A Compound Virtual Environment Using the Projective Head Mounted Display

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ABSTRACT: The design and construction of virtual worlds often requires the user to use various tools in different environments to create several types of elements which have geometrical properties and behavioral characteristics. Due to the inconveniences associated with this task, a compound environment for the task of constructing virtual worlds was proposed. This environment contains both the popular workstation as well as a surrounding virtual world. To realize this compound environment, a Projective Head Mounted Display (PHMD) prototype was developed, which effectively minimized the difficulty of going and coming between workstation and virtual environments. The PHMD was also able to address the problem that is common to traditional HMDs which involve false images. In this paper, the concept and development behind the PHMD and the compound environment are discussed.

KEYWORD: Virtual Reality, Augmented Reality, Head Mounted Display, Compound Environment, Object Modeling.

1. Introduction

1.1 Visual World Construction

A major difficulty associated with constructing a virtual world exists because of the need to use various tools in different environments. A virtual world contains many types of elements. For example, the object's geometry and behavior, the interaction between the hand and the object, the interface to control the virtual environment, the movement of view point (walk through), and the other functions. The programmer must design, realize, test, and revise these elements. According to the type of element and the phase of the task, the programmer utilizes several tools and environments. For example, the CAD on the window system is used for the geometry design, the text editor on a terminal for the programming of object's behavior, the virtual environment itself and text editor for the checking, debugging, tuning the interaction, etc.

A pragmatic problem is the difficulty of moving from one tool in an environment to another tool in another environment. When the programmer moves from the workstation environment with keyboard, mouse and display to the virtual environment using an HMD, he needs to put on the HMD, sensors, glove type input device, etc., and adjust or calibrate them and vice versa.

In short, to construct the virtual environment, the user needs to come and go frequently between the different environments mentioned above. This inconvenience represents a significant barrier because of the need to come and go between the environments (see Figure 1).

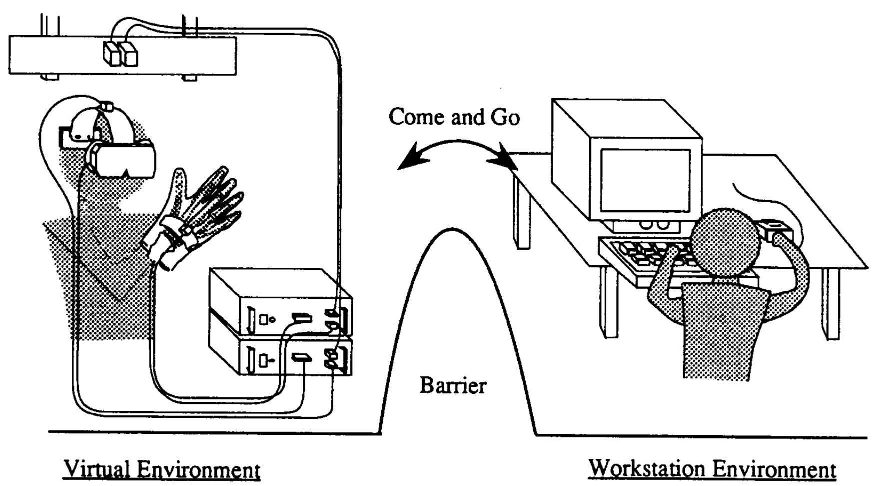


Figure 1. Virtual World Construction Task Requires Coming and Going Between Two Environments

1.2 Ergonomics and Art

One primary reason why this problem is important and must be addressed is that the task of constructing virtual worlds naturally requires much trial and error by nature. This seems to be derived from the fact that the virtual environment contains not only the logical aspect, but also the aspects pertaining art and the ergonomics. Namely, the programmer must not only test and debug the software to achieve the function as designed, but also needs to confirm the appearance of the virtual object, the feel of the interaction between the hand and the object, and their revision in order to improve the reality and/or presence. The latter activities could be considered as a type of ergonomics. However, it can be said that these activities actually lie on the boundary between the field of engineering and art.

For example, take the case of a controlling device such as the joy stick. In the case of a real joystick, the designer must consider the material of grip for easy use without slip. He must also consider the shape and the size in relation to the user's hand in the real world. The shape, material, range of movement, effects on the feel of use. In the case of the virtual joy stick, in addition to such factors, the resolution of the HMD, the accuracy and the noise level of motion tracking sensors, and the other features of virtual environment should be taken in consideration. Such features cannot be checked without the virtual environment itself because it is difficult to predict the system's feel and use during the engineering and programming process. The work which follows could be considered as a type of art work because of the many trial and errors activities involved.

