influence was less than that of navigation; instead, the comprehensive evaluation was significantly affected

Table III. Correlation between Image Swinging and Variance in Sensor Data

content	various values		negative correlations			no correlation
navigation	acceleration	x	9	1	0	0
		y	9	0	0	1
		z	4	4	2	0
	angular velocity	x	7 1 1 6	3	0	0
		y		0	0	0
		z		4	0	0
photos	acceleration	x	7	2	1	0
		y	9	1	0	0
		z	5	3	2	0
	angular velocity	x	9	1	0	0
		y	9	0	1	0
		z	4	4	0	2

by feeling the keystone. What it comes down to is that the subjects all tended to emphasize wearability. In addition, the subjects emphasized the feeling of image swinging while walking; in particular, navigation was more likely to do so because navigation needed high viewability. The comprehensive evaluation of the photo affected the feeling of the keystone. The reason is that it had good scores for the upper-side of the body, and the evaluation of the distortion-less wearing position was similar. The results of the analysis showed that the comprehensive evaluation was less affected by the appropriateness of the projected location, the appropriateness of the projected size, and the interruption by the hands and legs. However, the positions of the comprehensive evaluations received high scores and the positions of the comprehensive evaluation for the questionnaire entries had low scores, as a result, there is no great distinction between them.

Correlations. Because we investigated the correlation between the questionnaire entries on the feeling of image swinging and the sensor data on the acceleration and angular velocity for walking subjects, we calculated the correlation coefficients between the points of image swinging and the variance values of sensor data for each x axis, y axis, and z axis. Then, we defined the right and left of the subject as being the x axis, the back and front as being the y axis, and the top and bottom being the z axis. We selected some positions for each good and bad score on the feeling of image swinging. We calculated the correlation between the scores and the variance values for each position. Table III shows the correlations between image swinging and the variance in sensor data. This experiment had high correlations between them.

However, the z axis for the top and bottom is differed from the other axes.

3.4.3 *Discussions.* These results show that if the content and user contexts differed, the user evaluation differed for each wearable position and usage situation also. The optimum position differs for each situation too. For navigation, it is easy to view the upper part of the middle of the stomach (I) while standing. For walking, it is easy to view the lower part of the outside of the chest (G) for the same content. For photos, it is easy to view the lower part of the outside of the chest (G) while standing. For walking, it is easy to view the shoulder (B) for the same content. The reason that the optimal position of the wearing projector differs depending on the situation is that the optimal factor differs depending on the presenting content and the user contexts, and the optimal position differed accordingly also. The optimal factor for navigation is the feeling of image swinging because it needs high viewability. The optimal factor for the photo is the projected size because a high realistic sensation is preferred. The factor of the projected location between standing and walking is taken into account because the line of sight for the subjects while walking is farther than that while standing. The optimal factor while walking unlike standing is the feeling of image swinging. Moreover, the projected location and the projected size are different also depending on the situation. In brief, it is useful that our method can select a projector from multiple wearable projectors while taking into account the situation of the user. The weight of the mobile projector in this evaluation experiment was approximately 200 g. If it were made smaller and lighter, the user could use it comfortably, even at the side of the stomach or the side of the waist (C, D), avoiding such problems as hitting the arms or the head and shoulders (A, B) or the feeling of a heavy weight. The waist (M - P) had bad scores for projecting only small projected sizes. However, if a large projected size is projected by a short focus lens, they may project the appropriate projected size while standing. Regarding image brightness, we did not take into account that this experiment was conducted in a dim room. If the room were bright, the relationship between the brightness of the image and the projected location may be considered.

