A HMD for Users with Any Interocular Distance

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ABSTRACT

A prototype HMD which can automatically adjust interocular distance in the range of 55 mm to 75 mm in accordance with those of users. The main component of the HMD is a linear motor which shifts the modularized left and right eye's projection and camera optics in accordance with the measured interocular distance of a user. The total adjusting time of the distance is less than 10 seconds. The weight of the HMD is slightly less than 500 g and it is worn by a head belt. The HMD is somewhat heavy and unbalanced due to the distribution of the weight along the nose side but the head belt holds tightly the HMD on its place and it works well.

1 INTRODUCTION

HMD (Head Mount Display) has more than 50 years development history [1,2]. In this time, two types of HMD has been developed. One is surrounding type and the other is goggle type: The surrounding type blocks completely the users from the outside world. So users can be completely absorbed to the images provided by the HMD. But for the case of the goggle type, users can see both the image from the HMD and the outside world at the same time. For this reason, the former is devoted for virtual reality (VR) and the latter for both argument reality and virtual reality (AR/VR). The 1st introduction of HMD was done by Hughes Aircraft Company as the viewing glasses of pilot's helmet to display necessary flight data while asking no viewing direction change of the pilot [1,2]. The HMD was only for an eye since the pilot's no viewing direction change requires that the data should be projected to an eye only. The other eye should be focused to outside world. This brought a tremendous vision unbalance for the pilots. The goggle type has been developed to reduce the vision unbalance. The see-through capability. I.e., the users can see the world outside of the glasses, i.e., real world with the virtual world that is provided by the displays in the HMD, is the main property. This see-through capability enables the users to see the both real and virtual world through their two eyes. This capability made the HMD to find wide applications in such areas of combat, police, firefighters for areal map and other imaging information, and civilian for various uses [3,4]. Now the HMD is used as the main AR/VR displays for the purposes of CAD (Computer Aided Design), medicine research, simulation, gaming, edutainment, various training such as military, sports and other techniques, and medical diagnostics [5]. The increasing areas of applications made the HMD for individual instead of being used for few specific users. This individualization brought the necessity of having a HMD that can be adapted to users of having various interocular (or interpupillary) distances. The interocular distance represents the distance between pupils of left and right eyes of a user. The interocular distance is figured as in the range of 51mm to 77 mm [6]. Though this range is the widest among known interocular distance ranges but it only represents a group of people. Hence there can be another group of people who has wider than the range. In spite of the fact, the current HMDs are mostly designed to fit users with the interocular distances of 65 mm which corresponds to the near center value of the range. This results that the difference between the actual and the designed interocular distance range is more than ±10 mm. This values are much higher than the size of the light point that is getting into the pupil of user's each eye. Hence it is expected that this design can induce the problems of fusing the left and right eye images or seeing full displayed images for users with interocular distance other than 65 mm. To ease/eliminate the problems, many recent surrounding type HMDs have a new function of adjusting the interocular distance based on measurement [7,8] and prior knowledge. The manual adjusting of the interocular distance can be easily done with use of a manual knob and/or a wheel [9,10,11] if users can remember their interocular distances or the interocular distances can be measured before adjusting, because the left and right image projection optics are modularized independently. Due to this adjustment, the left and light eye images which are overlapped completely to each other at the distance where the projected images are focused are now separated slightly to each other. To compensate this separation, the center of each eye image should be shifted in accordance with the adjustments. This shifting should keep the disparity between the images the same as in 65 mm case. Instead of the image center shifting, the micro-display position can also be shifted back and forth to minimize the deviation [9]. There is also a HMD using a motor and accompanying gear mechanism to adjust the distance by shifting projection lens relative to the micro-display [12]. The presence of the gear mechanism makes the HMD heavier than 500 g.

For the case of the goggle type, no HMD that can adjust the interocular distance mechanically is introduced yet, except the design concept [13]. The adjustment of the interocular distance in the goggle type can be harder than that in the surrounding type. Since each of the left and light eye optics, which consist of a curved mirror and a waveguide in most see-through HMDs has already been modularized. Each module can be separately but synchronously shifted by a proper shifting mechanism with another module but installing a camera within the module to take pupil image can be very hard.

In this paper, a prototype HMD which can automatically adjust its interocular distances in accordance with the interocular distances of users are introduced. And also, the working principle and the performances of the HMD is described.