1.3 Features of the Environment

In this paper, the term "Workstation Environment" or "WE" will refer to the popular GUI based workstation. This system is comprised of a computer, fine CRT monitor, input devices such as keyboard and mouse, window system, graphical user interface techniques, and custom or manner of interaction. Also, the term "Virtual Environment" or "VE" will refer to the surrounding environment generated by a typical VR system equipped with HMD, motion tracking sensors, etc.

One merit of the WE is that the WE has plenty of useful properties. For example, the WE has many tools which have been developed. Also, there have been many interfacing techniques which have been refined for the benefit of the user.

Another merit is that we can use convenient input devices. This is not only restricted to the general mouse and keyboard because the WE can be equipped with force and/or tactile feedback devices. Also the text can be easily manageable owing to the high resolution fixed display and keyboard.

One merit of the VE would be the freedom of vision of the user. The user can look back or look around naturally, and investigate an object from various viewpoints.

Another merit of the VE would be that it offers a sense of real realism and perspective to the user. Owing to this feature, the user can, for example, examine if the arrangement of a set of virtual tools is convenient or not.

Due to their different features, the WE is good for detailed design task based on text and modeling tasks using the mouse and high resolution fixed display. Contrastingly, the VE is good for confirming the appearance and arrangement of objects, and for confirming the feel and use of the system via the user's sense of body.

1.4 Taking WE in VE

There are several ways to reduce the barrier between the two environments as shown in Figure 1.

The most ideal way would be to build all the tools in virtual environment. However, it is not reasonable because it means many properties of the WE are thrown away. There are many resources in the environment such as useful tools, software resources, interfacing techniques/customs, the user's mastery for such interfaces/customs, and familiar input devices such as the keyboard, mouse, locator, etc. Therefore, it is better to think of a method which can inherit such properties, to make use of them.

The simplest way would be to develop a very sophisticated HMD. If the HMD is easy to put on and off, easy to adjust, and stable enough on the user's head, there would be no difficulty for the user to come and go between the two environments. However, there appear to be several difficulties which will be noted in the next section.

Another method would be to take the work station environment as it is and put it into the virtual environment using a see-through HMD. This approach is a natural step if we observe the evolution of the window system from the character terminal as shown in Figure 2. In the workstation environment, the traditional character-based tools and the tools basing on GUI (modeler, renderer, etc.) are integrated. It is inconvenient to switch plural tools, however, they are in the same environment. Therefore, the user does not need to come and go between the different environments.

If the virtual environment could take in the workstation environment, the height of the barrier would be decreased and the resources in the workstation environment could continue to be utilized. This approach is reasonable because the virtual environment could then inherit almost the all elements in the window system as they are.

In this way, the user puts on a see through HMD all the time during the development task. When he uses the tool on the window environment, the image is seen only on the monitor of the workstation. He can use the text editor to modify the source code, CAD for the geometry modeling, and he can set the rendering attribute of the object using GUI, etc. This environment is proper for the design task that requires detailed description or indication.

For the confirmation of the appearance, position of objects, etc., the virtual environment would be advantageous. For example, the VE woruld be good for checking for ease of manipulation with the virtual controller. Two objects can be placed so that they can be compared at a glance. The arrangement of visualized data would easily checked to be suitable for the human perception, etc.

For this purpose, this study discusses the nature of the problem, proposes and realizes a head mounted display using a compact LCD projector, and constructs the virtual environment that takes in the workstation environment. The hurdle is the see through HMD and the metaphor to take the window system in the virtual environment. The former will be discussed in the next section, and the latter in section 3.

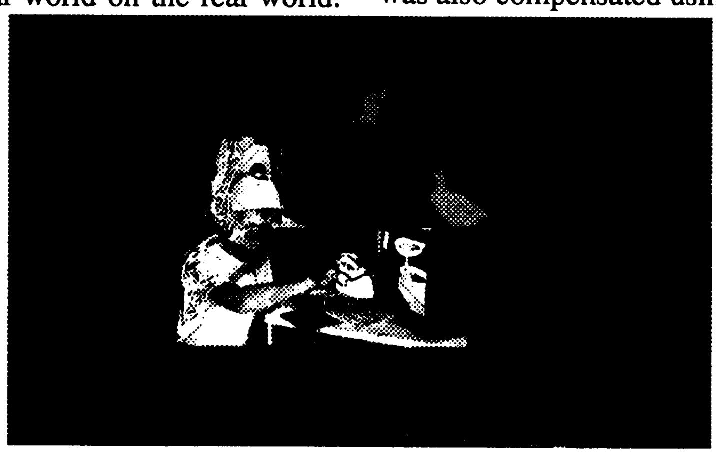
2. HMD

2.1 The First Prototype (STHMD)

The author has previously developed a see-through type HMD called STHMD in 1990 [Hirose & Kijima, 1990-a] [Hirose & Kijima, 1990-b]. In this subsection, the STHMD is described briefly, and the nature of the difficulty associated with long and continuous use is discussed.

