Public/Private Interactive Wearable Projection Display

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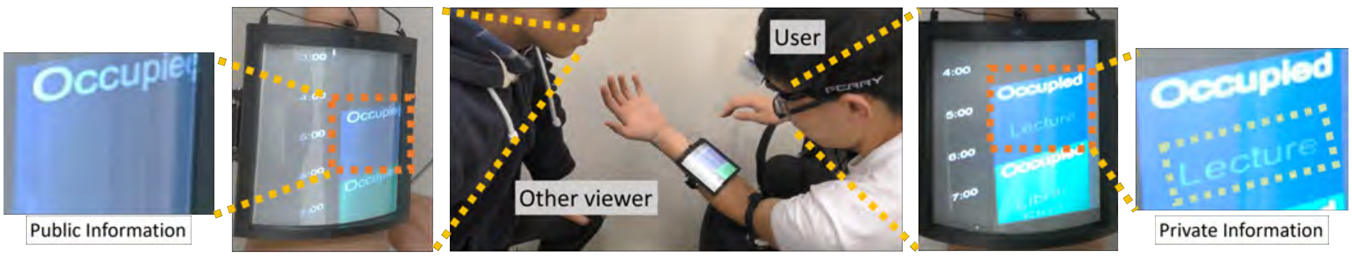

Figure 1: Private information only limited to user while Public information is visible to others.

ABSTRACT

We propose a wearable projection system that displays both public and private information concurrently. The system is composed of a 2-layer forearm mounted screen and a head worn device which projects images on the screen. The screen can be switched between two modes, light-diffusing mode, where projected image is visible to the surrounding viewers and light-transmitting mode, where projected image is only limited to the user. We conducted a set of design workshop to identify the optimal placement and interactions with this display system. We also implemented three display methods to present public or private information, which are contextualized with several use-case applications, supported with four sets of gestures.

CCS CONCEPTS

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

KEYWORDS

Public and private information, Retro-reflective material, PDLC switchable diffuser, Transparency-controlled display, Wearable display

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1 INTRODUCTION

In the context of mobile device interaction, there are two types of information, public information that can be shared with others such as picture or news and private information that is only limited to the user such as entering password or reading emails [Greenberg et al. 1999]. In certain situations, being able to view both public and private information simultaneously can be advantageous. For example, when sharing photos in a photo library with other people [Apted et al. 2006], the library may contain private pictures which user is required private view the photos before sharing them. Another example will be the Old Maid card game [Piper et al. 2006], where an opponent should possess no knowledge of other player's hands other than the number of cards to draw from the opponent's cards. Therefore, being able to view both public and private information simultaneously can allow smooth communication. However, current mobile devices lack support in this concept and users have to physically hide their mobile display in order to view private information.

Here, we propose a wearable display system that can control the flow of information, composing of a 2-layer forearm mounted screen and a head worn device. The screen consists of a film of polymer-dispersed liquid crystal (PDLC) switchable diffuser at the top-layer and a retro-reflective material at the bottom-layer, and the head worn device consists of a pico projector and a Leap Motion mounted on a pair of lensless glasses as shown in Figure 1.

The PLDC switchable diffuser is made of a flexible material that can switch between diffusion and parallel transmission at a high frequency by applying a very low AC current. When the diffuser is in the light-diffusing mode (opaque), the projected image is made public and visible to the surrounding viewers. When the film is in the light-transmitting mode (clear), the projected light is reflected by the retro-reflective layer at the angle of incidence, and is only visible to the user whose line of sight aligns with the projector.

A set of design workshops are conducted to investigate the best location on the body to place the system on and to learn the type of gestures the participants would like to use. We learned that the non-dominant arm is most optimal placement. On the basis of the proposed system configuration, we developed three display methods; a Temporal Switching Method, to switch between public and private information at an arbitrary time, a Spatial Switching Method to spatially separate public and private information into different physical areas, and a Simultaneous Method to display public and private information on the display concurrently. A Leap Motion is used to detect 4 different gestures; twist gesture, dominant and non-dominant finger gestures and scrolling gesture.

