SharpView: Improved Legibility of Defocussed Content on Optical See-Through Head-Mounted Displays

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Fig. 1. (a) shows the schematic of Optical See-Through HMD. User is gazing at the character A on the real scene. In this situation, the CG character A on the virtual display would be blurred by focus blur. (b) shows the user perspective when presented a normal image. The character A on virtual display appears thin and low contrast because of focus blur. (c) also shows the user perspective, but presented a SharpView image which is more visible compared to (b).

Abstract— Recently, AR techniques have been attracting attention and the Optical See-Through HMDs are cited as a useful device for these techniques. However, when the user is observing a real environment through such a display, the image on the display will be blurred because of the focus depth difference. In this paper, we propose the SharpView system to resolve it by pre-filtering the displayed image according to the user's eye information. We prove that the SharpView image has a higher legibility through three experiments: First, we investigate the rate of users pupil diameter change as a pilot test. Second, we confirm that our theory is correct via a psychophysics experiment. Finally, we run a comparative experiment with normal image presentation method. This technique allows simultaneous observation of the real environment and virtual display. Therefore, every Optical See-Through HMD should include our SharpView technique.

Index Terms—Augmented Reality, Optical See-Through Display, Focus blur correction, Point Spread Function, Image Sharpening

1 Introduction

1. **Context**:
   Focus blur on Optical See-Through HMD is very annoying

2. **Challenge**:
   Eyes PSF estimation and sharpening image generation by using it

3. **Approach**:
   Eyes PSF estimation
   Sharpening image generation

4. **Contribution**:
   Reduction of focus blur on Optical See-Through HMD

5. **Outlook**:

2 Related Work

The related work goes here.

1. **Light Field Display**:

2. **The difference between Light Field Display**:
   Low calculation time
   Application to existing Optical See-Through HMD

3 SharpView

3.1 Design

Focus blur is represented by convolution in the field of image processing. In the process of the image o reaches the imaging plane, it is convoluted with point spread function(PSF) p. As a result, blurred image b is displayed.

$$b = o * p \tag{1}$$

The symbol $*$ represents the convolution operation.

Defocussed image can be corrected given the PSF. B, P and O images are Fourier transform of b, p and o. Equation (1) can be expressed as follows in the spatial frequency domain.

$$B = O \cdot P \tag{2}$$

It is possible to obtain a corrected image O' by $O' = B/P$, but considering the noise, the following Wiener Deconvolution is optimal.

$$O' = \frac{B \cdot \overline{P}}{|P|^2 + |C|^2} \tag{3}$$

Here, $\overline{P}$ represents the complex conjugate of P. The C is a constant to prevent instability as a solution when the value of P is small as it uses the inverse of the SN ratio of the input image O. We apply this deblurring technique to create a sharpened image that has perceivably better visibility than original image.

$$S = \frac{O \cdot \overline{P}}{|P|^2 + |C|^2} \tag{4}$$

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In the case of our system, we apply Weiner filter to the original image O according to Eye's PSF of the user and present that sharpening image S to the Optical See-Through HMD. It is necessary to obtain the user's eyes of the PSF as it can give a highly visible image to a user who is watching a real environment.

We approximate the eye's PSF with a Gaussian function. When gazing at a point on the object in the back of the HMD virtual display, light rays emitted from the display reaches to a point on the retina at different intensities. The intensity distribution of the PSF p can be represented as Gaussian function by following equation.

$$P(x,y) = \frac{1}{2\pi\sigma^2} exp(-\frac{x^2+y^2}{2\sigma^2}) \tag{5}$$

In equation (5), σ is the focal blur size, x, y represents the pixel position. Thus, the eye of the PSF is regarded as a Gaussian function depending on one parameter σ, it is necessary to determine the value of the σ.

