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HMD with Pupillary Response Meter and Its Application to Virtual Lathe Operation

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Abstract

An HMD with a pupillary response that works under dynamic environment is developed. It is known that pupillary dilations and constrictions are governed by the autonomic nervous system. The HMD measure the pupil size with an infrared camera by image processing. Visual stimuli provided via video-see-through by the Augmented Reality technique. Virtual Environment of the lathe operation is used to display the accident to the participants without injury.

Key words: HMD, Pupillary meter, Virtual Environment, Machine Operation, Lathe

1. Introduction

In industrial site, there are many accidents caused by human error or human machine interaction fault, or verbose design of machine interface. It is necessary to study how cope with the situation of the accidents to analysis human behaviors in a moment of the happenings. However, there is a problem that the subjective mention of the participants didn't contain all events precisely in the field research. If the system acquire variation related to accidents or events from physiological response of the participants, it would be very useful. From analysis of a lot of these events, it would make a database for benefit to improve the human machine interactions.

If so, what is response of human in a moment of danger? Generally our heart throbbed violently in a critical situation. Beating of the heart is controlled by the autonomic nervous system (ANS). The role of the ANS is administration of life maintenance. The ANS consists of the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). An increase in the heart rate is caused by superiority of the SNS. It is known that pupillary dilations and constrictions are also governed by the ANS, for example, to adjust the amount of light entering the eye. There is also some evidence that different emotions associate with differential the ANS activity. Muscle of pupillary dilatations is connected to the SNS. The other side, muscle of pupillary constrictions is connected to the PNS. It seems that pupil size variation is related to both cognitive and affective processing. Hess and Polt [1] reported that changes in pupil size during the solving of simple multiplication problems could be used as a direct measure of mental activity. They also showed that mental activity was closely correlated with the problem difficulty, and pupil size increased with problem difficulty [2]. Emotionally provocation[3], fatigue[4] ,and cognitive load[5] are also related to the pupil size. These studies show physiological pupillary response was a valid index of observation of inside human. From the viewpoint, pupil size has been considered a potential computer input signal.

There are some advantages of other physiological responses. First, it is a nonintrusive method. No sensors have to be necessarily attached to the user. Second, pupil size variation is an involuntary index of the ANS activity. For instance, we can change breathing voluntary, but the pupil size can't. Third, the technology needed for the measurement of pupil size is relatively simple. The equipment of sensing the pupil is only an infrared TV camera. The difference of reflection against infrared rays between pupil and white-eye is utilized for detection of pupil size.

Accordingly, there are many studies ([6], etc) and equipments for pupillary meters (NAC EMR-8 JAPAN ,and so on). Almost of these pupillary meters were adopted configurations of optical-see-through. It is easy to display the visual stimuli to a participant. However, it makes the experiment of the pupillary response under static qualification, because it does not estimate luminous intensity quantitatively by the optical-see-through component. For dynamic environments, for example machine operations, the luminous intensity to a retina should estimate quantitatively. Consequently, we apply a video-see-through component to an HMD with a pupillary meter. The HMD is used two CCD cameras, one is an infrared CCD camera, and the other is a color CCD camera. The CCD cameras are located on the axes of the gaze directions for minimization of parallax. We developed the software to measure the pupil size by image processing.

And then, we propose a Virtual Environment (VE) that a lathe simulator with Virtual Reality technique is used as the way of observing a change of a pupil while the accident without injury. It is not good to experience an accident actually in the machine operation, because it is to hurt a person on purpose. The VR lathe gives accidental experiences to a participant by using oscillation of the handle or roaring by loudspeakers. In the previous virtual lathe[7], Lack of motivation of operators was a problem, because the presence of the virtual machine was poor expressiveness. It is expected that the proposed virtual lathe give more motivation to an operator by using a part of real lathe. The proposed virtual lathe is used of virtual and real conditions. An operator can revolve the wheel of the lathe in environments of composite real and virtual objects.

In this paper, we show the new HMD with a pupillary meter and the configuration of the accidental reproduce system with the VR lathe.

