Wearable Scanning Laser Projector (WSLP) for Augmenting Shared Space

Taro Maeda, Hideyuki Ando
NTT Communication Science Laboratories, Morinosato Atsugi-City, 243-0198 Japan
{Maeda/hide}@avg.brl.ntt.co.jp

Abstract

We propose the Wearable Scanning Laser Projector as a novel head mounted display for Augmented Reality (AR). AR commonly uses an Optical See-Through Head Mounted Display (HMD). Because the images in previous HMD's had been projected onto a specific focal length, it was difficult to observe both the object and the corresponding images at the same time when they exist at different depths. In our device, the center of the mirrors scanning the laser beam is aligned conjugate to the center of the wearer's eye. As a result, the light spot of the beam is always observed in the same direction of the sight on surfaces of any depth.

Key words: Augmented Reality, Laser projection, Wearable Computing, Focus depth, Time Delay Compensation

1. Introduction

We propose a Wearable Scanning Laser Projector (WSLP) projected from the head by a laser scanner. This head-mounted projection system uses rapidly scanned lasers to display information directly onto any object, effectively using the surface of the object as a "projection screen". Using this system, the wearer's augmented vision can be shared by their colleagues, both nearby and in remote locations.

Augmented Reality (AR) is a well-known domain of technology that enhances visual information in the real world with computer generated images. The see-through type Head Mounted Display (HMD) is commonly used in the field of AR for overlapping virtual characters and figures with objects of a real space, and superimposing normally invisible information to improve precision in assembly work and so on [1].

Moreover, shared space of information is researched in AR [2]. However, as described in [2], most see-through HMD's have an outstanding problem known as correspondence, in which the focus of the images does not correspond with the focus of the eye, except for objects of a real environment with a constant focal length (Fig.2). Thus, images of the real environment blur when focusing on the virtual environment, and vice versa.

Another problem lies in maintaining a constant relative position between the real and virtual environments, because the displayed overlapping images must correctly follow the head movement [4]. HMD's with a low frame rate for either display or motion tracking cause misregistration and vibration of the virtual object neighborhood within the real space, because the positional correction of virtual information cannot follow the measured head movement Reflex HMD [5] considers the delay of the image update by the PC etc. to attempt to resolve this problem but even this method is difficult for correction at a rate higher than the frame rate of the HMD.

To resolve these two problems, we propose a Wearable Scanning Laser Projector (WSLP) projected from the head by a laser scanner. Because this device projects virtual information directly onto the overlay part of the real environment by using the laser, virtual information always corresponds to the focus position of a real environment. Moreover, the stability at a fixed position of the overlay part improves by using a higher scanning speed than the head movement speed.

In the following, we explain the mechanism of this device, and describe comparative experiments between the see-through HMD and the WSLP concerning the two problems; correspondence (section.3) and stability (section.4).

