Distributed Display Approach Using PHMD with Infrared Camera

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Abstract

The aim of this study is to explore the feasibility of multiple display environment technology in the real world. In this paper, the wearable projector, with an infrared camera and light source, is used in combination with retro-reflective screens. The visible image and infrared light are projected to the screen and reflected back to the user's eye and the infrared camera. The screen location and the user's fingertip position are calculated using image processing to enable the interaction. Several examples or demonstrations have been constructed to show the usage of this configuration. The screen functions as both the visible screen and the high-gain infrared marker at the same time. Owing to high-reflection gain of retro-reflective screens, a small, lightweight projector can be used. Also, the high contrast between the screen and the other environmental object in the captured infrared image decreases the difficulty of image processing.

1. Introduction

1.1 Head Coupled Display

There have been several types of approach to augment the real world or to tighten the relationship between real objects and the world inside the computer. The devices used for such efforts to achieve a better interaction style are many, for example: a desk with projection, object recognition by image processing, ID tags, pen-type autonomous input devices, the handheld Personal Digital Assistant (PDA), etc [8][9][10]. Also, in the context of Augmented Reality or Mixed Reality there have long been efforts to apply the Head Coupled Display (HCD), since the ideal HCD could offer the most flexible environment. However, there are difficulties with the feasibility of the actual Head Coupled Display in our daily lives. One large difficulty is the sensing issue. First, the position and orientation of the user's head are required since the displayed content is tightly coupled with them. For general usage in our lives, the sensing equipment must be autonomous without any cable connection. Till now, there has been no suitable sensing device developed for this purpose. Second, the identification and the location of the object are also required for the augmentation of the object's appearance. This is important, especially in real-world-oriented computing. There are examples using a fixed camera and image processing for the enhanced desk environment [9][10]; however, they are limited to a desk that can provide relatively good environment for image processing. Last, the user needs to have a sensor or input device for the interaction.

Another difficulty is the occlusion issue. Both the optical overlay (optical see-through) display and the video see-through display sometimes hide or interfere with information from real objects. This problem becomes serious when we try to display the ambient information. Even in the case of video see-through, we need to track or register the object to enable the right occlusion.

1.2 Third Person Interface

The authors have proposed the “third person interface” [12]. The following is a brief description again.

The type of interactive display environment is classified in terms of person, i.e., the first, second, and third person. For an easier explanation, the analogy of the mirror is used here. First, the full immersion virtual reality (VR) configuration using Head Mounted Display (HMD) or (CAVE) offers the first person interface. The user’s consciousness enters the virtual world across the body mirror (i.e., display). “I” was virtualized as a model in the computer and interacts with the virtual object. Next, most of the computer interfaces, including the PDA and the wearable device, are classified as the second person interface. The user’s focus is on the world in the small hand mirror/display. “You” means the display and input device on which the user concentrates and with which he communicates. The third person interface can be explained as many fragments of mirror, i.e., many displays around the user. The user can see many aspects of the world at the same time. “He”/”She”/“It” always surrounds the user, and when the user begins the intensive communication with one of them, then it becomes a “You”, the second person.

1.3 Features of Third Person Interface

In this paper, the authors try to explore the technical feasibility of the third person interface. Several features seem to be required naturally from the description above.

Ambient Information: In daily life, we are obtaining a large amount of information without noticing it. For example, when we see the tree leaf swinging outside the window, we unconsciously notice that the wind blows. Such ambient information is important for our lives; however, it has been omitted in the context of computation [1]. Here, the authors do not mean to use the physical media that are originally ambient [1], but intends to have displays in ambiance. Display devices such as Liquid Crystal Display (LCD) and Cathode Ray Tube (CRT) are difficult to fuse naturally with other objects because they have higher presence by themselves. The device to display the ambient information needs to be ambient by itself.

Awareness Transition: We have different levels of awareness of many events and objects at the same time, and we rapidly change our focus of consciousness from one object to the other [1][2]. The third person interface needs to support three features. First, the user has already been aware of the information in the ambiance before he focuses on it. Second, the user can naturally and easily change the target of consciousness. It is not easy when we use the Personal Computer (PC) or PDA, namely the second person interface. We need to be notified by sound or blinking graphics at first. Also, we need to operate the device before the interaction, for example draw a different window to the foreground. Third, once when the user focuses on one object or a display, then the display needs to shift from the ambiance to the second person interface that enables detailed, natural interaction. Thus the third person interface needs to involve the capability of the second person interface.