Figure 3 shows the optical structure and the appearance of the STHMD. This HMD optically superimposed the virtual world on the real world. The image displayed on the small CRT was reflected on the beam splitter (half mirror) and was seen by the user's eye. The convex Fresnel lens between the CRT and half mirror magnified the image and the false image is seen further from the user's eye. The view finder for the portable video cam recorder was chosen as the display because the LCD display was then heavier and less bright (The see through HMD requires brighter display than the normal HMD). The position of each unit could be adjusted to the user's IPD.

This STHMD was used for several demonstrations, such as superimposing the internal structure of a mechanism on the actual machine, superimposing the result of a modal analysis on a real beam interactively according to where the user impacted the beam, and in a task which involved connecting a virtual bolt with real nut. An algorithm was developed to compensate for the distortion of the polhemus sensor data [HKSI90a], and the time lag was also compensated using a sort of Kerman's's



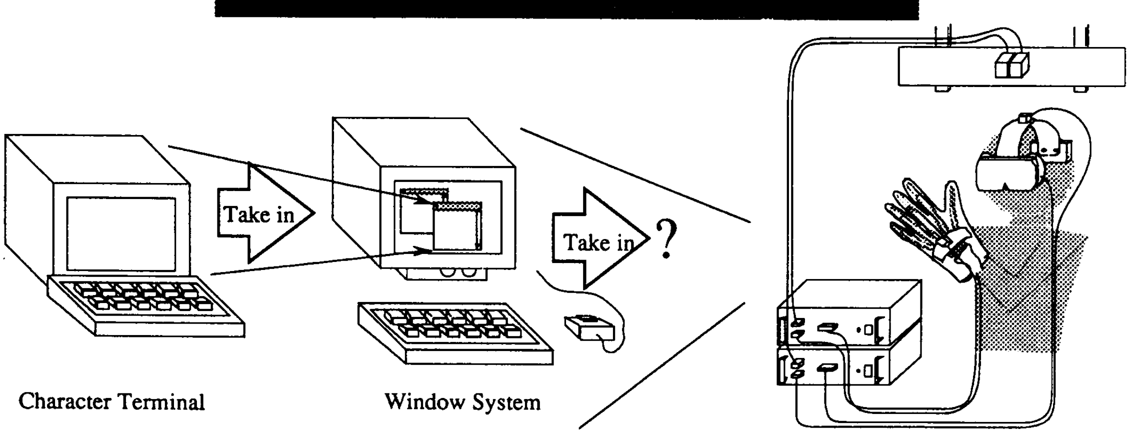


Figure 2. Compound Environment: Virtual Environment Takes Workstation Environment into it

filter in order to match the position of the virtual object with that of the real object [HKSI90a].

This STHMD was good for such demonstrations of augmented reality [Milgram, Drascic, et. al, 1995]. However, the defects for long time use also appeared through the usage, design and improvement. In the next section, the authors describe the problem.