A different potential system configuration for a similar purpose is to combine an optical see-through HMD such as Google Glass [Google 2013] to view private information, with a smartphone to support public information. However, in comparison, our system can concurrently display both public and private information using an inexpensive and small projector that provides a wide-angle field of view.

Here is a summary of our contributions.

- Through a design workshop, we investigated the optimal location of the body for user to place our system.
- We developed a system that can switch between public and private information by projecting images on a new type of screen.
- We propose three display methods based on the properties of the proposed display surface technologies.
- We prototype several applications to demonstrate the advantage of our new system.
- We developed interactive controls to detect user's gestures when interacting with our system.

2 BACKGROUND

Our public/private wearable display system is inspired by a number of existing research concepts: new interaction methods designed to leverage the user's body, novel projection surfaces, and wearable projection systems. An overview of these research areas is provided.

2.1 Interactions

Weigel, Mehta and Steimle [Weigel et al. 2014] performed an investigation to determine preferred locations of various skin-specific input modalities where they found that the non-dominant forearm to be suitable for an on-skin input for the upper limb, while the palm and forearm were suitable to support privacy. Gustafson, Rabe, and Baudisch [Gustafson et al. 2011] found that the palm interface to be a more accurate interaction surface for pointing gestures as compare to a traditional empty space interface. Blasko, Coriand, and Feiner [Blasko et al. 2005] explored the interaction design space of a wrist-worn projector by implementing an interactive information browser base on the wrist interactions. SenSkin is a band type device wrapped around a user's arm to measure the skin deformation of the forearm using multiple optical sensors to detect gestures such as tweaking or pressing [Ogata et al. 2013].

2.1.1 Projection Surfaces: Izadi et al. [Izadi et al. 2008] developed SecondLight, a system that projects on a computer controlled diffuse surface that switches between clear and diffuse using two projectors. Our technique is similar but employs one projector. Lumisight Table [Matsushita et al. 2004] provides a projection surface that directs projected images to a particular user. The software can control the type of information to be presented to each individual. Smith and Piekarski [Smith and Piekarski 2008] developed occluding mask (parallax barrier) with numerous holes to allow multiple users to view public and private information. The LCD display under the mask is spatially multiplexed to provide private information to each user. Tracs [Lindlbauer et al. 2014] is a display technology, consisting of two LCD displays with a backlight and a polarization adjustment layer to display 3 forms of information: personal (private), communication (transparent to others), and collaborative (public).

2.1.2 Wearable Systems: Our proposed system is similar to the Harrison, Benko and Wilson's OmniTouch [Harrison et al. 2011] where both systems employ a pico projector to project information on user's arm and hand, and a sensor to interact with information using gesture. The major difference is that our system presents both public and private information, while OmniTouch only limits to public information. Sato and Sakata [Sato and Sakata 2015] developed Toe detection, a similar system with a chest-worn device projecting images onto the floor and an RGBD camera to detect foot gestures. Users can select regions on the projected image by placing their toe on a location. Inami et al. proposed a head-mounted projector system [Inami et al. 2000], where users can view AR information displayed on retro-reflective materials added to objects and environments by projecting them from the head. Similarly, AR-Scope [Yoshida et al. 2008] tracks an object with a camera to project the image according to the object's position. Pearson, Robinson and Jones [Pearson et al. 2015] explore the possibility of extending personal smartwatches into public displays.

3 DESIGN WORKSHOP

We conducted a series of design workshops to better understand how users would want to view and interact with public and private information presented on a wearable display. Three design workshops were conducted with three participants each; one in Japan and two in Australia. Each workshop was conducted in 3 parts where the first part was a structured interview, to evaluate the participants' impression on public and private information and to learn the parts of the body where the participants prefer to view these information and their preferred gestures. We found that a majority of the participants preferred to view information on the hands or forearm, while preferring three main gestures; a swap gesture above the display, a finger swap along the display's edge and touching the display. The next part of the workshop was to evaluate the ranking of 9 predefined locations to place the display on their body. Each participant was asked to place pre-cut white pieces of paper on each location, ranking each position according to their preferences, while mimicking gestures of using the display. From the findings, the palm was indicated as the prime location for private information and the non-dominant forearm was the optimal position for both public and private information. As for preferred gestures, a majority felt that holding one's hand in front of their face worked well for private information and touching the display or twisting their wrists were preferred to turn on the display. In addition, a few participants also considered waving gesture for a scrolling motion as well as finger gestures to enter commands. These suggested gestures are then implemented on our system, which will be further explained in the later section. Finally, the last part was to get new proposals from participants on the design of the display and their preferred location. These different ideas would be interesting to be developed for future displays.

