A Study of Laptop with Projector Camera System for Collaboration

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Abstract

A system composed of projectors and cameras is called ProCams. Projectors have been miniaturized enough to be installed in a laptop or a cell phone, and many research have been conducted on ProCams. In these research, a small projector was attached to a laptop, called Bonfire [5][17][24]. Our goal in this research was to demonstrate multi-user interactions using a laptop system such as Bonfire. We designed and implemented an interactive surface called ShareSurface that was used to share information with other users in the vicinity of the laptop with ProCams. We conducted user studies to investigate the effectiveness of ShareSurface for computer-supported cooperative work (CSCW), which involved performing a manual task using real-world objects on ShareSurface. From the results, the effectiveness of ShareSurface in CSCW was confirmed to be the same as that of a fixed type exiting collaboration tool.

1. Introduction

A system comprising a projector and a camera is called ProCams. A typical ProCams system captures images of real-world objects using the camera. Then, it estimates the position/posture of the user and detects the shape/position/movement of the objects. The attached projector projects the information onto a wall, a tabletop, an object, or a human body as an overlay image. Much research related to ProCams has been conducted. However, most of them have focused on the interaction between the user and the information projected onto a large wall or tabletop. In addition, the projectors used in those studies were also large and could not be embedded in other products. Recently, projectors have been miniaturized to a size that can be held in one hand. Therefore, some of the research on ProCams has been conducted using handheld projection devices [1] or mobile projection devices [9]. In this research, we have designed and implemented a small interactive surface called ShareSurface to share information with other users in the vicinity of the laptop with ProCams. Further, we conducted user studies to confirm the effectiveness of ShareSurface. Even though the interactive surface is small, ShareSurface can enhance CSCW with real-world object in the same way as a fixed type exited collaboration tool.

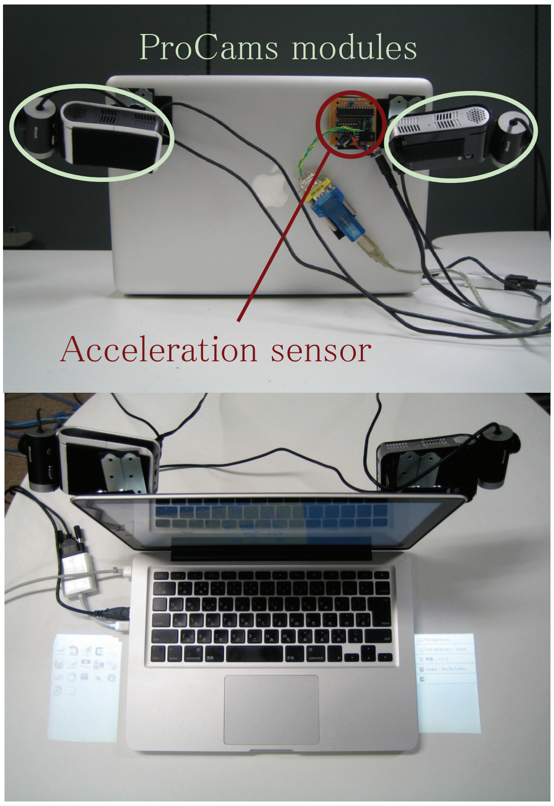

Figure 1: A prototype of the laptop with ProCams. Two ProCams modules and an acceleration sensor are attached to the back of the laptop display (top). Two projection surfaces appear on either side of the laptop keyboard (bottom).

2. Related Work

ProCams comprises a projector and a camera, and the system can capture images of real-world objects and project the information based on the images onto other real-world objects. In this way, we can easily create augmented reality (AR) spaces. Typical research on ProCams include the "augmented surfaces" project [16]

CollabTech 2012 , August 27-29, 2012, Hokkaido, Japan.

Figure 2: An example of projection markers.