Configuration: The first person interface, such as the Head Mounted Display, could deal with the ambiance and enable the easy change of awareness. However, such configuration is still far from maturity, especially when it is used as the wearable device in our daily lives. The largest obstacle is the sensing as discussed in 1.1. Since the displayed content is closely related to the real world and the user's head location, it is necessary to measure it. The magnetic or ultrasonic sensor can be used for the activity within the laboratory environment. Therefore, another type of configuration is required.

2. Proposed Configuration

2.1 Projection Head Mounted Display (PHMD)

The Projection Head Mounted Display (PHMD) is relatively recent technology. The principle of the PHMD was proposed with the first prototype by one of the authors in 1995 [3][4]. This prototype is used for an application to lay out and design furniture. This was based on the idea of moving the object among the multiple spaces, enabling the seamless connection of the spaces, similar to the Pick-and-Drop [8]. The user can grab and change the location of furniture using a flying mouse (both for 2D and 3D) in the surrounding Virtual Environment (VE). He can push it into the CRT and modify the shape there, then grab and draw it back to the surrounding VE.

Afterward, the retro-reflector was introduced to enable the stereoscopy for the projection display [5] in 1996, and soon the PHMD was used with the retro-reflector [6][7], showing a series of impressive demonstration [14][15].

The fundamental principle of the PHMD is the optical conjugation between the user's eye and the optical center of the projection. Due to this conjugation, the image is projected from the user's eye position and seen from there. This arrangement enables the user to watch the image without distortion when the screen is at an angle to the line of sight or the screen is bent, because the viewing transformation is the inverse of the projection transformation and the distortion derived from the screen's shape is canceled.

The PHMD potentially could have wider field of view than the general HMD using the false image. In the typical configuration as shown in Fig.1, the major limitation of field of view (FOV) is derived from the location arrangement of eye, mirror, and projection lens, not from the projection optics. In this structure, the FOV is limited to within 90 degrees.

The structure and the optics for the PHMD have not yet been fully investigated. There are devices and structure that could be useful for the PHMD, such as reflective LCD, crystal laser scanners, DMD (Digital Micro-mirror Device), mirror scanning displays like as the Private Eye, the pinhole lens configuration, etc. There is the potential to realize a wider FOV to support peripheral vision.

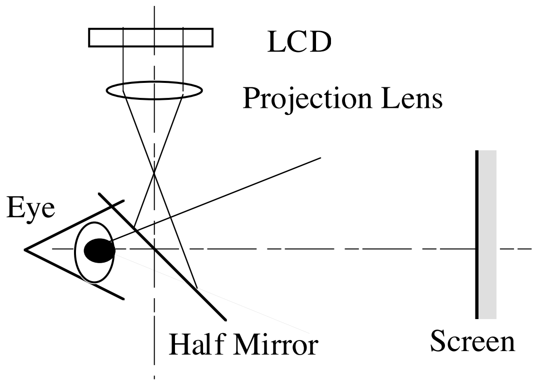

Fig. 1. Structure and Principle of PHMD

The authors have developed a series of PHMD as shown in Fig. 2 - Fig. 6. One of the essential issues to make the small projector was the power-weight and power-heat ratio of the light source. A halogen lamp of five watts used for Rev.1 causes the overheating problem of the LCD panel even with the heat protection using a hot mirror and a heat absorber. The light source is divided from the projection head and they are connected by optical fibers in Rev.2. In Rev.3, the current prototype, hi-luminance white LED (light emitting diode) block is attached to the projection head. The projection head for each eye was composed of an LCD panel (Sony LCX009AKB, 0.7 inches, 800x225 pixel), a projection lens block (18 mm diameter), and the light source. The LED block generated the luminance of approximately 250 millicd/mm2 and was enough for use within the room, but not for outdoor usage. All the optical components were off-the-shelf products. The lens block was designed to be exchangeable. For the lens block we were mainly using, the field of view was 38 degrees (diag.) and the designed focus distance was forty centimeters. With the smaller diameter, the longer focus depth was achieved while the image became darker. The weight of this PHMD is about 120 grams including the harness.