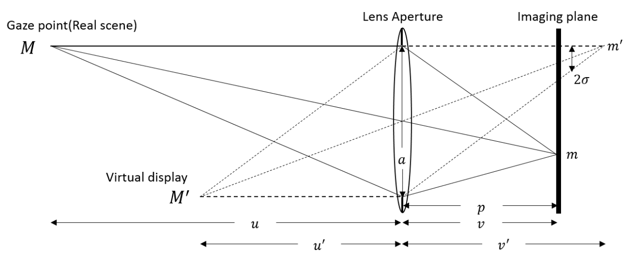

Fig. 2. Optical system of the lens camera model

Consider the optical system when using the optical see-through HMD in order to determine the σ of eye's PSF. In figure 2, the middle lens means the crystalline of the eye and the right imaging plane means the retina. The user is gazing at the point M on the real environment. The light emitted from the point M is imaged at the point m on the imaging plane through the lens. In this case, the light emitted from the point M' on the virtual display is imaged at the point m' on the back of imaging plane and blurred image is projected on the imaging plane. The radius of blur is equal to σ of the Gaussian function. This σ is derived as follows from the triangle ratio and lens equation.

$$\sigma = \frac{av}{2}(\frac{1}{u'} - \frac{1}{u}) \tag{6}$$

Then, it is necessary to scale the parameter from the image plane to a virtual display. If the radius of the blur on the display expressed as σ_d, the ratio is expressed as follows.

$$\sigma : \sigma_d = v : u' \tag{7}$$

Here, we can calculate the σ_d from equations (6) and (7).

$$\sigma_d = \frac{a}{2}(1 - \frac{u'}{u}) \tag{8}$$

a is the pupil diameter, u is the distance from eyes to gaze point, u' represents the distance from eyes to virtual display. σ_d depends on these three parameters. When using for image processing, it may be converted to the pixel size from the dot matrix of the virtual display. Therefore, a, u and u' are required to determine the eyes PSF.

In regards to a,the pupil diameter depends on light environment and stress. If it's bright, pupil diameter becomes small. Inversely if it's dark pupil diameter becomes large. In addition, fatigue due to strenuous tasks also affects the pupil diameter. Because of these changes, it is necessary to acquire the pupil diameter at a constant rate, so we attach a camera on the inside of the HMD. u represents the distance from eyes to the gaze point.

3.2 Implementation

The SharpView system was developed and runs on the following machine specifications
- OS: Windows 7
- RAM: 8GB
- CPU: Intel Core i7 820 @2.9GHz
- OSD Head Mounted Display: Google Glass
- Eyegaze Tracker: The Eyetribe Tracker
- Java JRE 7
- OpenCV 2.6.4
- Kryo Networking Library

4 Pilot test

It is necessary to know about the rate of the pupil diameter change before we demonstrate the feasibility of SharpView. As mentioned in Section 3, the pupil diameter change depends on two factors: Light environment and Stress levels. We can keep the environment light constant, but we cannot control the stress levels the user experiences during use. So, we will measure the rate of pupil diameter change in the following pilot test. The results of this pilot test changes the design of following experiments. If the amount of subject's pupil diameter changing is minimal, a single pre-experiment acquisition of the pupil diameter size is sufficient. However, if there is significant change during the experiment, we must get the pupil diameter between each comparison.

We use a system combining OpenCV and OpenGL to present pre-calculated SharpView images on an Android device. OpenCV is used for creating the image of SharpView, and OpenGL is used for rendering it to the display. The android terminal is covia's FLEAZ F4s, which has 4 inches display and 480 $\times$ 800 resolution, which is connected with a PC as a second display. We calculate pupil diameter using the iViewETG from SMI Corporation. It features pre-calibrated infrared cameras which can record user eyes. Analyzing the recorded videos will allow us to analyze the rate of pupil diameter change.

For the experiment we recruited three male(age 23-27, ϕ : 25). All had normal vision and didn't use glasses or contact lens. Also we ensure normal vision using a simple acuity test. This experiment is a pilot study, so three subjects is enough to conduct the experiment.

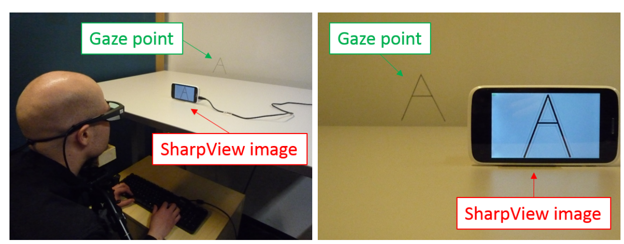

Fig. 3. Left: Experiment environment of Pilot test, Right: User perspective

The experimental environment is shown in the left of Figure. 3. Subjects are fixed their head position by a chin-rest and wear a head-mounted gaze tracker. The whiteboard has the character A written on it, and placed 1.0m from the user. The Android terminal is placed 0.5m from the subject view point so as not to overlap from subjects perspective, as shown in the right of Figure. 3. The subjects can switch the image on the Android device using the space key on the keyboard and select which image has better visibility using the enter key. We instruct the subject to compare the on-screen image while observing the letter A on the whiteboard. We deter the subjects from looking at the Android terminal screen by tracking the users gaze, and switching off the android terminal display when the user is not focused on the intended target.