4. IMPLEMENTATION

4.1 Prototype Constructed According to the Results of the Evaluation

We implemented a prototype of our system. Figure 15 shows a user wearing the prototype. Figure 16 shows a user with the prototype. We implemented the prototype according to the results of the evaluation in Section 3, and used three mobile projectors. The system changes the projector based on the content and user situation. For example, when the user views navigation content while standing, projector A is selected. When the user views navigation content while walking and photo content while standing, projector B is selected. When the user views photo content while standing, projector C is selected. The projected location and size of each projector is assigned based on the results of the evaluation. The user contexts are recognized using the data of an acceleration sensor and an angular velocity sensor. We used a Sony VGN-SR94FS computer, whose platform was Windows 7 as the PC; two Optoma pocket projector PK101s and the Adtec AD-MP15AB as the projectors; two Micomsoft XMOV-2s as the video scan converters; and two I-O data USB-RGBs (resolution 1024 x 768 pixels) as the external graphics adapters. We used the Wireless Technology WAA-006 as the acceleration sensor and the angular velocity sensor. We implemented the prototype system using Microsoft Visual C\#.NET 2008.

Fig. 15. Snapshot of a user wearing the prototype.

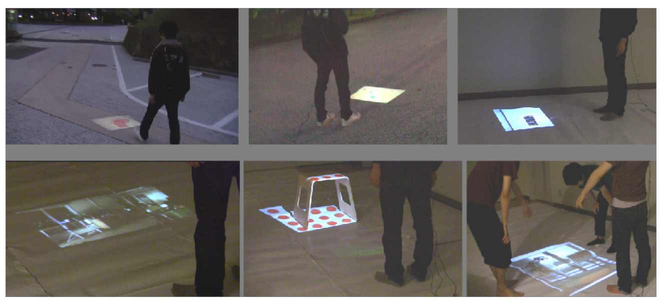

Fig. 16. Snapshots of a user with the prototype.

The first author actually used the prototype by changing his contexts and content. He could view projected images comfortably even if the situation and contexts changed. He had an uncomfortable feeling at the moment when the projected location and the projected size were changed for adjustments because he was not able to trace the projected image visually. The three mobile projectors felt a little heavy. However, they did not pull his clothes and did not interrupt his movements. In the future, we will reduce the weight of the system, and create an alternative way of wearing it.

4.2 Application

Several applications are associated with supporting a user who has multiple projectors. For example, if the prototype cannot project an accurate project image because of an obstacle, one application can select a projector that projects other planes automatically. Another application can detect the appropriate projected plane such as a white and a flat and can select a projector that projects the plane automatically. Another application can project a large-sized image display to project tiled and calibrate by multiple projectors. If the projected image is interrupted by a user's hand to control it with motion of his hand, he

Fig. 17. Snapshot of using the prototype in a campaign to raise funds.

cannot view the projected image correctly. In this situation, one application can make up the interrupted projected image using multiple projectors. In the future, it can be used to distribute information in a town; it is an application that intuitively displays the projected images in the projected location and size. We implemented the application detecting the interrupted obstacle.

The application projects the 16 circles arrayed in a 4 x 4 matrix for a moment at a regular interval and detects the centers of gravity coordinate of each circle by a mobile camera mounted on a mobile projector. At this time, if each circle is not detected or if the center of gravity coordinates of the circle is displaced by comparing the center of the initial gravity coordinate when the camera detects the obstacle in the projected image, the application selects another projector for projecting another plane automatically. We used the Sony VGN-SR94FS computer, with Windows 7 as the PC; the two Optoma pocket projector PK101s as the projectors; the two Micomsoft XMOV-2s as the video scan converters; and one of the I-O data USB-RGBs (resolution 1024 x 768 pixels) as the external graphics adapter, plus a Buffalo BSW32K01H as the camera. We implemented the prototype system using Microsoft Visual C++.NET 2008 with an OpenCV library.

4.3 Actual Use

We used the prototype on a campaign to raise funds for the Kobe Luminarie on December 3rd, 5th, 8th, 10th, and 13th, 2009. The Kobe Luminarie has been held annually since December 1995 to commemorate the victims of the Hanshin-Awaji earth- quake and has been a symbol of reconstruction. Figure 17 shows a snapshot of using the prototype in the campaign to raise funds. We projected letters and images on the road, and the letters were changed dynamically upon receiving some money. Special effects appeared when the images were touched by attendees.