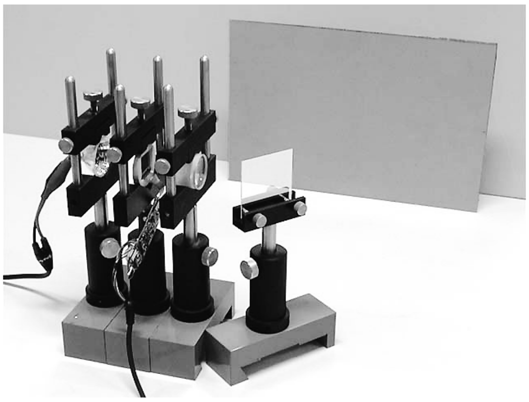

Fig. 2. Confirming the Optical Design
(PHMD Rev. 0. Kijima, Oct 1998)

Fig. 3. Head Mounted Configuration
(PHMD Rev. 1. Kijima & Haza, Mar. 1999)

Fig. 4. Light Source is Divided for Heat Protection
(PHMD Rev. 2. Haza & Kijima, Jul. 1999)

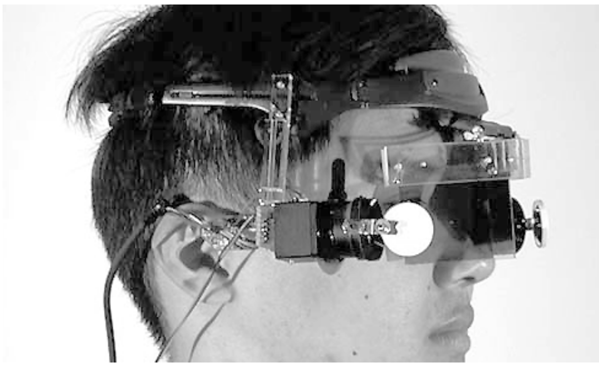

Fig. 5. Current Prototype in Stereoscopic Configuration (Rev. 3. Haza, Miwa & Kijima, Dec. 1999)

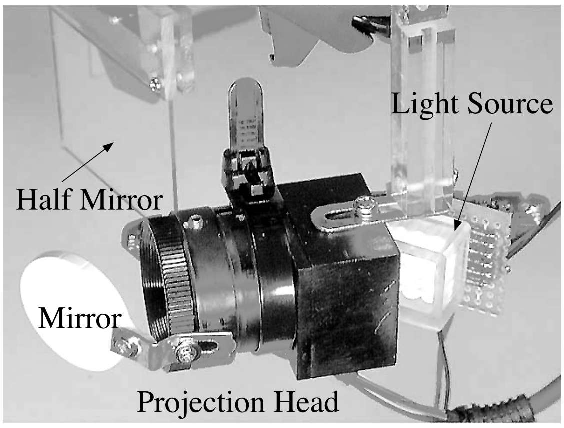

Fig. 6. Projection Head of Current Prototype

The PHMD became more practical by the introduction of the retro-reflective material as the screen. This material reflects the incoming light back to the direction of the light source. The image is projected from the user's eye position to the reflector and goes back to the eye position. Almost all the energy from the projector goes back to the eye and there is only minimal loss. Therefore, small, light weight, dark projector can be applied as the PHMD.

Another merit is the capability of stereoscopy. The image projected from one eye goes back to the same eye and does not reach to another eye. Then each eye can see the different image from the corresponding projector.

The retro-reflective screen is the cloth covered with small glass beads. This is the cheap material that is widely used for the road signs. Many displays can be attached easily in low cost. Also this material can be folded and stored in a pocket like as handkerchief.

2.2. Vision Based Measurement Using Infrared Camera

To achieve the relative location of the user's head to the screen, an infrared NTSC CCD (charge coupled device) camera and the infrared LED light source are attached to the PHMD, and the vision based measurement is applied. When the original shape is known, the screen's location relative to the user's head can be calculated from the image of the screen. The point of this configuration is that the screen served as both the visual display for the user and the anchor of the vision based measurement at the same time.

Generally speaking, the method of controlling the environment, other than the image analysis algorithm, is important for the actual application. Since the calculation power of the wearable configuration is limited, a clever way to achieve the clear image of the necessary target is required. The first device is that the LED and camera were optically conjugated with each other. Due to the high gain of the retro-reflector, the small, low-powered LED can serve well enough as the bright light source to achieve the clear image on the screen. The next idea was the differential image calculation. The infrared light was turned on and off synchronized to the frame and the difference of images was calculated. Thus the background noise was largely decreased and the high-contrast image of the screen was achieved.