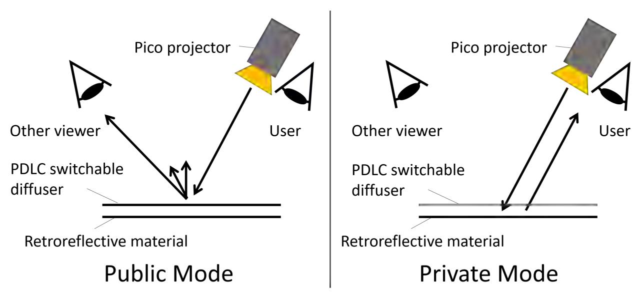

Figure 2: Principle of our method.

3.1 Conclusions

These workshops have influenced several of our design decisions, where we decided to choose the forearm as the optimal location for our display system and concentrate on touch and gesture based interaction. However, as developing a compatible touch-based technology is quite a challenge as retro-reflective material interferes with Leap Motion's sensor, we decided to opt it out in this phase and improve it in future works.

4 PRINCIPLE

4.1 Basic Principle

Our proposed display system can control the flow of public and private information. Figure 2 illustrates the principle of the system, where it comprises of a 2-layer screen, composing of a polymer-dispersed liquid crystal (PDLC) switchable diffuser on the top layer and a retro-reflective system on the bottom layer, and a head worn device, consisting a pico projector and a gesture recognition device, Leap Motion mounted on a set of lensless glass.

The PDLC switchable diffuser is made of a flexible material that can switch between diffusion and parallel transmission at a high frequency by applying a very low power AC current under a computer control. When the diffuser is in light-diffusing mode, the projected image will diffuse on the material and the image will be visible to the surrounding viewers. When the diffuser is in light-transmitting mode, the light will pass through the PDLC and will be reflected by the retro-reflective layer back to the user who is wearing the head worn device as the user's line of sight is aligned with the projector, allowing more privacy.

4.2 Three Types of Display Methods

We proposed three display methods to switch between public and private mode as illustrated in Figure 3. The top figure depicts the Temporal Switching Method, where user can easily switch between public and private mode, allowing information to be fully public or private. The middle figure illustrates the Spatial Switching Method, a method to show public and private information separately, where public information is projected on another surface such as the user's hand while private information is projected on the display. The bottom figure shows the Simultaneous Method, a method to display both public and private information on the display at the same time. Here, the diffusion and transmission mode of the PDLC will be switched simultaneously at high frequency while being synchronized with the images from the projector.

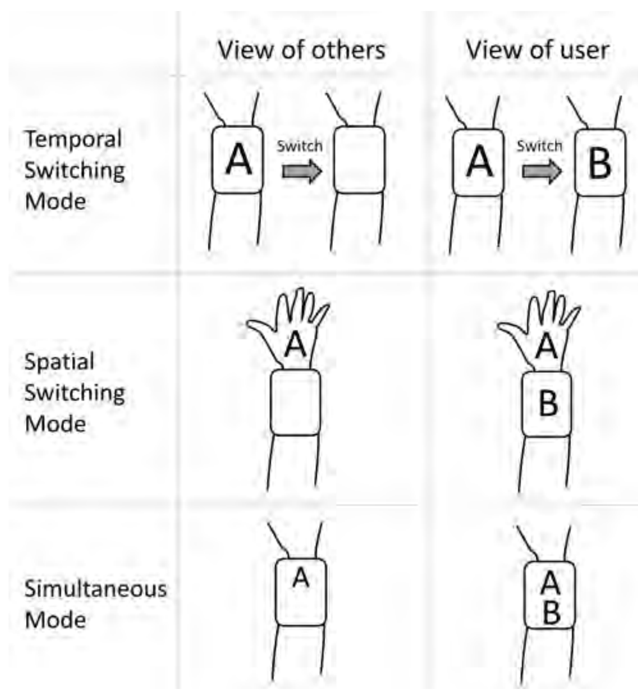

Figure 3: Types of Display Methods. A represents public information, and B represents private information.