Because this system has high portability and can be used anywhere where there is a plane for projection, not only a floor but also someone's back, we can use this system flexibly. Many attendees were interested in our system, and we contributed to the campaign to raise funds.

5. CONCLUSION

We described a method for selecting a projector from multiple wearable projectors, wherein the method considers user contexts and presentation content. We implemented a prototype of this system. The evaluation demonstrated the effectiveness of our method.

In the future, we plan to evaluate the prototype. We will investigate the optimum position of the wearable projector, taking into account various content, contexts, and other planes of projection such as walls or hands.

REFERENCES

BROWN, M., MAJUMDER, A., AND YANG, R. 2005. Camera-based calibration techniques for seamless multiprojector displays. *IEEE Trans. Visualization Comput. Graph. 11*, 2, 193–206.

CRUZ-NEIRA, C., SANDIN, D. J., AND DEFANTI, T. A. 1993. Surround-screen projection-based virtual reality: The design and implementation of the CAVE. In *Proceedings of the ACM SIGGRAPH*. ACM, New York, 135–142.

DAMERA-VENKATA, N. AND CHANG, N. L. 2007. Realizing super-resolution with superimposed projection. In *Proceedings of the IEEE International Workshop on Projector-Camera Systems*.

HELICOPTER BOYZ IN YOMIURI LAND. 2010. A movie. http://www.youtube.com/watch?v=P0tOOcgcHTE.

HOSOI, K., DAO, V. N., MORI, A., AND SUGIMOTO. M. 2007. VisiCon: A robot control interface for visualizing manipulation using a handheld projector. In *Proceedings of the International Conference on Advances in Computer Entertainment Technology*. 99–106.

KANBARA, M., NAGAMATSU, A., AND YOKOYA, N. 2010. Augmented reality guide system using mobile projectors in large indoor environment. In *Proceedings of Workshop on Personal Projection via Mobile and Wearable Pico Projection*. 16–19.

KHAN, A., MATEJKA, A., FITZMAURICE, J. G., AND KURTENBACH, G. 2005. Spotlight: Directing users' attention on large displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems Extended Abstracts*. 791–798.

KONISHI, T., TAJIMI, K., SAKATA, N., AND NISHIDA, S. 2009. Projection stabilizing method for palm-top display with wearable projector. In *Proceedings of the 13th IEEE International Symposium on Wearable Computers*. 13–20.

KURATA, T., SAKATA, N., KOUROGI, M., OKUMA, T., AND OTA, Y. 2006. The BOWL ProCam enabling interaction using nearby and far projection surfaces. In *Proceedings of the Virtual Reality Society of Japan Annual Conference*. 1C2-2 (in Japanese).

MCFARLANE, D. C. AND WILDER, S. M. 2009. Interactive dirt: Increasing mobile work performance with a wearable projector-camera system. In *Proceedings of the 11th International Conference on Ubiquitous Computing*. 205–214.

MISTRY, P., MAES, P., AND CHANG, L. 2009. WUW-wear Ur world: A wearable gestural interface. In *Proceedings of the ACM Conference on Human Factors in Computing Systems Extended Abstracts*. ACM, New York, 4111–4116.

RASKAR, R., BAAR, J. V., BEARDSLEY, P., WILLWACHER, T., RAO, S., AND FORLINES, C. 2003. iLamps: Geometrically aware and self-configuring projectors. In *Proceedings of the ACM Special Interest Group on Computer Graphics*. ACM, New York, 17–22.

TAJIMI, K., KONISHI, T., SAKATA, N., AND NISHIDA, S. 2010. Study of floor projection with wearable projector. In *Proceedings of the KJMR2010*. 164–173.