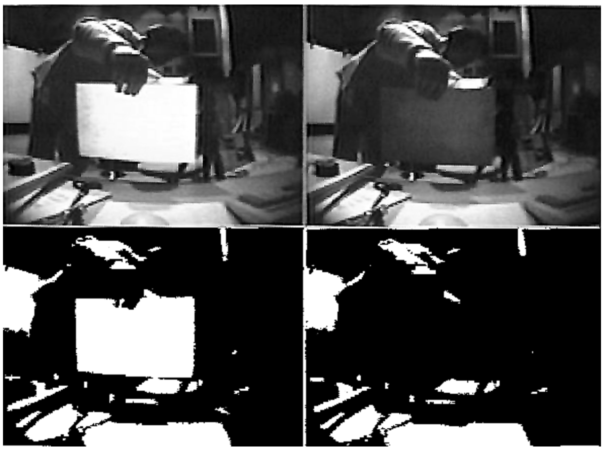

Fig. 7. Differential Image Capture
(Top) Original, (Bottom) Binary Image
Infrared Light is (Left) ON (Right) OFF

The following is a brief description of the image processing. At first, the edge detection was performed from the captured image and the longest edge was regarded as the outline of the screen. After compensating for the distortion of the camera, 12 lines at every 15 degrees were circumscribed to this edge. The shape of screen was approximated as a convex polygon with 24 vertices. The number of vertices was reduced to the quadrangle, referring to the distance between the neighboring vertices and the angle of neighboring edges. Thus the first approximation of the quadrangle was achieved. Next, the image was divided into four regions by using the diagonal lines of this quadrangle. Using the minimum squared error method, four lines were fitted to edges in each region. Last, the screen's location relative to the user's head was calculated. This calculation is robust when a part of the screen is hidden by the user's hand, because this is based on the edge information, not the vertices' information.

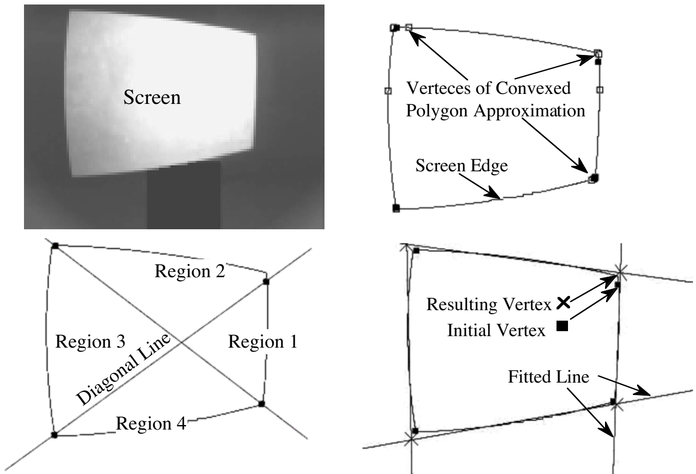

Fig. 8. Detection of Screen Edge and Screen Vertices. (top left), Original Image (top right) Approximation to Convex Polygon (bottom left), Shrunken Quadrangle and Division (bottom right) Line Fitting by Mean Squared Error Method

2.3 Fingertip Detection and Interaction

In addition, when the user places a finger on the screen, it is seen as the dark area in the bright screen. The second order moment of finger image is estimated and fingertip position is calculated. The user can interact with the displayed object with his fingertip.

For example, the user can draw graphics on the screen with his fingertip. The screen represents the drawing plane in three-dimensional spaces and the user can move it with the other hand. Then the spatial object can be drawn.

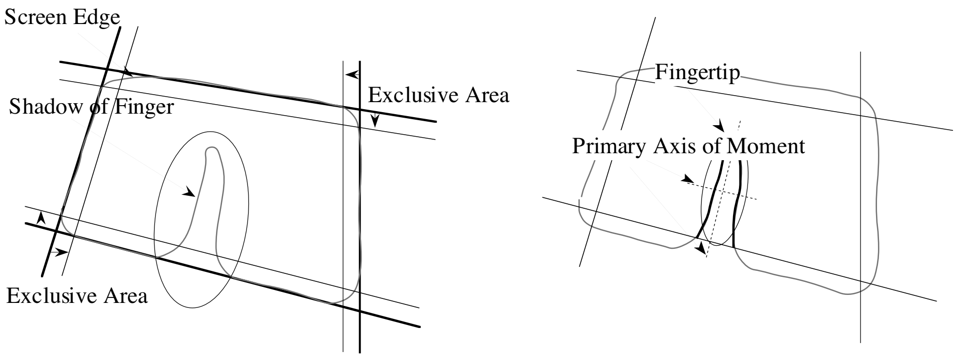

Fig. 9. Fingertip Detection

2.4 Multiple Screen

For the distributed display environment, the capability to deal with several screens within the view of the camera is important. For this purpose, both the geometric transaction and the screen identification are needed.