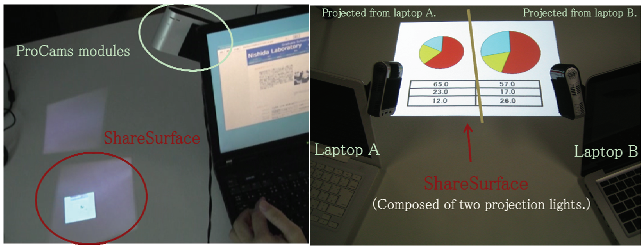

Figure 3: ShareSurface.

by Rekimoto et al.,"iLamps" project [13] by Raskar et al.,"WUW" project [9] by Mistry et al., and Tachi's project [4]. Most previous research on ProCams have used large fixed projectors and cameras. However, projectors have been miniaturized. In iLamps, ProCams was used as a handheld device. Another feature of ProCams is the ability to identify the 3D shapes of a projection surface by means of structured light techniques [18]. ProCams can be used in several ways. ProCams devices are smaller than projection surfaces, and another merit of ProCams devices is that they can be used as interactive surfaces

With ProCams, an ordinary projection surface becomes an interactive surface. As the projector displays information and includes computer vision technologies, users can interact with the projection surfaces. Researchers have constructed interactive projection surfaces on tabletops, walls, and floors. Wellner constructed the “DigitalDesk” [21] with ProCams fixed to a table and realized integrated interactions between real-world papers and interactive projection surfaces. Pinhanez’s “Everywhere Displays projector” [12] changes an entire room into an interactive space by means of a projection system that uses movable mirrors to reflect projection lights. Wilson’s “PlayAnywhere” system [23] consists of a small ProCams device. He also showed that interactive projection surfaces could be easily realized everywhere. Cao et al. implemented handheld projection devices [1], which enable users to construct interactive projection surfaces on the wall. In this research, multi-user interactions using interactive projection surfaces, such as data exchange and composing projections were demonstrated. The “Bonfire” system [5] proposed by Kane et al. uses a laptop attached to ProCams. It enables the construction of an interactive surface using only one laptop. Several interactions were demonstrated using ProCams and the interactive projection surfaces [17][24].

Basically, our research aim to interaction among Procams and Tabletop surface. Related tabletop systems includes the "DigitalDesk" project [21], "augmented surfaces" project [16], and "PlayAnywhere" project [23]. As the projectors display information on the tabletops and the cameras capture their images, ordinary tabletops become interactive projection surfaces. Computer vision hand-tracking, recognition of a hand gesture, and overlay projection onto a real-world object can be realized using ProCams. Most of these projects used a fixed projector and a camera. However, the "PlayAnywhere" system [23] proposed by Wilson could be moved and used to construct interactive projection surfaces on several tabletops. The laptop with ProCams, developed herein by us, can be easily moved and used to construct an interactive projection surface anywhere. Other work includes the "DiamondTouch" project [2] by Dietz et al., "SmartSkin" project [15] by Rekimoto. Although we can easily enhance a tabletop system by attaching sensors to detect the user's hands or by attaching devices to present haptic feedback, such a system can hardly be moved owing to its large size.

According to these observations, most research on tabletop systems have been conducted under immobile conditions, and research considering the location of the tabletop systems are few. However, we suppose most of the interactions proposed in these studies can be provided by our system.

Many research have been conducted on CSCW on interactive surfaces, most of which have used a large surface. The "WeSpace" project [22] by Wigdor et al., and "UbiTable" project [19] by Shen et al. aimed to implement CSCW on interactive surfaces. WeSpace had integrated walls, tabletops and laptops, and demonstrated that interactive surfaces could be useful in collaborative exploration. UbiTable constructed a system that integrated laptops and an interactive tabletop, and, in that work, the concept of access authority to the data on the interactive surfaces was discussed. In previous work, there is also the "AgoraDesk" system [7] proposed by Kurihara et al., which was intended to support remote cooperative work on interactive surfaces. The information on the interactive surface was shared with a remote location, and the users could communicate with each other through the AgoraDesk. The Overlay Surroundings, which we mention below, are based on this.

ShareSurface, which we mention below, is expected to influence the user's communication in a manner similar to this work.

3. Laptop with ProCams

We have implemented a prototype system of a laptop with ProCams to implement interactive surfaces. We have attached a ProCams to a laptop. We next describe a distortion correcting method that will be required when the system is put to practical uses, and a method of obtaining the relative position of each laptop that will also be required to implement multi-laptop interactions. We describe the whole system below.

3.1. Prototype System

We have constructed the first prototype system of a laptop with ProCams, as shown in Figure 1. This system used two small projectors (ADTEC AD-MP15A), two USB cameras (Microsoft Life Cam Cinema) and an acceleration sensor (ANALOGDEVICES ADXL202). The projector and the camera were integrated to create a ProCams module. To keep a distance from a tabletop, the modules were attached to each bezel of the laptop (MacBook MB466J/A) display. The projectors displayed the information on either side of the laptop keyboard, directly, as shown in the bottom portion of Figure 1. Because of this, the size of the projection surfaces was sufficient to display the shortcut icons or pop-up information; however, it was too small to display pictures or documents. To implement interactions using a laptop on a tabletop, we suppose the size of the projection surface should be about 30cm x 30cm.