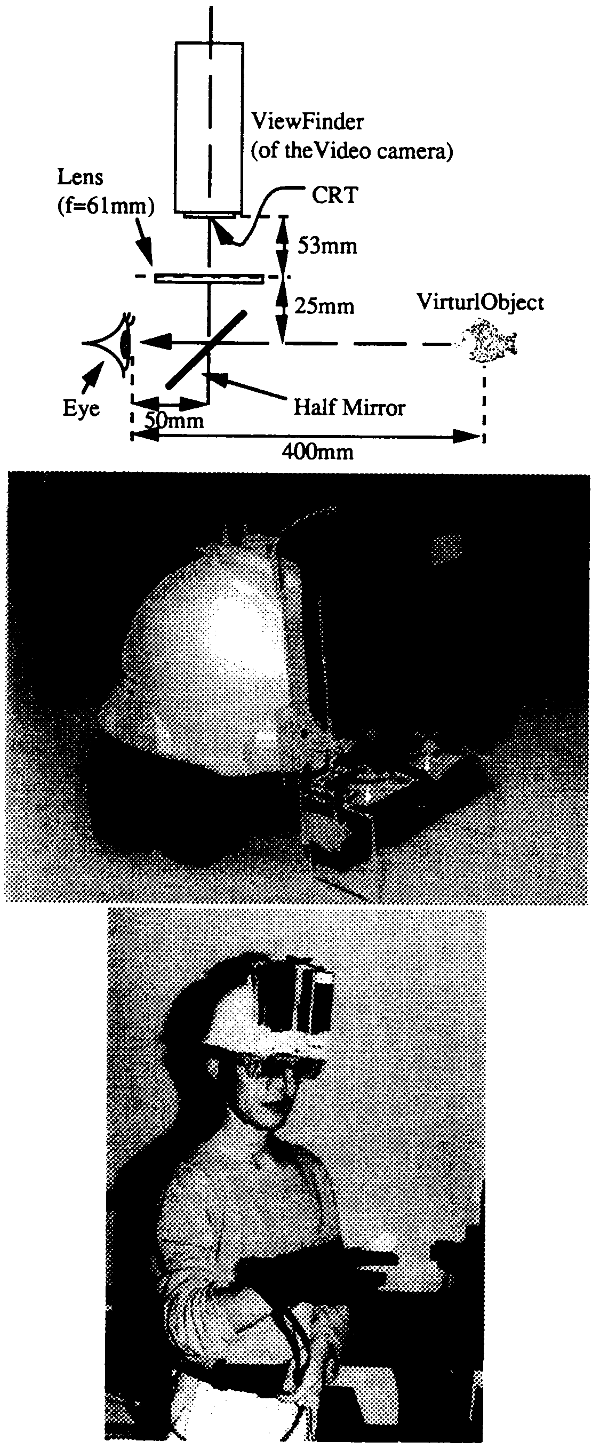


Figure 3. Optical Structure, Appearance of STHMD

2.2 *Problem Areas*

Such a type of see-through HMD has some fundamental problems by nature. In this subsection the problems simply concerning the HMD hardware are discussed.

2.2.1 Optical System

One problem area is the design of the optical system. It is a difficult task to effectively display the correct false image to the eye. Generally, the HMD displays the false image of the LCDs or the small CRTs using optical systems. The false image should be at the correct position, with correct size and orientation [Robinett & Rolland, 1992].

There are several tradeoffs. One is the tradeoff within the aberrations. The lens have five sorts of aberrations including the distortion and distribution of the focus. They are combined in the tradeoff relation. To compensate all of them within a degree, we need to combine several lenses [Born &Wolf, 1965]. As for the distortion, it should be noted that a wider field of view is difficult to achieve by nature because the distortion is in proportion to the cube of the field of view. Roughly speaking, the distortion is not negligible when the field of view is wider then 50 degree [Nussbaum, 1968].

Another point is the tradeoff between the diameter, i.e., the weight of the lens and the robustness of the displayed image when the position of the optical system becomes different from the designed place. If the diameter of the lens becomes smaller, the output pupil becomes smaller. The user can not see the false image when the relation between the optical system and eye differs a little from the designed one. The Gaussian region (Paraxial region) also becomes smaller. This decreases the quality of the false image, and the distortion and the aberration increases. On the contrary, if the diameter becomes larger, the optical system becomes heavier.

One final point is the trade off between the size of the LCD and its weight. If the LCD becomes smaller, the HMD becomes lighter. However, the magnification of the optical system also increases and the quality of the image decreases even if the optical system is placed correctly as designed. Also, the robustness against the displacement of the optical system from the designed position will be decreased.

In summary, if the weight of the HMD increases, it becomes more difficult to place it firmly at the designed position when the user's head moves. On the contrary, if the weight of the HMD decreases, it becomes difficult to design a robust optical system.

2.2.2 Binocular System

A binocular system has problems especially in a binocular HMD.

For one thing, the distortion causes incorrect parallax. The distortion for each eye differs especially when the optical system is designed to have a wider exit pupil such as in the case of VPL Eyephone. Therefore, the horizontal line cannot be fused (Figure 4). When the HMD moves from the designed position, the distortion increases and the disarrangement of two images also increases.

Another point is the problem concerning the installation of the HMD on the head. If the HMD rotates around the normal vector of the user's face, it causes not only the IPD (Inter Pupil Distance) mismatch, but also the disarrangement of horizontal line seen from each eye. This is out of the adjustment capability of the human eye (Figure 5).

For the purpose of this study, we did not need such ab accurate image as compared to a case of augmented reality, where the fusion of the real object and the virtual object is necessary. However, eye fatigue should be minimized for long-time use. Therefore, the HMD should not cause the problems mentioned above even when the HMD moves from the designed position due to prolonged usage.

2.3 Projective Head Mounted Display (PHMD)

In this section, the author proposes the concept of the Projective Head Mounted display (PHMD).