To identify the screen, the infrared filter material (RayShade, Dainippon Ink & Chemicals, Inc.) was attached to the screen and used as a sort of bar code. Approximately 80 percent of visible wavelength passes through this material and 50 percent of infrared rays are cut. The performance of this material was enough for identification by image processing. However, the infrared (IR) bar code was slightly visible to the user. The merit of using the IR tag is that the larger area of the screen can be used because it does not hide the visible screen area as the visible bar code does.

For the geometric transaction to achieve the relative location, the authors should say that our current implementation is rather simple and there is much room for improvement left in the future.

In our current system, the length of each screen's outline was achieved from the first stage of the image processing. The system regarded this length as the priority. The calculation described in 2.2 and 2.4 was performed only for the screen with the first priority. For the rest with lower priority, only the gravity center of the screen's outline was calculated. The gravity center, the outline length, and the registration information of the fixed screen (such as in 3.1) were used as the marker simply to check the result of relative location calculation and identification. For the "calendar" demo in 3.2, the screen with the second priority was used as the schedule display.

2.5 Issue of Speed and Solution

The common difficulty in applying the computer vision to the HCD system is the issue of speed, since the vision calculation is not a low-cost calculation.

To solve this problem, the authors have developed the image correction technology called Reflex HMD [13]. The angular velocity of the head is measured using the small gyroscope sensor and this data modifies the driving signal of the LCD panel inside the HMD. This approach can reduce the delay time caused by slow sensing cycles, graphics generation rate, and lag by calculation down to one video frame. This technology can easily be applied to PHMD.

3. Applications and Demos

In this section, several usages are described. Since the ambiance of the screen and the transition of the user's focus are difficult to show on paper, the content, usage, and interaction are mainly described here.

3.1. Pasted Window

The pasted window demo shows an example of ambient contents. A video camera was placed outside the laboratory building, and the captured scene was displayed on the retro-reflective screen on the wall. The user's relative location to the screen was calculated and used to give the motion parallax using the simple image-based rendering. Fig. 10 shows the appearance of this demonstration. As compared with the configuration using a CRT, LCD, and the magnetic sensor, the retro-reflective screen costs less, is easy to set up, and allows the user to move freely without cable connection. In addition, the PHMD enables adequate occlusion. When the user's hand is in front of the screen, it hides the scene outside the window. This feature gives a natural feeling to the user.

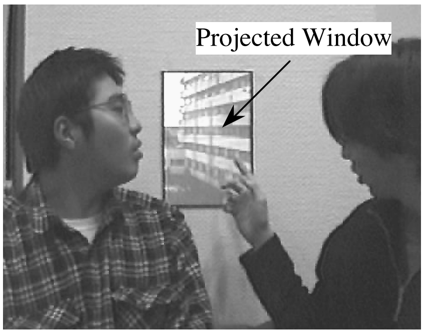

Fig. 10. "Pasted Window" - Projected Window on Wall Showing Scene Outside

3.2 Information Attached to Object

Fig. 11 shows the “Digital Price Tag” application. A small tag made of reflector is attached to the product in the supermarket, and the current price is projected on it. The location of the tag field and the ID of the product are achieved by the infrared camera. Fig. 12 shows the “Calendar” application featuring the small interaction. The calendar itself is the reflector without any print. The date is displayed on it. The user can draw his plan by using the fingertip operation on the calendar.

Fig. 11. Digital Price Tag Attached To Product

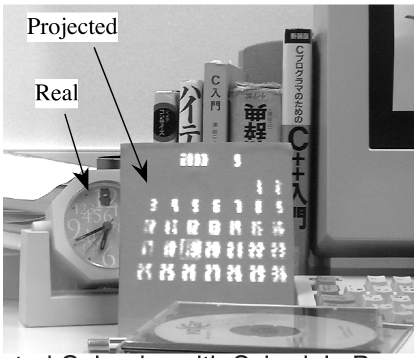

Fig. 12. Projected Calendar with Schedule Board Functionality

3.3 Display on the Body

Fig. 13 shows the “Internal State” application. A reflector is attached to the back of the user’s hand. According to the heartbeat and blood pressure, the graphics of the blood vessel are animated.