We assume that ProCams that are composed of small, wide-angle, and focus-free laser projectors will be embedded in each bezel of the laptop display. However, the projected images are distorted, except when the light axis of the projector faces the projection plane vertically. We implemented a distortion correcting method using an acceleration sensor. We attached a tri-axial acceleration sensor to the back of the laptop display. From the acceleration value determined by this sensor, which changes with the angle of the display, we can calculate the angle between the laptop display and the tabletop. By obtaining the geometric relationship between the laptop and the ProCams, in advance, we can correct the distortion of the images from the calculated angle [20]. To achieve multi-laptop interactions through projection surfaces, each laptop must obtain the relative positions of the other laptops. In this paper, we implemented the system using only projectors and cameras. In this system, after placing the laptops, one particular laptop projected a marker of a given size onto the tabletop, as shown in Figure 2. By capturing each marker with its respective camera, the other laptops could obtain the relative position to the marker, and finally recognize the relative positions and orientations of each laptop [11]. We used a marker created by various dots for this purpose. The positions of the dots were the only and most important pieces of information.

3.2. ShareSurface

We have implemented a space in which a user can share information with other users using ProCams, attached to a laptop, and we call this surface ShareSurface. This surface is shown in the top portion of Figure 3. ShareSurface can also set a larger display space than a single laptop provides, by joining projection surfaces from multiple projectors attached to laptops placed on same tabletop, as shown in the bottom portion of Figure 3. Moreover, ShareSurface can obtain a brighter projection image by overlaying projection surfaces from multiple projectors with the projection image from one projector. The system can also identify a user's hands and recognize interactions with real-world objects on ShareSurface using the ProCams attached to the laptops.

The usage examples we consider for ShareSurface include casual meeting displaying data, browsing, editing or exchanging data, overlaying images onto real-world objects and games, using hands. All these usages have been made possible by previous research on tabletop interfaces.

4. ShareSurface For Collaboration

We have conducted experiments on ShareSurface when used for manual tasks. To see only the effects of the display function of ShareSurface, we had made a simple experimental design. Participants performed some manual tasks using two methods. It should be noted that each technique we propose for ShareSurface has already been mentioned or proposed in prior research [5][15][17]; our research does not propose new techniques. Technically, the SharedSurface is a combined laptop computer and projection tabletop. However, we also wish to confirm that ShareSurface provides the same functionality as past great research. One such function is the normal condition that information is displayed only on the laptop display. Another is the ShareSurface condition that information is displayed on both the laptop display and ShareSurface. In this way, we thought we could determine the effects of the display function of ShareSurface, when added to the regular features of a laptop. We timed each task and logged failure counts during the performance of each. There were three participants and three laptops with ProCams in each experiment. These laptops were placed on the same table and made a circle. We also asked the participants to perform some manual tasks in the center of the table. In the ShareSurface condition, ShareSurface also appeared on the center of the table. The size of ShareSurface was about 20 x 20 cm, and it was produced by three laptops with ProCams. However, it was hard to

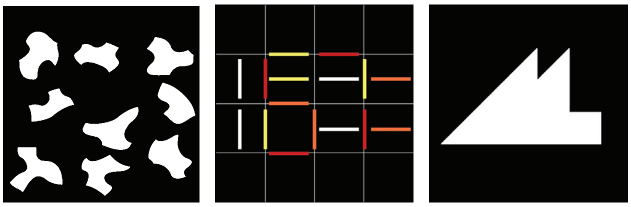

Figure 4: Projected image of each task. (Left: Searching Pieces, Middle:Fitting Pieces, Right:Tangram)

project this size from one projector attached to a laptop. As such, more than one projector was used to produce some portions of the surface. We conducted three tasks, mentioned below. Basically, all of the three tasks are derived from [17]. A major difference from the above contribution, however, is that we conduct this user study in the context of collaboration between multiple users; that is, we look at multi-user interactions.