2 The Prototype HMD

The prototype HMD basically consists of two optics modules for left and right eyes. Each module consisted of a micro-projector for image projection, a micro-camera and an infrared LED for user's interocular distance measurement, a half mirror to direct the projected image to the pupil and direct the pupil to the camera, and a linear motor to shift these components. It also needs the assistance of a PC and a monitor to check the proper wearing of the HMD to get a clear image of the eye and a controller to record image. The first 3 components are fixed to a light body and the body is mounted on the moving arm of the linear motor. They are shifting as a body. This design eliminated the necessity of rotating the half mirror in accordance with the module shifting to keep the projected image the same place. However, the shifting accompanies shifting of the center of the projected image, the image center should be moved to the opposite direction of the shifting with the same amount of the shifting [13]. The micro-camera and the micro-projector are in the same side but the camera is on the top of the projector. The distance from the camera to the pupil is about 78 mm: The pupil to the half mirror is distanced around 12 mm and the half mirror to the micro-camera/micro-projector is 66 mm. The panel size of the projector is 6.7 mm X 9 mm (11 mm in diagonal) with resolution of 1280 X 760. The shifting amount of the image center is defined by the image resolution and the focused image size. When the modules are shifted mm and the horizontal image size and pixel numbers in the same direction is mm and , the pixel amount to be shifted is given as . For example, when a user with the interocular distance of 55 mm wears the HMD, the left and right eye modules should be shifted 5 mm to the right and 5 mm to the left directions, respectively, by their corresponding linear motors. This means that each eye image is also shifted the same direction and amount as its corresponding module. By the relationship above, the number of pixels that should be shifted is calculated as . The projection optics are designed to display 500 mm (400mm X 300 mm) image size at focused image distance 500 mm from the pupil. The LED with the center wavelength of 850 nm is located at the side of the camera to illuminate the eye. This infrared source has a higher reflectivity from the iris compared with visible light. This higher reflectivity increases more the contrast between the pupil and the surrounding iris compared with the visible light. Consequently, the pupil image is clearly distinguished from the iris. The position and diameter of the pupil can be easily determined with use of a proper edge detection algorithm. The linear motor for each of left and right eye optics modules are fixed on a platform of the HMD with the same height. The distance between the center of the half mirror is set to 65 mm for the static case. The arm of each linear motor is shifted symmetrically and synchronously to that of the other linear motor. Hence since each arm moves 5 mm to the left and right directions, the distance between two optics modules can be adjusted from 55 mm to 75mm. Hence the total adjustable interocular distance range will be 55 mm to 75 mm. As the micro-camera, a raspberry camera with resolution of 3280 X 2464 [14] and each pixel size of 1.12μm is used. The viewing angle of the camera is 62° (Horizontal) X 48.8° (Vertical). The image from each camera is wirelessly transmitted to a computer and the interocular distance is computed and the distance information is wirelessly back transmitted to the linear motors to adjust the interocular distance. To measure the interocular distance, a raspberry camera is installed from 78 mm from the pupil. When the viewing angle 62° X 48.8° of the camera is considered, the camera can cover 94 mm X 71 mm on user's face and 80 mm X 60 mm on the half mirror position. However a half mirror with the size of 35 mm X 35mm and aligned to 45° is used, the pixels covered by the half mirror are 1017 (3280 X 35/(80 X 1.414)) (H) X 1437 (V). The numbers of pixels corresponding to the pupil sizes of 2 mm ~ 8 mm are 70 ~ 280. These pixel numbers are within the pixel numbers covered by the half mirror. The projected image size from the image projector should be 14 mm(H) X 7.2 mm (V) on the half mirror to focus image at the 500 mm distance from the eye. This size is small enough to be covered by the half mirror. The camera is on the top of the projector but located at near the end of the projector's objective. Hence it does not suffer its field of view blocking by the projectors. Fig. 1 shows the optical schematic of the HMD. It shows the image shifting. The centers of images are shifted the same distance and direction as those of the modules. Hence the image center should be moved to the opposite directions of modules' shifting directions.

The operating steps of the HMD is shown in Fig. 2.

When a user wears the HMD, his/her eye image appears on the monitor. The user can adjust wearing position of the HMD to get the clear images of his/her eyes by seeing the monitot image. When the clear images are attained, the user presses a bottom on the controller to order the raspberry camera to record the image. The recorded image is wirelessly sent to the PC and the interocular distance is calculated from the left and right eye images, then the distance information is wirelessly sent to the HMD to make the linear motor to shift its arm to adjust the interocular distance. In the PC, the center of the image to be projected is shifted in corresponding to the pixel numbers calculated from on the measured distance. Then the image from the projector will be projected.

3 Interocular distance measurement

In the HMD, the interocular distance is defined as the distance between the lens centers of the left and right eyes for the surrounding type and between the centers of the half mirror in the goggle type. To adjust the interocular distance of the HMD, the prior measurement of the distance is necessary. There are several known methods of estimating the distance: The 1st is manually measuring the distance with use of a ruler by seeing his/her face through the mirror. The 2nd is using mobile phones' cameras of users or cameras with the assistance from a special software. This method may not be different from the eye-tracking method used to track viewer's eye positions to find the viewer's viewing direction in 3-D displays [15]. The mobile phones/cameras are used to take a photograph of their faces at a known distance and find the interocular distance with the software. But they are not accurate methods of measuring the distance because the pupil is hardly identified from the iris of each eye, especially for Asians. For the Asian, the dark brown color of the Asians' iris makes difficult to discriminate the pupil that appears as a dark circle in near the center of the iris. The 3rd is using the reflected light pattern from each eye when a specially designed infrared light pattern illuminates the eye' pupil [16]. Since the reflected light pattern changes as the interocular distance changes. It is the most accurate method of all because the measurement accuracy is claimed as 0.2 mm but it is a very expensive method. It needs many infrared light sources for each eye. This method does not change the interocular distance of the HMD but only adjusting the center positions of the left and right images based on the measurement. However, the 1st two methods are for the manual adjusting. The manual adjusting is simple but it is inconvenient because the adjustment can be repeated for several times until it is properly adjusted. The manual adjustment should be accompanied by the left and right eye image centers adjustments. Otherwise, the adjustment can induce more depth distortions. The adjustment range of the manual methods are up to 51 mm to 72 mm.