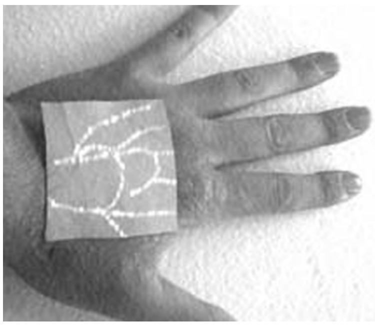

Fig. 13. “Internal State” Demo: Visualized Blood Vessels

This type of screen can be pasted anywhere on the body. Especially the palm and the back of the hands are good places for the display. It is true “palm computing”.

3.4. Space Slicer Screen

Fig. 14 is the demonstration application to show the active use of the screen location measurement as the second person interface. The sliced image of human brain using the MIR (magnetic resonance imaging) data is displayed on the screen. As the user holds the real screen and moves it, the slicing plane in the virtual world reflects the location of the real screen. Thus the user can see various slices of the brain. Also the user can draw the graphical memorandum on the sliced image with his fingertip. The combination of the PHMD, the reflector screen, and the infrared camera can be applied also as the second person interface in the three-dimensional space.

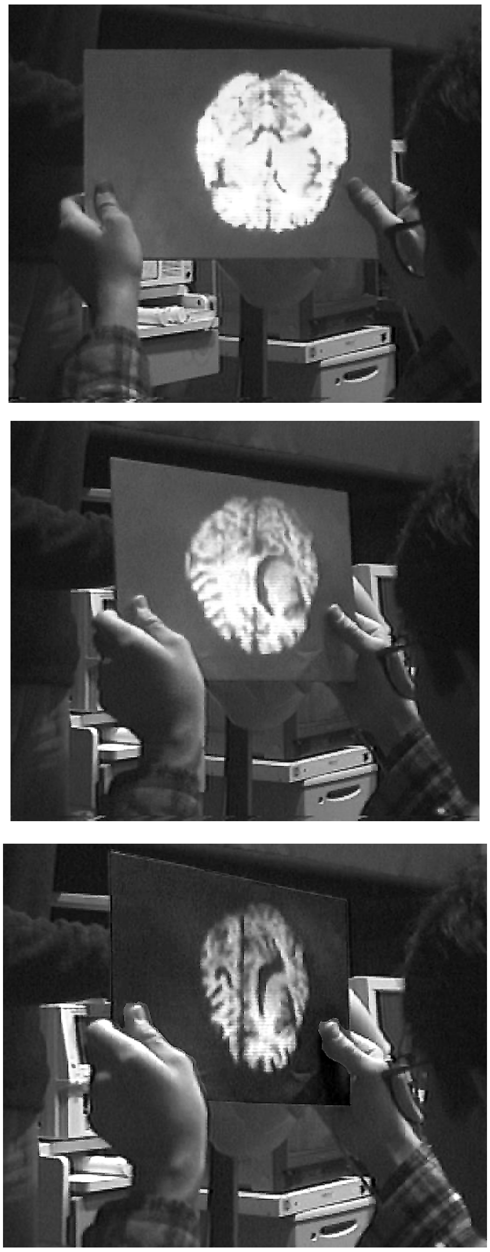

Fig. 14. Application: Interactively Slicing MRI Brain Image with Handheld Screen

4. Summary and Future Work

Aiming to attach many interactive displays to our daily lives, we have proposed a novel configuration of wearable display with interface capability. A small, lightweight, head mounted projector was constructed and used with a retro-reflective cloth screen. An infrared camera attached to the projector was used to measure the user's head location for the rendering and his fingertip's location for the interaction. The main idea was to multiplex the role of screen using visible and infrared wavelength as the marker for the computer vision and display for the user.

Several applications were developed to show examples of usage. The proposed configuration had enough capability to support the premise that had been claimed. Since this configuration is autonomous in terms of sensing, it can be used in the larger space of our daily lives, not limited to the space of a laboratory.

The authors should say that the current implementation in this paper showed only the feasibility of this configuration, and that there is much room for improvement. The major issues are the view angle of the PHMD and the image processing to deal with several screens at the same time. For the PHMD, there are potentially many other optical structures and useful devices left to be investigated. For the vision calculation, there has already been the example of dealing with several markers to locate the user's head, that could be applied to our configuration.

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