The first task is referred to as "Searching Piece." This task requires participants to search for the piece that is missing in a displayed image, selecting from ten pieces. The real pieces are placed on the center of the table, and a life size image of nine of the pieces is displayed on the laptop displays. In the ShareSurface condition, the same life size image of nine pieces that is displayed on the laptop display is also displayed on ShareSurface. The starting time for the task is when the image of the nine pieces is first displayed, and the finishing time is when the three participants find the piece that is missing in the displayed image; that is, when they agree that it is the required piece. We logged a "failure" if the identified piece was incorrect.

The second task is referred to as "Fitting Pieces." This task requires participants to put 16 pieces on a prepared piece of paper in a pattern that replicates the displayed image. The size of each piece is 0.5 x 4 cm. There are four colors: 4 are red, 4 are orange, 4 are yellow and 4 are white. They were made from poster board. The required positions are different for different colors. A life size arrangement plan image, including basic grid lines, is displayed on the laptop displays. The image includes the positions where participants should place the pieces. In the ShareSurface condition, the same arrangement plan image that is displayed on the laptop display is also displayed in life size on ShareSurface. The starting time for the task is when the arrangement plan image is displayed, and the finishing time is when all pieces are placed on the paper. We logged a "failure" if the positions of the placed pieces are not the same as the required positions.

The last task is referred to as "Tangram." Tangram is a dissection puzzle consisting of seven flat shapes. This task requires participants to recreate the same shape that is displayed as a silhouette image, using seven pieces. A life size silhouette image is displayed on the laptop displays. In the ShareSurface condition, the same life size silhouette image is displayed on the laptop display and on ShareSurface. By moving the seven pieces placed on the table, participants make the same shape that is displayed in the silhouette image. This task is largely influenced by inspiration and luck. Although we thought it was not important to time the task, we did so in the same manner as the other two tasks.

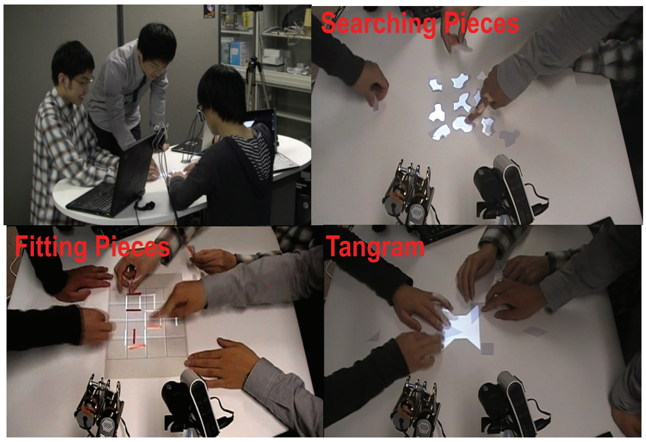

Figure 5: Appearance of conducting each task.

Figure 4 shows example images of the three tasks. Figure 5 also shows subjects conducting each task. In "Searching Piece" and "Fitting Pieces," participants performed two practice runs and five real task runs, in each of the normal-ShareSurface condition. In Tangram, participants performed one practice run and three real task runs in each condition. We asked the participants to fill out a questionnaire at the end of all tasks. The questionnaire items included a request to evaluate whether "The visibility of the contents displayed on ShareSurface was good," "The working efficiency increased with ShareSurface," "The conversation increased with ShareSurface" and "You want to use ShareSurface if it is available." Participants answered on a seven-point scale (agree: 1, disagree 7). There were fifteen participants (aged 22 to 25 years). Each group included three participants, and we collected five sets of group results.

Result. Figure 6 shows the completion time for each

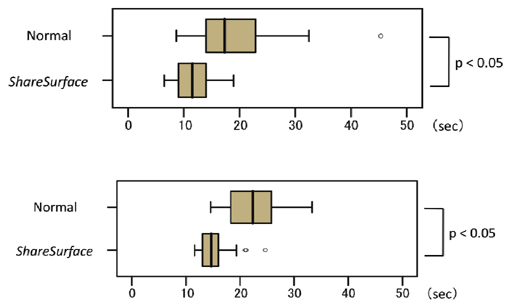

Figure 6: Task completion time. Searching Piece (top). Fitting Pieces (bottom).

task. Applying a Wilcoxon's signed rank sum test, there were significant differences ($p < 0.01$) between the normal condition's completion time and the ShareSurface condition's completion time in the "Searching Piece" and "Fitting Pieces" tasks; the time in the ShareSurface condition was shorter than that in the normal condition. "Failure" was confirmed only in the "Searching Piece" task: once in the normal condition and twice in the ShareSurface condition.