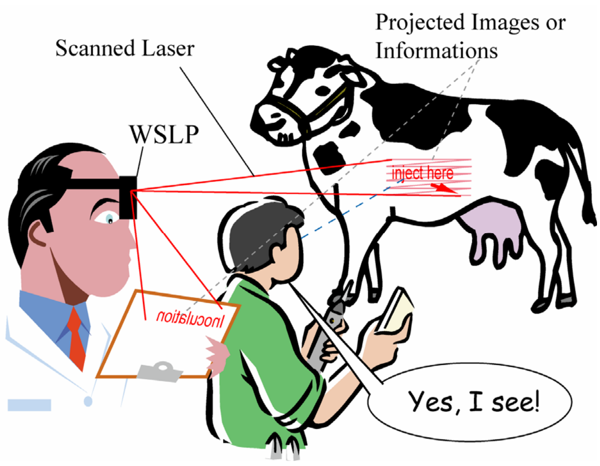

Fig.1: Wearable Scanning Laser Projector

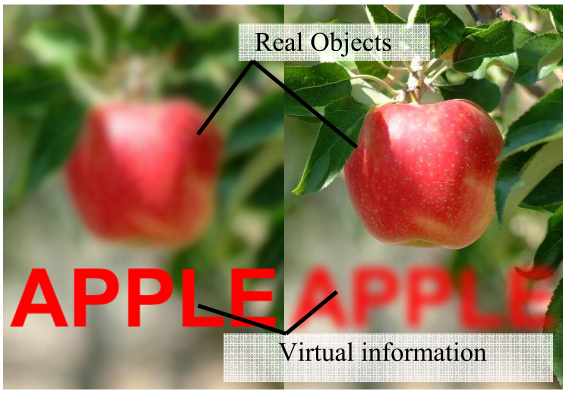

Fig.2: Disagreement of focus

2. Mechanism and Characteristic of WSLP

WSLP is composed of a galbanomirror (SCM1015, made by Chiba Seimitsu Ltd., with a response frequency of about 800[Hz]) and a red semiconductor laser diode (HL6501MG, made by Hitachi, Ltd., with a wavelength of 650 [nm], and output power of 35[mW]) orthogonal to the two axes (Fig. 3).

This device scans an object in the real space (each axis of x-y plane) with the laser output of a red semiconductor laser diode. Currently, characters are drawn by a raster scan, and figures are drawn by a vector scan. Characters and figures can be projected to an arbitrary position with respect to the horizontal (40[deg]) and vertical (30[deg]) axes. Fig.4 shows the hardware composition of the WSLP. The raster scan transmits information of an arbitrary part of a captured image on the PC, and displays the position to the BRAM of the FPGA by USB1.1. The FPGA controls the scanning of galbanomirror (length is 32[dots], side is 256[dots], and frame rate is 40[Hz].), and drives the laser based on the data in BRAM.

This device measures the head movement using a gyro sensor (MDP-A3U9 (analog output) made by NEC Tokin Ltd.). The angular speed of the gyro sensor output is converted into the position by integrating the microcomputer (PIC18F252 made by microchip Inc.). The controller (FPGA) fixes virtual information to the object regardless of the head movement according to the head angle measurement.

Moreover, the laser output and the line of vision are arranged on the same axis. Therefore, the size of the projection view image of the wearer doesn't depend on the distance of projection.

Our galbanomirar units are very lightweight, with a weight of only 15[g] per unit. Further, the total weight of the X-Y scanning projection unit is about 85[g]. Moreover, the device may be conveniently equipped because there is hardly any obstruction of the view of the wearer.

We explain the characteristic of WSLP as follows.

(1) The corresponding focus of the real and virtual environments

When virtual information is overlapped onto an object of the real environment with the WSLP, the object or the neighborhood is projected as a screen. Therefore, the position and the focus of virtual information and the object are always corresponding.

(2) Head response that doesn't depend on frame rate

The scanning of drawing and the movement of the drawing position can be achieved with the galbanomirror of the WSLP at the same time. Therefore, the drawn figures and characters can be moved independent of the drawing frame rate. Moreover, it is possible to respond sufficiently with respect to the head movement, because the maximum response frequency in the movement maximum angle (40[deg]) is about 500[Hz].

The next section describes a comparison experiment with the conventional HMD with regard to the two above points.

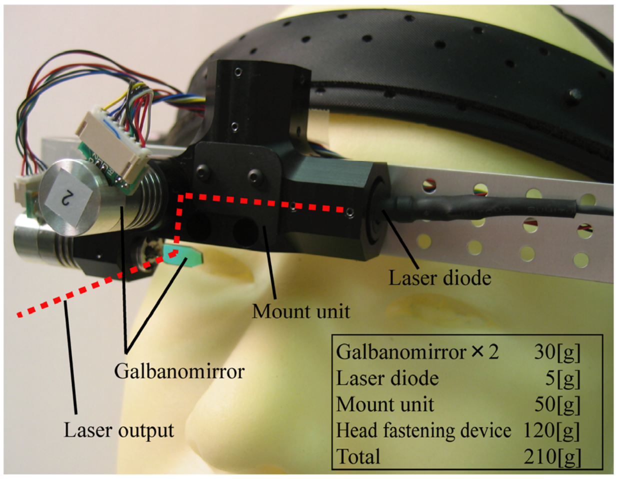

Fig.3: Wearable Scanning laser projector (WSLP)