2. Apparatus of an HMD with a pupillary meter

Figure 1 shows the picture of the new HMD with a pupillary meter. The base of the HMD is the i-glasses (Virtual I-O). The HMD is assembled two cameras and six LED into the i-glasses for video-see-through composition. A color board CCD camera (Mintron MTV-54B0N, 1/4" CCD, lens F=2.0) is attached on the face of the left eye's arc mirror. The role of the camera is to take the outer environmental image for video-see-through. Because the center of the camera's lens corresponds to the left eye's gaze direction, a participant do not feel that something was wrong with the field of vision. For a pupillary meter, an infrared board CCD camera (Sharp MK09323E 1/3" interline transfer CCD, lens F=1.8) is attached on the face of right eye side. The role of the infrared transmit filter (Kodak 87C latten filter) is to cut the visible light, illumination of the backlight. Six infrared LED (Stanley AN304, peak 950nm) are used for infrared illumination around an eye (Figure 1(c)). These LED are able to switch for external trigger by a PC.

First, we describe the video-see-through part in Figure 2. The video signal (NTSC composite) from a computer video card (Matrox G400 DH, second display) is displayed on the LCD of the HMD. The image on the LCD is exposed by the backlight at (A), and then the image is projected to the oblique half mirror at (B) and the arc half mirror at (C). The image is reflected and through the mirrors again, and then arrives at the eye at (E). The route of the video-see-through is (A) $\rightarrow (B) \rightarrow (C) \rightarrow (B) \rightarrow (E)$.

Second, the part of the pupillary meter is shown. The eye at (E) is illuminated with IR LED. The projection of the eye is through the oblique half mirror combined with the image from (A). The composite image is through the arc mirror at (C). When the image passed through the IR transmit filter, the visible ray involve the image from (A) is cut off. Then, the IR CCD captures the IR only image at (D). Usually, the pupillary responses of right and left eye are the same, so it is enough to do it by right eye. The route of capturing the pupillary meter's image is (E) $\rightarrow (B) \rightarrow (C) \rightarrow (D)$.

Figure 3 shows the captured image by the IR camera. The characteristic of luminous intensity of the HMD was measured by an illuminometer (HIOKI LUX HiTESTER 3423). Figure 4 shows the luminous intensity related to the grayscale input from the computer. The relationship between the value of grayscale and the luminous intensity of the HMD is nonlinear, so we made a look up table from the results, and used it.

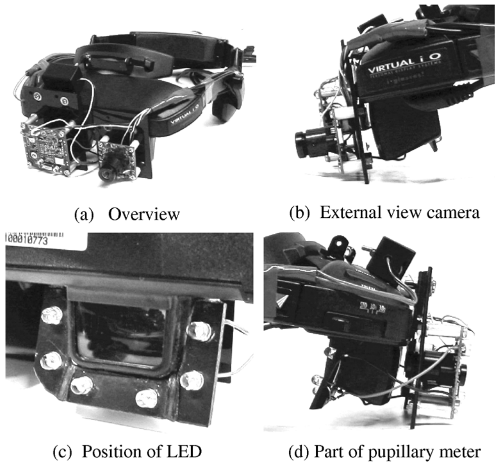

Fig. 1: The HMD device.

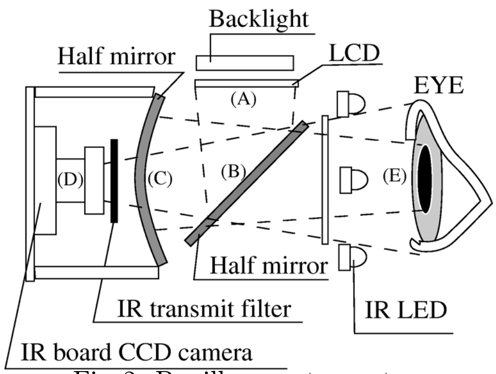

Fig. 2: Pupillary meter system.

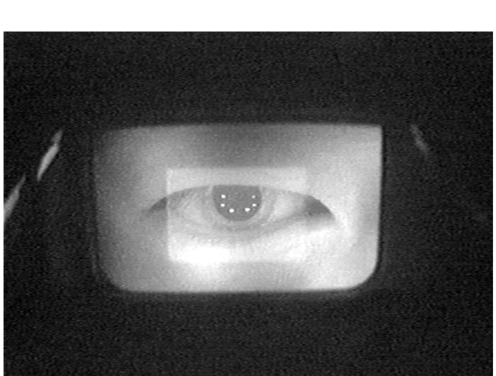
Fig. 3: Eye image of IR camera.