2.3.1 Aim

The aim of the PHMD is to provide the following features:

1. Robustness:

The PHMD is robust against the slipping from

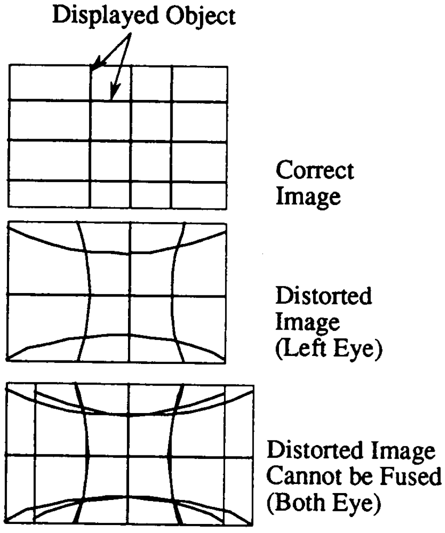


Figure 4. Binocular System with Distortion

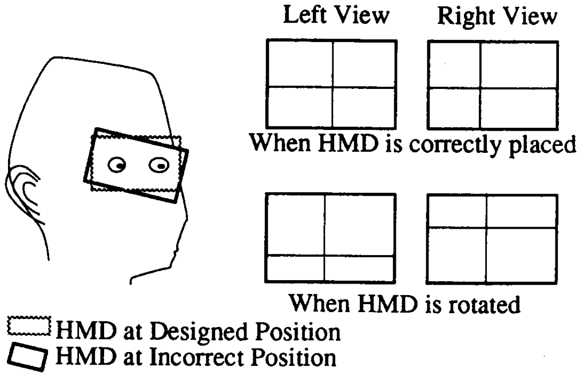


Figure 5. Binocular System with Rotation

the designed position. It can be used continuously for many hours during construction tasks for a virtual world. Therefore, user's fatigue should be minimized not only when the user wears it at the correct position, but also when it becomes off centered.

2. Eyeglasses:

The PHMD can be easily used with eyeglasses. This feature is important for the see-through HMD.

3. Little Mental Pressure:

The PHMD does not cause much mental pressure derived from the existence of an unfamiliar foreign body (optical device) placed in front of the user's eyes.

4. No Need for Special Screen:

The PHMD does not require a special screen while a general projection display usually does. In addition, projection at right angles is not necessary.

5. No Need for Large Projection Space:

The PHMD is a sort of HMD while it uses a projector to achieve the real image. As compared with the large projection display that need a large projection space, the PHMD does not, and can be easily installed.

2.3.2 The Principle of PHMD

The principle behind the PHMD is the agreement of the projection volume with the viewing volume. Figure 6 explains this principle.

The center of the projection corresponds to the view point, and the projection volume corresponds to the viewing volume. Namely, the projection transformation and the perspective transformation are the same. Therefore, if the projected image on the screen is distorted, the image is seen without distortion by the user's eye that is near the projection center (See Figure 6).

For example, a square is projected as a trapezoid when the optical axis does not cross the flat screen at right angles (Figure 7). This trapezoid is seen as a square from the projection center. Therefore, the screen does not need to be flat nor does it need to be at right angles to the optical axis of projection.

Figure 8 shows the appearance, optical structure and specification of the prototype PHMD. The PHMD is composed of two half mirrors (projection mirror and eye mirror), one mirror (vice mirror), a small LCD projector and a helmet. The image is projected from the LCD projector, bent by the vice mirror along with the shape of the user's head, reflected onto the projection mirror, and onto the ceiling. The projected image on ceiling then goes through the projection mirror, and is reflected onto the eye mirror and reaches the user's eye.

The distance from the LCD projector to the center of the projection mirror via vice mirror is designed to be equal to the distance from the center of user's eyes to the projection mirror via the eye