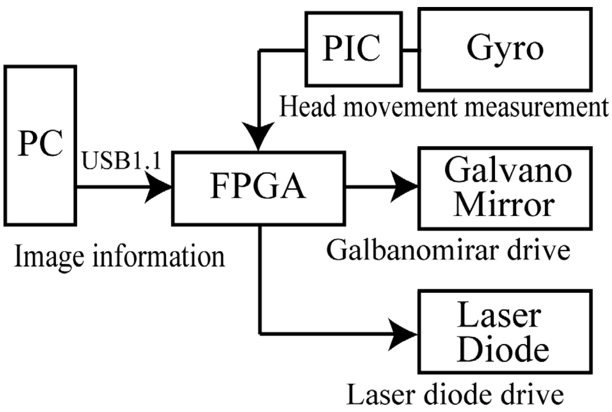

Fig.4: Hardware composition chart

3. Experiment 1: Focus Consistency

3.1 Outline of experiment

Fig.5 shows the apparatus of the experiment. We change the distance from the subject to the fixation point (+ sign in the object). For this experiment, a virtual Landolt ring is projected onto the object by wearing an HMD (MediaMask made by Olympus Ltd.) and a WSLP, and the equivalent eyesight is measured by this overlapped Landolt ring.

The subject was to answer either "open" or "shut", when the space of this Landolt ring was changed in this experiment. We measured the width of the space over eight trials when the subject's answer changed. We then converted the mean value of the answer into equivalent eyesight. This experiment has one fixation point (0.3, 0.6, 0.9, and 1.8[m]), and one subject (34-year-old male, eyesight 0.5 with the naked-eye).

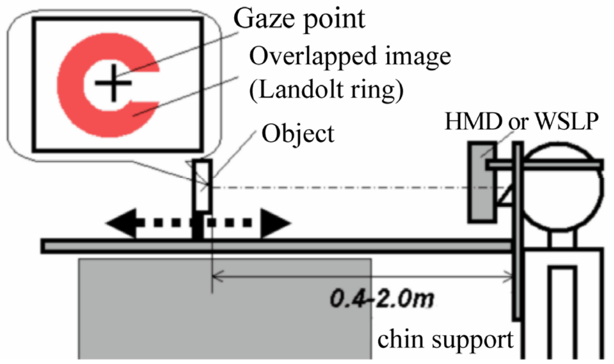

Fig. 5: Experiment 1: Focus consistency experiment

3.2 Experiment result and consideration

Fig.6 shows the experimental results. The eyesight value of the HMD reaches a peak at the aspect position 0.9[m] neighborhood. The eyesight value decreases when it is far or near from the peak. Therefore, we think that the focus of HMD is fixed to the peak value neighborhood. On the other hand, the eyesight value of WSLP improves as the distance to the fixation point increases. However, the eyesight value of WSLP decreases along with the movement near the gaze point. We believe the reason for this is that the beam sutra of the laser is larger than the space of the Landolt ring, and therefore the visibility deteriorates. This problem may be relieved by converging the beam spot size of the laser with the collimator lens. The best eyesight value by WSLP was the same as the usual eyesight measured for the subject. The eyesight value of the WSLP was higher than that of the HMD. The reason for this is not only the low resolution of the HMD, but it is also difficult to match all focal lengths of the fixation point, even if using a high resolution HMD.

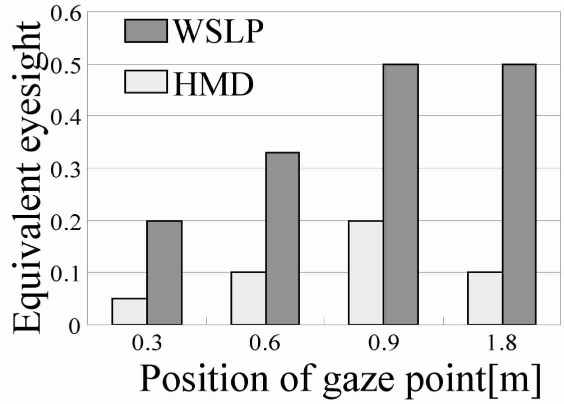

Fig. 6: Relation of equivalent eyesight to gaze point position

4. Experiment 2: Head Movement Response

4.1 Outline of experiment

In this experiment, the WSLP is fixed to an equal rotor-platform to the head movement, which is driven with a sinusoidal motion (Fig.7). We confirm geostationary overlapping of virtual information onto the object (graph paper) with the driven rotor-platform.