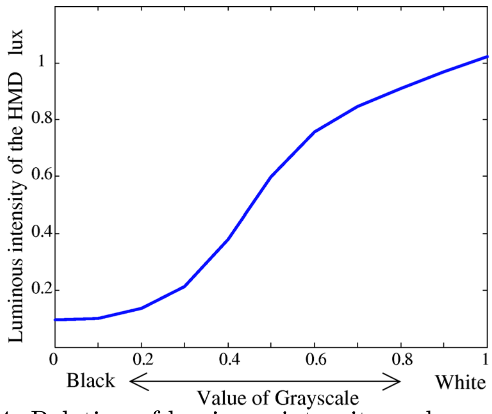

Fig. 4: Relation of luminous intensity and grayscale.

3. Procedure of image processing for the pupillary meter

The configuration of the pupillary meter is shown in Figure 5. Two computers communicated with each other via Ethernet. One computer (CPU Intel Pentium II 550MHz, Linux 2.4) is an exclusive for image processing of pupil. The other computer (CPU AMD Athlon 1.0GHz, Windows98) is used for generation of the augmented reality. Video recorders are used for recording the visual stimulus.

The method of pupillary meter is based on image processing technique. A video capture card (Bt878 video chip) with Video for Linux (V4L) library captures the video signal from the IR camera. Then, each frame of the image is processed for acquiring the pupil size. The purpose of the image processing is to extract the pupil diameter from the captured image. The area of the pupil represents black area, and the other area of white-eye and skin represents white area. So, the procedure is to extract the black circle shape from the white canvas. The procedure is this:

- Clipping the area involved the pupil
- Binarization the area by adjusted threshold
- Labeling with joint dots
- Detection edge of each labeling domain
- Calculate the circle form factor from the edge points
- Election of the greatest circle form factor's area
- Fit to parameters of elliptic formula to the elected area by the least squares method
- Get a horizontal radius of the ellipse as the pupillary diameter.

The elliptic formula is this:

$$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1$$

a represents a horizontal radius of the ellipse, b represents a vertical radius. The expression of the circle form factor is this.

$$Circleformfactor = \frac{4\pi S}{L^2}$$

S represents the size of the labeling domain. L represents the circumference of the labeling area. If the labeling area is nearly circle, the value turns out 1.0. Because of defects by reflection of LED's light spot, to fit elliptic shape is effective to reduce error in this case. The process rate of the procedure is about 30Hz. The resolution of the pupillary image is about 0.11 mm per pixel.

Flash response of pupil was measured when a participant put on the HMD with 0.1sec flash image (white circle of 20degree FOV). Figure 6 shows the result of the pupillary responses by the flash lighting. The result corresponded with results of physiological textbooks.

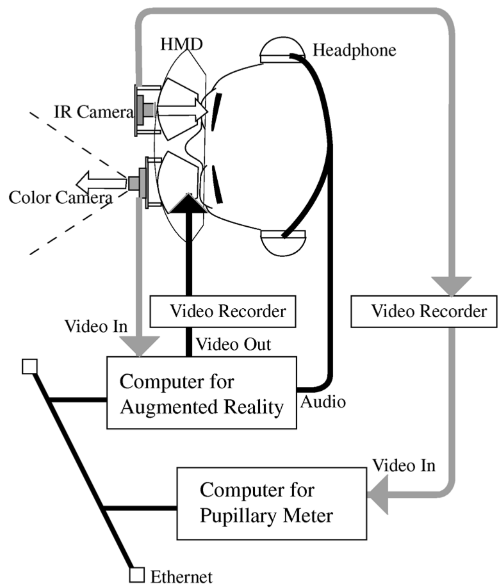

Fig. 5: Component of Pupillary meter and Augmented Reality.

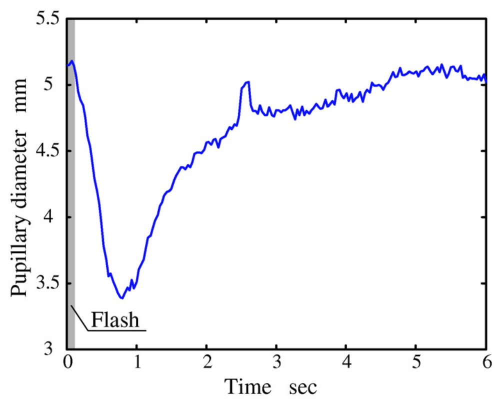

Fig. 6: Average profile(N=5) of flush response.