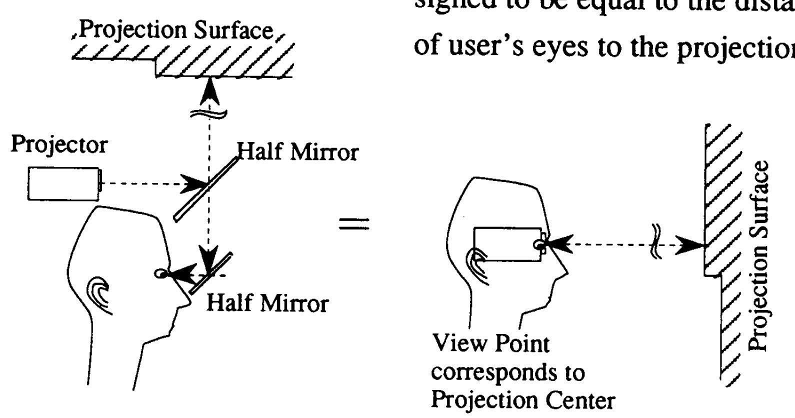


Figure 6. Concept of the PHMD

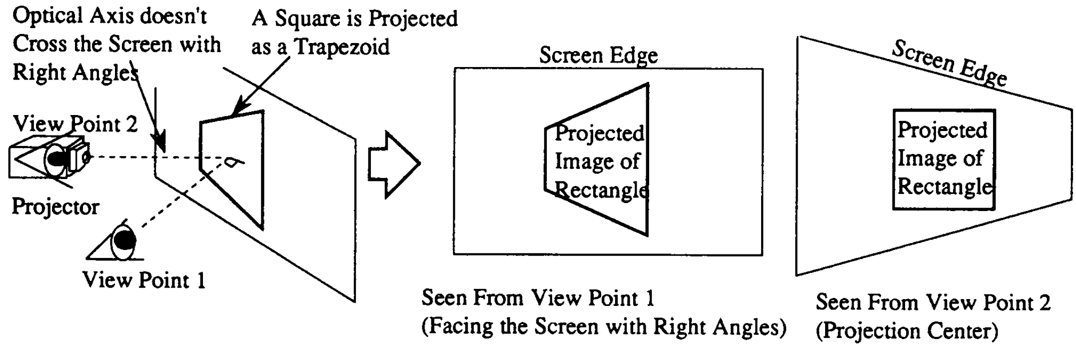
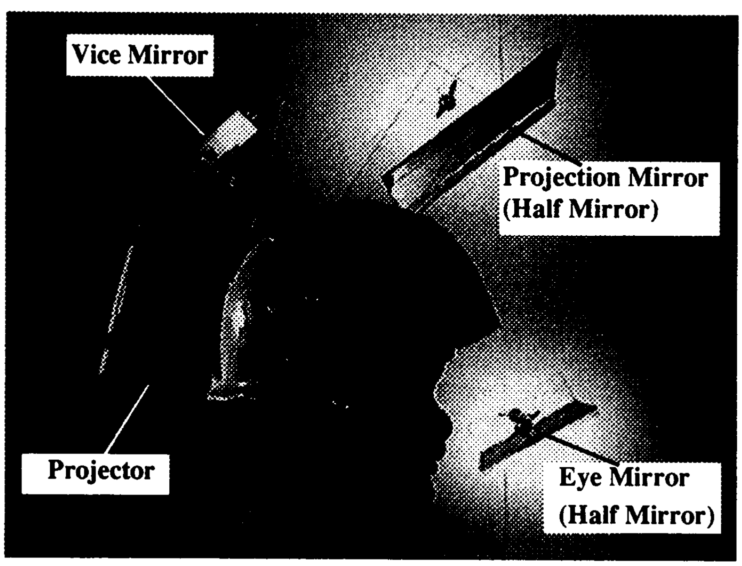


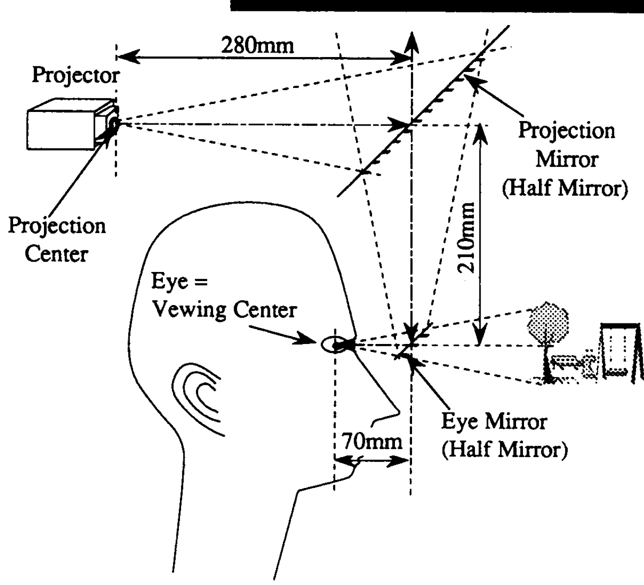
Figure 7. Viewing Volume and Projection Volume

lens. Strictly speaking, the projection center does not coincide with the view point. However, it is negligible because the distance from one eye to the other is relatively small compared to the projection distance (distance from the projector to the ceiling).

2.3.3 Merits of PHMD

The PHMD has several merits. Firstly, the PHMD uses the real image as opposed to a normal HMD which use the false image. This means there is no disarrangement between the vergence and accommodation. This contributes to the decrease of





Weight	1300 g	
View Angle	Holizontal	~ 30 deg
	Vertical	~ 22 deg
Projection Distance	~ 2.4 m	
Size of Image	60 inch (at 2.4m)	
Pixel	100,000	
Light Source	30 W halogen balb	
Projection Lens	f=28mm F2.2	
Projector (JVC PD-V7)	Size	71x70x159mm
	Weight	390g

Figure 8. Appearance, Optical Structure, and Specification of the PHMD

potential eye fatigue.