In this experiment, we evaluate the geostationary and stability of the head movement measurement value. Therefore, the control input to the WSLP was the rotation angle of the rotor-platform (encoder value of the rotation drive motor). At this time, the evaluated value of geostationary and stability is the measured values of the blur width of the virtual information at the rotation angular speed changes.

The amplitude of the rotation angle of the rotor-platform is 10 [deg]. The angular speed is 5-70 [deg/sec], because the maximum head movement of a human is about 60 [deg/sec]. The distance of the object from the WSLP is 2.8[m].

The blur width is visually read from the graph paper (object).

Moreover, we assume that the HMD renews the image according to the frame rate, and the theoretical value of the blur width is calculated from the delay of the frame rate.

We compare the blur width of the HMD with the blur width of the WSLP.

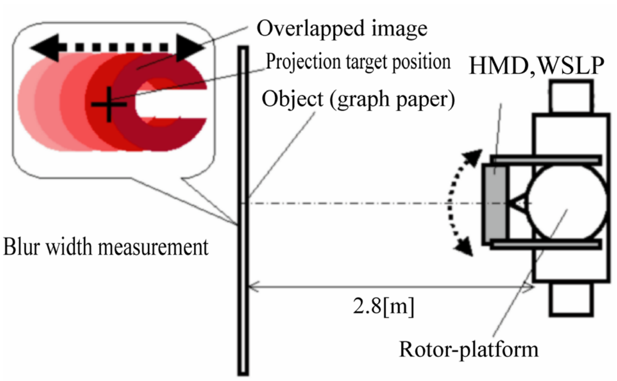

Fig. 7: Experiment 2: Head response experiment

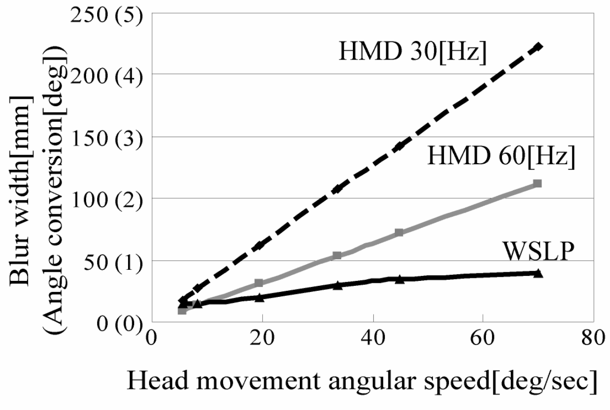

Fig. 8: Relation between head movement angular speed and blur width.

4.2 Experiment result and consideration

We show the results in Fig.8, including the experimental value relating the blur width and the equivalent head movement angular speed on the WSLP, as well as the theoretical value relating the angular speed and blur width of a generic HMD with the frame rate (30 and 60[Hz]).

From Fig.8, we find that the experimental value of the blur width of the WSLP is smaller than the theoretical value of the blur width of the HMD. Compared to typical head movement speeds of about 60[deg/sec], the blur width is about 35[mm] against the 2.8[m] previous projection plane (the angle conversion is about 0.7 [deg]).

With regards to fixing virtual information based on the head movement with respect to the object, WSLP is more advantageous than the update at each frame.

However, the experiment result of the WSLP was wider than the blur width assumed from the response frequency of the Galbanomirror. The cause of this is due to the direction of the sinusoidal drive equivalent to head movement, since the response delay is caused by the inertial force of the mirror, and may therefore be resolved by increasing the response control gain of the Galbanomirror. There is a tradeoff, however, because the weight of the motor increases when the motor torque is increased for a gain increase.

In this experiment, we used the encoder value of the rotor-platform for the characteristics evaluation of the WSLP. When we use the WSLP as a wearable device, we use a gyro sensor that detects the angular speed. It is necessary to integrate the measured angular speed for the head movement to fix virtual information. However, the integration error and the measurement error margin drifts with the integration of the angular speed. We should therefore suppress this error margin.

5 Design Discussion of WSLP

We described the advantage of the display system by the architecture of WSLP. Next, we discuss the design theory to decide the relevant ergonomic parameters of this device.

5.1 Display area of information

Behavior support methods using vision-based AR (superimposing character information onto an object of a real space) has attracted considerable research interest. For example, character information superimposition technology is an effective means of intellectual support.