4. Apparatus of the Virtual Lathe

The virtual lathe is made of the real lathe (MECANIX Shop-Ace USL5 model2). Figure 7 shows the photo of the lathe, and Figure 8 shows the VR lathe system. The VR lathe has a haptic device that is composed of the DC motor (JAPAN Servo DME44BB 15W) and the servo driver (OKAZAKI Sangyo TITECH ROBOT DRIVER PC-0121-1). The revolution of the feed wheel is measured by the rotary encorder (OMRON E6C-CWZ3E, 1000 pulse/rev). The measurement of the axis torque of the feed wheel is used of the strain gauges bridge (KYOWA Dengyo KFG-1). Arrangement of these devices does not obstruct the operation of real lathe, so the VR lathe is able to use under both virtual and real environment.

The registration marker is used for composite virtual image of the workpiece and work tool during the VR environment. The system uses the Augmented Reality Tool Kit (ARToolKit)[8] for registration of the marker's position and orientation. The ARToolKit is a library of image-based registration functions from a single camera by rectangle markers. The image captured by the color CCD on the HMD is used for the registration of the marker. Figure 4shows the mixed image of the virtual work objects on the real environmental image. The refresh rate of the mixed image is about 20 fps.

ECG (electrocardiogram) by surface electrodes on the breast is recorded (1KHz digital sampling) for verification of the ANS activity during the machine operation.

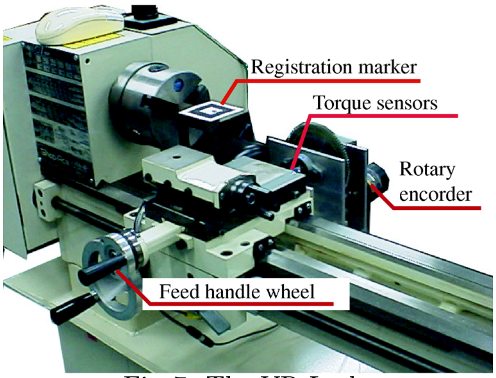

Fig. 7: The VR Lathe.

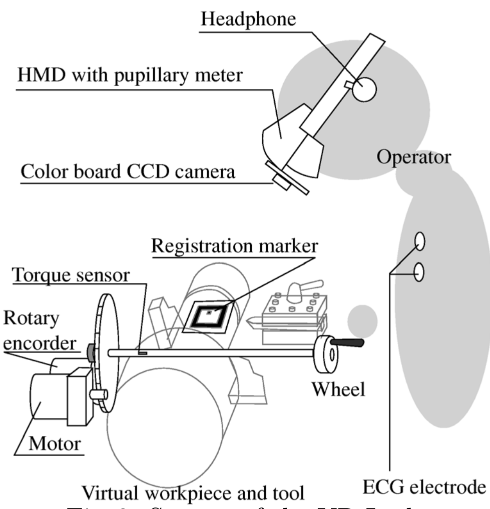

Fig. 8: System of the VR Lathe.

5. Experiment and Results

Two subjects (age 23,31) participated the experiment. The task was that the subjects machined on the VR lathe to a feed of 5mm. They did the task ten times without rest. We asked them to report the condition of the operation by clicking the mouse. Pupil pictures were recorded with video for off-line jobs of pupillary meter. Electrodes

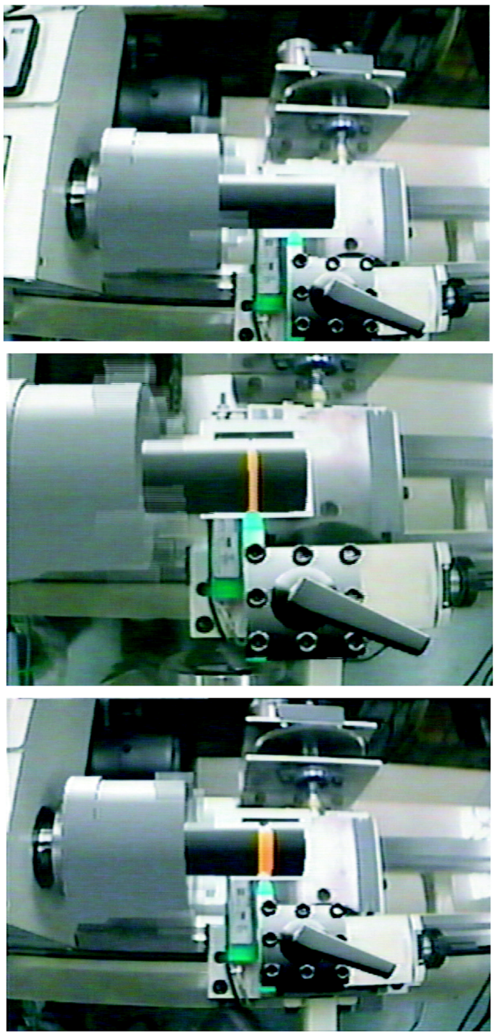

Fig. 9: Sample image of the VR Lathe.