Furthermore, the PHMD is robust against incorrect placement on the user's head. The PHMD has a very large exit pupil and does not produce the distortion derived when the position of the eye becomes off-center from the optical axis. Consequently, the problem mentioned in section 2.2 does not occur.

Moreover, the PHMD does not require a large projection space because the ceiling is used as the screen. A projection display needs not only a special screen, but also a large vacant space to secure the optical path (projection volume). To achieve the large field of view, the size of the screen and the projection volume should be large. Due to this feature, the projection display is difficult to install.

The PHMD does not require a large vacant space for its optical path. If the optical path is not bent by the mirrors, the optical path from the PHMD to the wall is sometimes interfered by the obstacles such as other people, equipment for the experiment, bookshelves, tapestry, etc. By bending the are rarely obstacles which lie between the head and the ceiling.

In summary, the PHMD has both of the merits of a large projection display (robustness of image) and that of a traditional HMD (the compact installation space, the freedom of view point, the dynamically wide field of view).

3. Integrated Environment

The prototype environment using the PHMD was built for the virtual world construction tasks.

Figure 9 shows the set up of this prototype. The position and the orientation of the user's head were measured by Polhemus Fastrak. The mouse with another polhemus sensor was used either in the workstation environment (2D mouse) or the virtual environment (3D mouse).

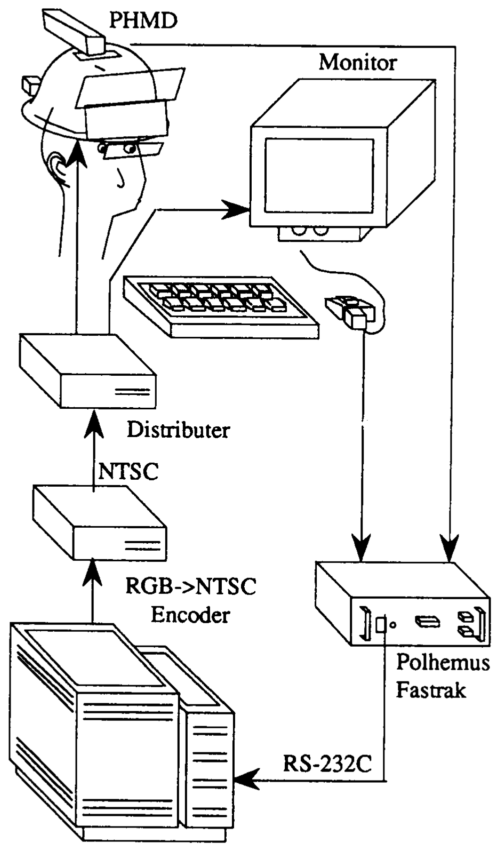


Figure 9. Setup of Prototype Sys‿m for Compound Environment

The workstation environment was use‿ as a "detailed/fine workbench" as opposed to the ‿irtual environment which has free but coarse surroundings.

In the prototype environment, a simple CAD tool and a virtual environment browser were realized. The CAD tool existed in the workstation environment for the geometry modeling and for assignment of the rendering attributes. The user operates the CAD tool with GUI style interface with keyboard and mouse. When the user finished forming an object, he could then grasp the object on the monitor, draw it from inside of the monitor, and place it into the external virtual environment. On the other hand, when the user was not pleased with an object in the virtual environment, he could grasp and push it back into the monitor for further change or refinement. Figure 10 shows this sequence.

The position and orientation of the head are used for the switching between these environments.

When the user looks at the monitor, the CAD is displayed. Otherwise, the virtual environment is displayed via the PHMD.

As mentioned , this approach is similar to that of the window system, which took in the character terminal as a window. The workstation environment is viewed as a special 'window' in the surrounding virtual environment. The operation of drawing the object from and pushing it into the monitor corresponds to the operation of cut and paste.

As part of this study, the author also introduced the walk through function with the metaphor of driving a vehicle. The software was extended to have the walk-through mode in addition to the CAD mode. These modes are switched via keyboard, and the walk through function is also operated via keyboard.

The following is an illustration of an example task sequence:

In the walk-through mode, the user looks around in the virtual world using PHMD to find the target object. Then he operates the keyboard to viatually move the vehicle and the workstation environment along with himself. During the walk through, the user can see the virtual environment on the monitor, and he can also look around in the virtual environment via the PHMD. When the user comes close enough to the target object, he can then begin 'draw and push in' operations. If the object is just outside his reach, the user can 'get off' the virtual vehicle. (i.e., he stands up from the chair in front of the monitor in order to approach the object).