However, simultaneity is an important aspect (without eyes moving) of gazing an object and reading support information in vision-based AR. Moreover, an information superimposition system is unsuitable for reading long streams of text.

Thus, we discuss the design of the display area (number of characters and the viewing angle, etc.) that can be referenced in consideration of human perception characteristics.

It is described in research on human visual characteristics [6] as follows. The identification rate of the character decreases by parting from the fixation point when the human momentarily sees the character. The regular size of the character of a newspaper about 50[cm] away from the eyes is about 0.5 [deg], and for large fonts such as headlines is about 1.0 [deg]. If the size of the character is about 0.1-1.0 viewpoint [deg], the range of effective view can be recognized from the fixation point by the central area of the retina at each radius of 5[deg]. It has been reported in [6] that the acknowledgment of the character (simple identification and classification, etc) is a viewpoint of about 10 [deg].

From these results, the display area that can be momentarily recognized is 10 [deg] in the horizontal direction, and about 10-15 characters can be displayed in this area.

There is a distinct advantage of using not whole area scanning but partial scanning and scanning area movement in the design of the device. The movement of the displayed image doesn't depend on the frame rate as explained in the previous section. Further, we obtain sufficient brightness with a low power laser diode, which can safely be used for projection in everyday environments. In addition, Galbano-motors of non-resonance type can be miniaturized in a narrow vibration range, because a high torque is needed in proportion to the range of the mirror drive. Motors with high torque need a large size and weight, and are therefore unsuitable for a wearable device.

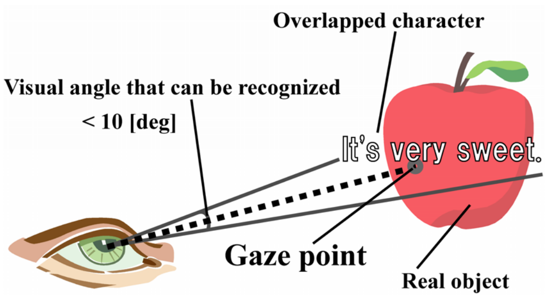

Fig. 9: Range that can be recognized without moving eyes

5.2 Resolution in the display area

5.2.1 Relation between galbanomirror driving frequency and resolution

We discuss the necessary resolution within the display area. The required response characteristics of the horizontal and vertical galbanomirror and the laser are shown by the following expressions.

$$Vf = Fr \quad (1)$$

$$Hf = Vf \times \frac{1}{2} Hn \quad (2)$$

$$Lf = Hf \times Hr \quad (3)$$

Here, Fr is the frame rate of drawing images and characters, Vf is the vibration frequency required for the vertical direction galbanomirror, Hn is the horizontal scanning lines number, and Hf is the vibration frequency required for a horizontal galbanomirror. Scanning lines are halved because the scanner draws by both the right and left directions, as a round trip. Hr is the resolution of the horizontal dots. Finally, Lf is the driving frequency of the laser. (Please see Fig.10)

The WSLP system explained in section 2 has a frame rate Fr of 40[fps], a vertical resolution Vf of 32[dots], and a horizontal resolution Hn of 256[dots]. Therefore, the performance that responds to a vibration Vf of 40[Hz] is necessary for the galbanomirror in the vertical direction. The performance that responds to a vibration Hf of 640[Hz] is necessary for a horizontal galbanomirror. Finally, a response performance of 163840[Hz] is required driving frequency of the laser Lf .

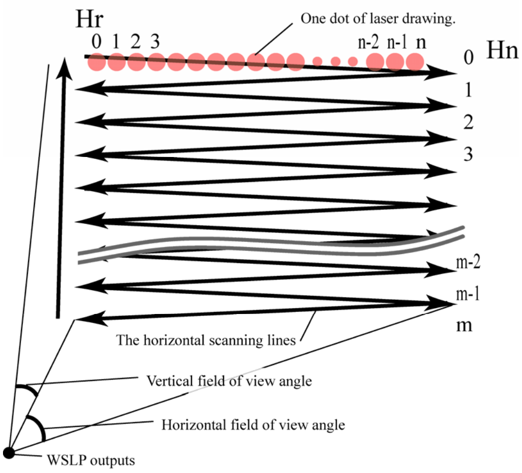

Fig. 10: Outline of Scanning

5.2.2 The relation between resolution and eyesight

We now consider how much resolution is necessary for the display area, based on characteristics related to human eyesight.