of ECG pasted on their breast. The external trigger synchronized these devices. Stimuli were the oscillation of the wheel and the loud sound. Each stimulus occurred at random. Total number of the stimuli was three or four in the procedure. In analysis of the data, HR (heart rate) was obtained from the R-R intervals of the ECG. Value of pupillary diameter was low-pass filtered (cut-off 60Hz). Figure 10 shows the profiles during the event. The pupillary diameter of each event was slightly increased. However, there were few samples to discuss the significant of the results.

6. Conclusions

The HMD developed was worked for pupillary meter. Collaboration of the new HMD and the VR lathe is new ergonomics equipment for analysis of human behavior. However, more experiments are needed in order to proof the significant of the HMD with the pupillary meter.

References

1. E. H. Hess and J. M. Polt: "Pupil size as related to interest value of visual stimuli," *Science,* vol.132,

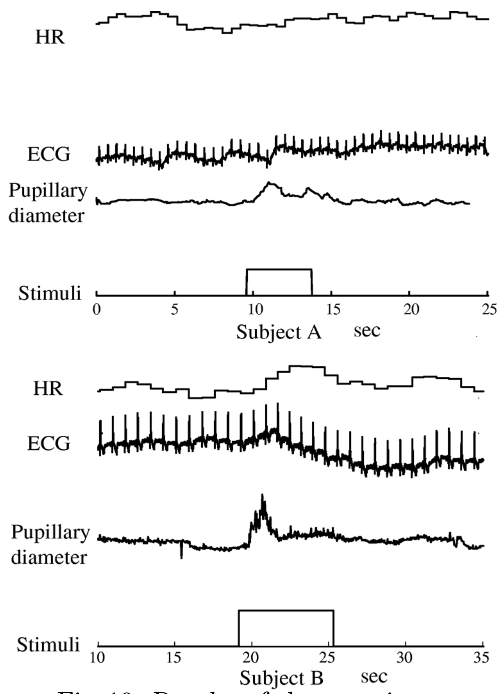

Fig. 10: Results of the experiment.

pp.349-350 (1960).

2. E. H. Hess and J. M. Polt: "Pupil size in relation to mental activity during simple problem-solving," *Science,* vol.140, pp.1190-1192 (1964).

3. Timo Partala, Maria Jokiniemi, and Veikko Surakks: "Pupillary Responses To Emotionally Provocative Stimuli," *Eye Tracking Research & applications symposium (ACM),* pp.123-129, Nov. 6-8 (2000).

4. Atsuo Murata: "Assessment of Fatigue by Pupillary Response," *IEICE TRANS. FUNDAMENTALS,* vol.E80-A,No.7 (1997).

5. D. Kahneman, and J. Beatty: "Pupillary Diameter and Load on Memory," *Science,* vol.154, pp.1583-1585 (1996).

6. Kazuhiko Ukai, Shinya Saida, and Norio Ishikawa: "Use of Infrared TV Cameras Built into Head-Mounted Display to Measure Torsional Eye Movements," *Japanese Journal of Ophthalmologic,* vol.45 ,pp.5-12 (2001).

7. Kazuhiko Kobayashi, Nobuyoshi Hashimoto, and Hideo Kato: "Simulation of Boring Operation with Lathe by Means of Mixed Reality," *Trans. of the Virtual Reality Society of Japan (TVRSJ),* vol.4, No.4, pp.685-690 (1999) (in Japanese).

8. H.Kato, M. Billinghurst, I. Poupyrev, K. Imamoto, K. Tachibana: "Virtual Object Manipulation on a Table-Top AR Environment," *In Proceedings of ISAR 2000,* Oct 5th-6th (2000). ARToolKit website: "http://www.hitl.washington.edu /research/shared_space/download/"