In this way, the barrier between the two environments is decreased and the user can easily come and go between the environments.

4. Conclusion

In order to create a compound environment which contains both a workstation and virtual environment, the Projective Head Mounted Display (PHMD) was designed and developed. As a result, the barrier which exists for the user between these two environments was minimized because of the PHMD and the compound environment which it supports. In the same way that the workstation window system evolved from the character based terminal, the evolution of compound environments with both workstation and virtual world capabilities will become necessary for the future progress and construction of virtual worlds.

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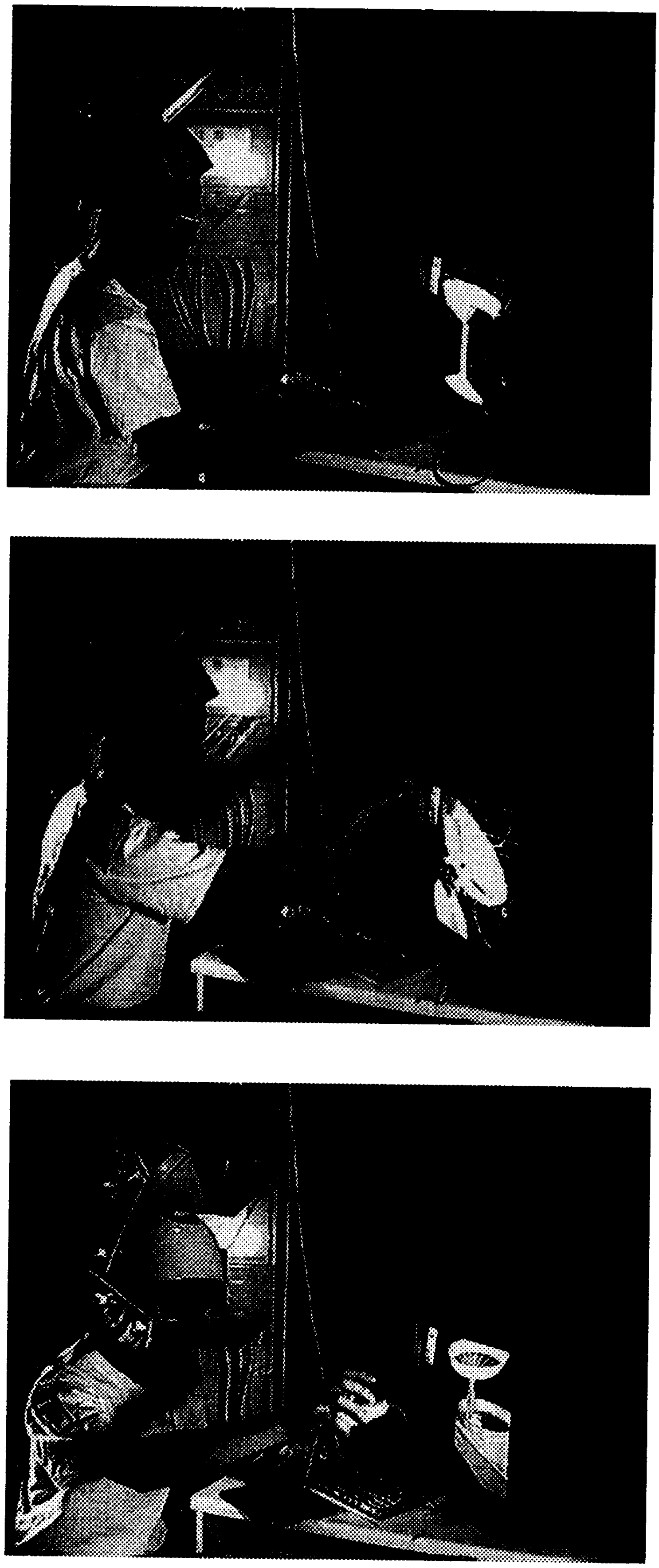

(a) The user is working in the workstation environment. He uses the CAD with keyboard, mouse, and general GUI.

(b) The user pushes the object into the monitor (workstation environment)

Pushing In

(c) The user grabs the object in the virtual environment with 3D mouse.

(a) The user is working in the workstation environment. He uses the CAD with keyboard, mouse, and general GUI.

(b) The user graspthe object in the workstation environment. (drawing the object from the monitor)

Drawing Back

(c) The user places the grasped object in the virtual environment.

Figure 10. Sequence of Task

(Coming and Going Between the Virtual Environment and Workstation Environment)