4.3 Gestures

We proposed three display methods to switch between public and private mode as illustrated in Figure 3. The top figure depicts the Temporal Switching Method, where user can easily switch between public and private mode, allowing information to be fully public or private. The middle figure illustrates the Spatial Switching Method, a method to show public and private information separately, where public information is projected on another surface such as the user's hand while private information is projected on the display.

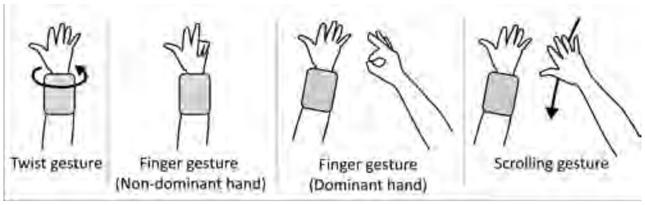

Figure 4: Set of Hand Gestures.

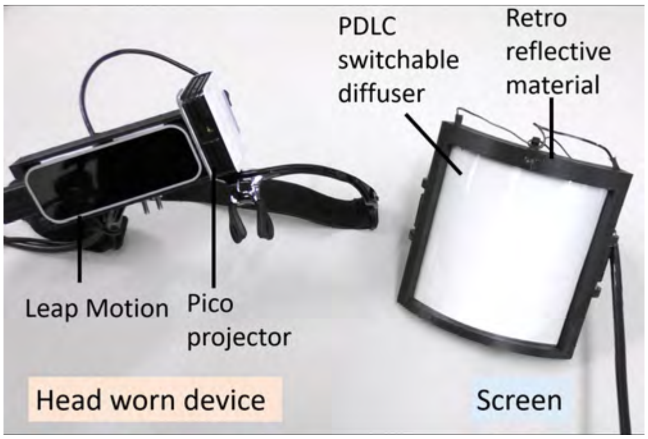

Figure 5: Hardware Equipment.

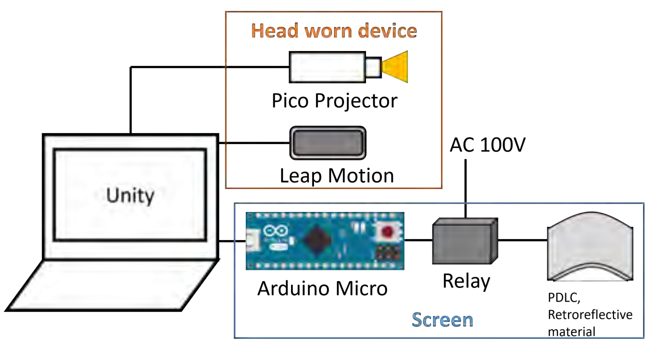

Figure 6: System Configuration.

The bottom figure shows the Simultaneous Method, a method to display both public and private information on the display at the same time. Here, the diffusion and transmission mode of the PDLC will be switched simultaneously at high frequency while being synchronized with the images from the projector.

A twist gesture allows user to switch information displayed by twisting the arms that holds the screen. This gesture can support operations such as turning on/off the system or changing display modes. The finger gestures allow user to enter commands such as entering/cancelling a current input or returning to the original state. We implemented a two-finger gesture for the non-dominant hand and a click gesture, which closes the user's forefinger and thumb for the dominant hand. A scrolling gesture allows user to scroll through information vertically or horizontally using the dominant hand.