As the result of the questionnaire, there were significant differences between the normal condition and the ShareSurface condition in the "Searching Piece" and "Tangram" tasks, with respect to: "The visibility of the contents displayed on ShareSurface was good." However, there was no significant difference in the "Fitting Pieces" task. There were significant differences in all tasks with respect to: "The working efficiency increased with ShareSurface." There was no significant difference in any of the tasks with respect to: "The conversation increased with ShareSurface." There were also significant differences in all tasks with respect to: "You want to use ShareSurface if it is available."

5. Discussions and Conclusion

There were different behaviors between the normal condition and the ShareSurface condition. In the normal condition for the "Searching Piece" task, we observed that participants first took pieces, brought them to the laptop display and then compared them to the displayed image. On the other hand, in the ShareSurface condition, we observed that participants put pieces directly onto the image displayed on ShareSurface. Displaying images near the pieces, participants could easily compare the pieces to the images and did not need to move their hands very much. Therefore, the time until the end of the task was made shorter. In addition, putting pieces directly onto the images displayed on ShareSurface, participants could easily distinguish between pieces when compared to the images of the other pieces. In the normal condition of the "Fitting Pieces" task, we observed that participants put the pieces onto the prepared paper, comparing the paper to the image displayed on the laptop display. The paper put on the table provided no indication of direction, and participants therefore needed to talk about which direction should be considered "upward." This was because participants were placed around the table, making a circle, and all laptop display indicated images with the same direction, thus some participants had to place the piece on the paper in a direction contrary to their laptop image. On the other hand, in the ShareSurface condition, we observed that participants moved the prepared paper on ShareSurface and put the pieces directly onto the piece images that were projected onto the paper. In this case, the direction problem mentioned above was not observed. It thus appears that ShareSurface reduced burdens, including subjects' need to move their eyes to compare the displayed image to that on the paper and subjects' need to temporarily memorize the position where the piece must be placed. In the normal condition of the "Tangram" task, we observed that participants put the pieces on the silhouette image, displayed on the laptop display, in order to compare the sizes of the pieces and the silhouette image. There were two groups in which all participants surrounded one laptop and they worked by first putting the pieces onto the laptop display, although the other three groups worked on the tabletop. On the other hand, in the ShareSurface condition, participants usually worked on the center of the tabletop. However, there were some participants that worked on the laptop display in order to compare the sizes of the pieces and that of the silhouette image. From the interview, following the experiments, subjects thought they might be distracted because the other participants were working on the tabletop, or they felt that the silhouette images on the laptop display were clearer than those on ShareSurface, because three projectors were used to construct ShareSurface, thus there was some displacement of the projection images.

From the results of the questionnaire, the visibility of images used in the "Fitting Pieces" task on ShareSurface was worse than that of other images used in the "Searching Piece" and "Tangram" tasks. This might have been caused by the delicacy and color of the image content for those images used in the "Fitting Pieces" task. The displacement of the projection images or the projectors' brightness might provide the participants with poor visibility. The projectors we used in this experiment were not laser projectors. Unfocused images from the projectors factored into this result, but we assume that laser projectors would overcome this problem. From the free description of the questionnaire, some participants mentioned that occlusion was not experienced at all, in any of the tasks. This is because the other two projectors cover the plane of ShareSurface and the projection images are not hidden when a participant blocks the projection image from one of the three projectors with his/her hand. From answers to the following questionnaire items: "The working efficiency increased with ShareSurface," and "You want to use ShareSurface if it is available," we found that participants knew that ShareSurface had increased their working efficiency and it was effective, even if its visibility was not good. There was no significant difference in the answers for questions about increases in conversation. In these tasks, we can say that ShareSurface has more influence on working efficiency than on conversation. These three tasks had solutions; therefore, conversations were not observed much. To evaluate ShareSurface's effectiveness for communication, we suppose that we should conduct additional experiments that invite conversations, such as making a travel plan. Also, we note again that each usage of ShareSurface had already been mentioned or proposed in past research. Our research does not propose new usages and the Shared Surface is a combination of a laptop computer and projection tabletop, as in past work. However, we can also say that ShareSurface provides the same functionality as the designs of past great research [8][16][17].

As a result, displaying information on ShareSurface is effective for CSCW with real-world objects, reducing working time and burdens. However, the visibility of images displayed on ShareSurface is dependent on the contents of the images. Therefore, improvement of our system should be required.

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