When the image of eye is obtained, the pupil position and size can be calculated with an open CV. This software is basically based on edge detection algorithms such as Sovel or Canny assisted by a morphology transform to find the pupil position when the boundary between the pupil and iris is not clearly identified. However, when the boundary is clearly identified, Hough Transform can be used without the edge detection algorithm. It is expected that the accuracy of measuring the interocular distance cannot exceed more than 20 pixels. The pixel numbers are corresponding to the thickness of the lines from the edge detection algorithms. Since the 2 mm diameter pupil has 70 pixels, the accuracy can be around 0.6 mm. It will be less than 1 mm which is the typical unit of defining the interocular distance.

4 Performances of the HMD

The main function of the HMD is adjusting its interocular distance in corresponding to the user's interocular distance measurement. Hence the linear motor is an essential component of the HMD. Fig. 3 shows the linear motor movement with optical module on its arm. The motor can move 28mm/sec. This speed is fast enough for the adjustment, Total weight of the module with the linear motor is around 80 g. However, the linear motor takes slightly more than 60 % of the weight. Since the moving accuracy of the linear motor is less than 100㎛, the total accuracy of the adjusting is not exceeding 1 mm. The prototype HMD, and the eye image and measured interocular distance are shown in Fig. 4.

5 CONCLUSIONS

The HMD can adjust its interocular distance from 55 mm to 75 mm with the accuracy of less 1 mm. The linear motor shifts almost in real time for the distance range. The HMD including the head belt do not exceed more than 500 g. The processing time of adjusting is less than 10 sec. The weight is somewhat heavy for the HMD but the head belt can hold the HMD tightly. However, it should be reduced more.

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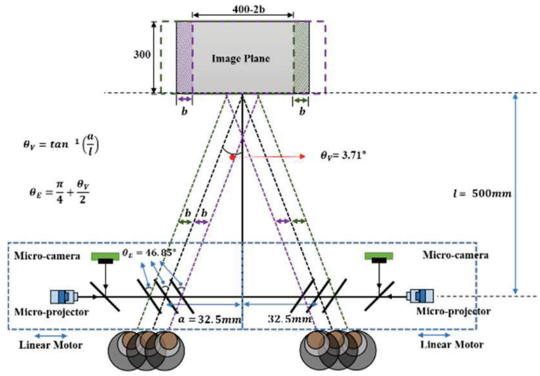

Fig. 1. The optical schematic of the HMD

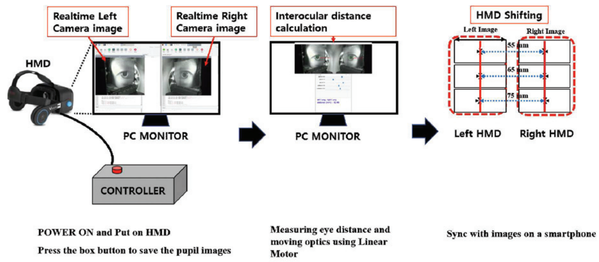

Fig. 2 The operating steps of the HMD

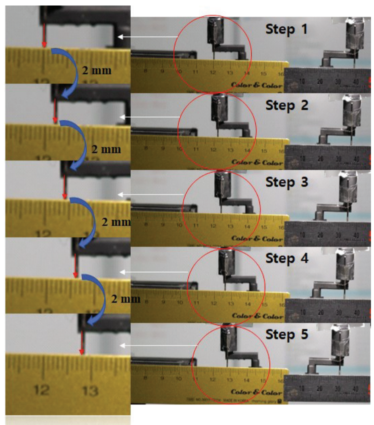

Fig. 3. The linear motor movement test (movement interval = 2mm)

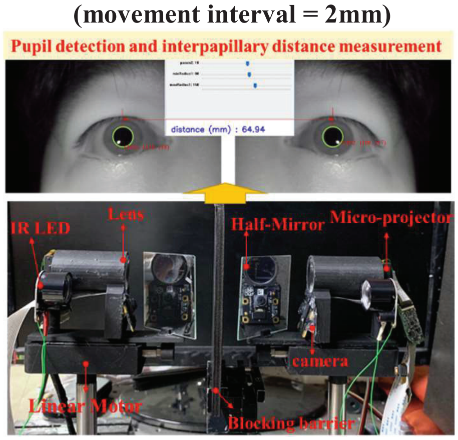

Fig. 4. The prototype HMD and the eye image with measured interocular distance