Being able to distinguish features with 1.5[mm] width at a distance of 5[m] from a subject's eyes is equivalent to an eyesight of 1.0. In a word, it is 1[min] (1[min] =1/60 [deg]) when converted into the viewing angle.

The conversion from this viewing angle to the necessary resolution is shown as follows:

$$\theta r = \theta d \,/\, Hr \quad (4)$$

Here, θd is the vibration angle of the galbanomirror (optical angle). Hr is the resolution of the horizontal (vertical) dots (laser spot). θr is the converted resolution to angle.

The WSLP system explained in section 2 has an angle θd of 8[deg], and a horizontal resolution Hr of 256[dot]. Therefore, θr is about 0.031 [deg], which is equivalent to a human's eyesight of 0.5 (2[min] ≅ 0.032[deg]).

5.2.3 Display of static and dynamic images

The WSLP system explained in section 2 was aimed to display characters and symbols. Therefore, this device has only a resolution of 36[dots] for a single character sentence in the vertical direction.

We consider an aspect ratio in which to project figures and images other than characters. From the field of view measurement result obtained in [8], the necessary aspect ratio is about 4:3. Therefore, the display area presumed most appropriate has a vertical direction with a range of 7.5[deg], when the range of the horizontal direction is 10.0[deg].

When a character corresponding to 1.0 eyesight is displayed in the display area, the necessary resolution is 600*450[dots], because the vertical field of view angle is 10[deg], the horizontal field of view angle is 7.5[deg], and the frame rate is assumed to be 30[Hz].

At this time, we discuss the performance demanded from the galbanomirror and the laser. In this condition, the frame rate is 30[Hz], the horizontal scanning lines is 450[lines], and the horizontal resolution is 600[dot].

When calculating, the laser driving frequency is 4.050[MHz], the horizontal galbanomirror driving frequency is 6.750[kHz], and the vertical galbanomirror driving frequency is 30[Hz],

However, achieving a 6.750[kHz] driving frequency for a non-resonance type galbanomirror is difficult. On the other hand, it is easy to drive at this frequency using a resonance type galbanomirror formed by the manufacturing process such as Micro-Electro-Mechanical Systems (MEMS)[9]. It is thus possible to achieve it by combining the resonance type galbanomirror of high-speed and low amplitude angle with the non-resonance galbanomirror of low-speed and high amplitude angle for the horizontal drive (Fig. 11).

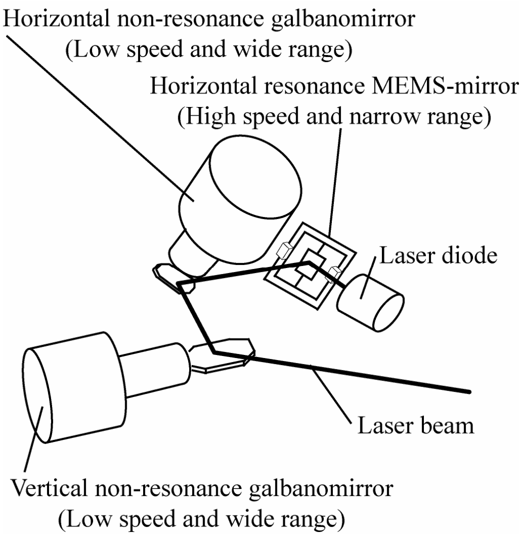

Fig. 11: Proposal for 4:3 aspect ratios

6 Conclusion

In this research, we propose the Wearable Scanning Laser Projector as a new head mounted display for AR. This head-mounted projection system uses rapidly scanned lasers to display information directly onto any object, effectively using the surface of object as a "projection screen". Using the WSLP, the information can be shared with nearby friends and colleagues who are not wearing similar devices.

Our WSLP solved the two most outstanding problems of see-through HMD's, namely the conflict of focus between the virtual environment and real environment, and the instability of virtual information fixation when the head moves. We experimented on focus consistency and head movement response for verification.

Moreover, we discussed the design of a WSLP suitable for an information title system, although this system is also particularly useful for performing interpersonal tele-operation tasks.

The WSLP can be used for not only as an information display device but also an information detection device, in detecting the reflected light of the laser like the bar-code reader.

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