4.4 Tracking Process

Initially, the system requires to be calibrated before it can be used; by calibrating the projector to the Leap Motion and calibrating the projection area in relative to the non-dominant hand.

4.5 Viewing Angle

Although the retro-reflective material can reflect most of the light at the direction of incidence, some light may still diffuse onto the material. Therefore, the user can see the image even from a place slightly displaced from the incident angle. The private image can be seen from the direction of less than 3 degrees in the incident direction while the public image can be seen from the direction of less than 50 degree in the incident direction.

5 IMPLEMENTATION

Figure 5 illustrates our proposed system and Figure 6 illustrates the system configuration. The upper layer of the screen is a P5DLC switchable diffuser from NSG UMU PRODUCTS CO., LTD while the bottom layer is Scotchlite High Gain Reflective Sheeting 7610 from 3M. The two layers are stacked and held together with an adhesive tape and are protected by a 3D printed casing. Velcro bands are attached to the casing to firmly mount it onto the user's arm. A very low AC current of 0.25mA is applied across the film through an electrical relay to trigger the light transmission mode, i.e. private mode, while with no power supply, the film will remain in light diffusion mode, i.e. public mode.

A sub-module containing a MOC-3043M, made by Fairchild Semiconductor International, Inc., as an electrical relay circuit and an Arduino Micro (5.0 V) is connected between the diffuser and the main power supply. The circuit is driven by Arduino to perform the switching of the diffuser when a respective command is sent through the serial channel. Another part of the system is the head worn device, consisting of a Leap Motion as a tracking device and MiNi Ray as the pico projector attached to a pair of lensless glasses. The projection axis and camera lens's principle axis are fixed to be parallel with each other. The size of the projector is 44 $times44$*times* 14 mm, and the weight is 27 g. Leap Motion locates the user's hands and arms in 3D space, using the information to build appropriate gesture-based user interfaces.

A central computer connects all components of the system. A software, Unity, is used to project images on the screen, to track hand gestures with Leap Motion, and to send a serial command of 20Hz to Arduino to switch the diffuser on and off, synchronizing the content displayed by the projector and diffuser. Unity also synchronizes the turning on and off of the screen with the projected contents. Public and private information images are displayed at 10 Hz.

6 USE CASES

Several applications as explained below were created to demonstrate the benefits of the three display methods.

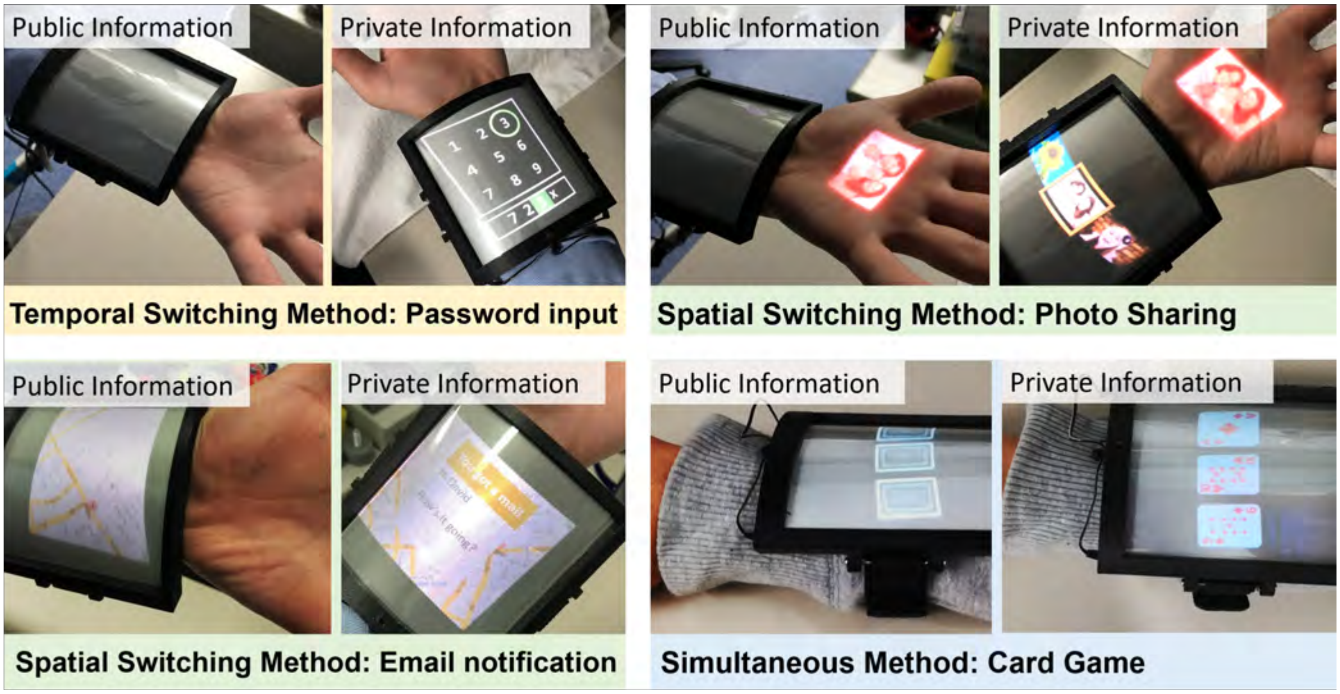

Figure 7: Use-Case Application.

6.1 Temporal Switching Method

6.1.1 Password Input: An example of Temporal Switching Method is entering a password in a mobile context (Figure 7 upper left). Users can switch between public mode and private mode with the twist gesture. At private mode, user can enter password with a mid-air gesture by moving the dominant hand in the air and placing the cursor on the password number and clicking onto it. The scrolling gesture in both the vertical and horizontal direction allows user to position the cursor over a numeral.

6.2 Spatial Switching Method

6.2.1 Photo Sharing: An example of Spatial Switching Method is highlighted with our photo sharing application (Figure 7 upper right). A private photo library may contain personal pictures that are not intended to be shared. The user first searches the library that is projected on a private screen which is only visible to the user for images they wish to share, and make a hand gesture to signal that the photo is be projected onto the user's palm, where it serves as a temporary screen. The palm extends the projection area and allows us to provide a secure display method.

6.2.2 Email Notification When Viewing Map with Others: Another example is to present two applications at once (Figure 7 bottom left). User suddenly gets an email notification when the user is sharing a map with another person. Here, the user can read the contents of the email in private mode by scrolling and at the same time, the map is displayed continuously in public mode to the others. As the private display is switchable, the private application itself may be placed in public view mode. In this case, the email itself can be displayed to the others who are viewing the map.

6.3 Simultaneous Method

6.3.1 Schedule Sharing: Projecting two different images onto the same area is demonstrated in a schedule-sharing app shown on Figure 1. An hourly schedule is projected onto the screen attached to the user's arm. The details of public event will be shown to all viewers, while details of private event are only presented to the user. This creates two different views within a limited projection area without switching between views. The simultaneous projection of information allows the user to observe public and private information that are aligned with each other, simplifying the presentation of the user's schedule.

6.3.2 Card Game: A card game demonstrates another example of the Simultaneous Mode (Figure 7 bottom right). The system projects onto the same location allowing the user to view the face of a card projected in private mode, and the opponent to only see the back of the card projected in public mode. We can use this function effectively in card games like Old Maid, where the opponent decides which card to draw from the user by making the appropriate hand gestures.

7 CONCLUSION

In this paper, we presented a head worn projection system that displays on a custom projection surface to support both public and private information concurrently. The projection surface is a 2-layer screen with a computer controlled switchable diffuser (film of PDLC) on top and a retro-reflective material underneath. The head worn device is a pair of lensless glasses with a pico projector and a Leap Motion controller. When operated at a high frequency, the diffuser can present simultaneous public and private information on the screen. Three methods of presenting public or private information are described: Temporal Switching Method, Spatial Switching Method, and Simultaneous Method. Four hand gestures were developed for our system to support user interaction: twist gesture, dominant and non-dominant finger gesture and scrolling gesture. These methods were contextualized with five use case applications.

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