There are 7 degrees of sharpening between -0.6% and 0.6% in 0.2% intervals, two intervals are selected, omitting same comparisons, and each comparison is repeated four times, totaling 42 comparisons the

subject performs. The absence of the Optical See-Through HMD will not affect results as we are confirming the rate of pupil diameter change, which is unaffected by the display screen used.
Experimental results are shown in the graph of Figure. 4.

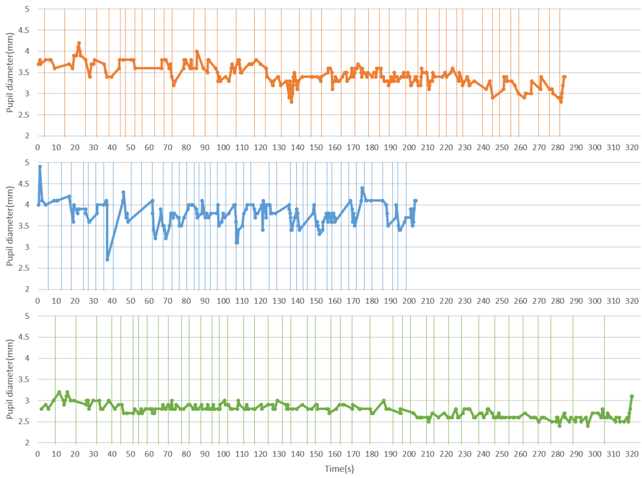

Fig. 4. PilotTest result

From the experimental results, we can confirm that the subjects pupil diameter of the subject changes throughout the task and this rate differs between individuals. We then verify whether this changes will be a problem during future experiments. First we split the changes in pupil diameter of each subject for each 42 times of comparison. We then represent the biggest difference between the pupil diameter measurements at each of the time domains as a percentage. We add the 2% error from the gaze tracker in the ratio and counted the number of trials which deviation lies within 10%.

The result was as shown in Figure. 4's right upper corner. Subjects 03's changes in pupil diameter was minimal during the task, we can trust 35 out of 42 comparisons will be accurate. However, with Subjects 1 and 2, many trials deviate more than 10%, This means that if we gave image comparison tasks, more than half of the result would be unreliable.

Using this result, we can determine the pupil diameter for the majority of subjects varies significantly during the image comparison task.This means that when performing image comparison experiment, we must obtain the pupil diameter before each comparison and use that value for creating a new SharpView image.

5 Psychophysics Experiment

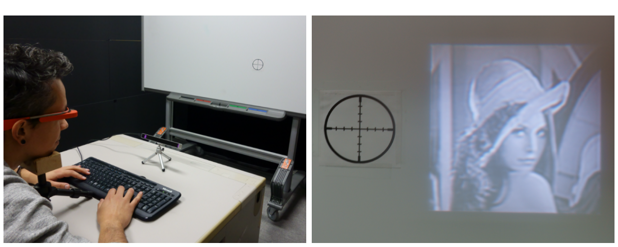

Fig. 6. Left: Experiment environment of PP exp, Right: User perspective

1. **Overview**:

2. **Experimental Platform**:
   Software
   Hardware: Google Glass, iView ETG

3. **Participants**:
   10 young people

4. **Task and Procedure**:
   Task: Pupil radius calculation, Image comparison(7*6 times)
   Procedure: Indication, Repetitive tasks

5. **Variables**:
   Pupil radius, Eyes PSF

6. **Results**:

7. **Discussion**:

6 Comparative Experiment

The Comparative experiment goes here.

7 Conclusions

In future work, We must calculate the gaze direction of the user from a gaze tracker and also estimate the shape of the camera position and environment by using Visual SLAM or a similar system. By doing that, it is possible to theoretically estimate the distance to the gazing point from the viewpoint position.u' represents the distance to the virtual display from eyes, which takes a unique value in the optical see-through HMD.For example, Google Glass's virtual display is equivalent to 25 inch display located at the depth of 8 feet. It is possible to present always an image which has the optimal sharpening degree to the user if we are able to calculate these parameters in real time.

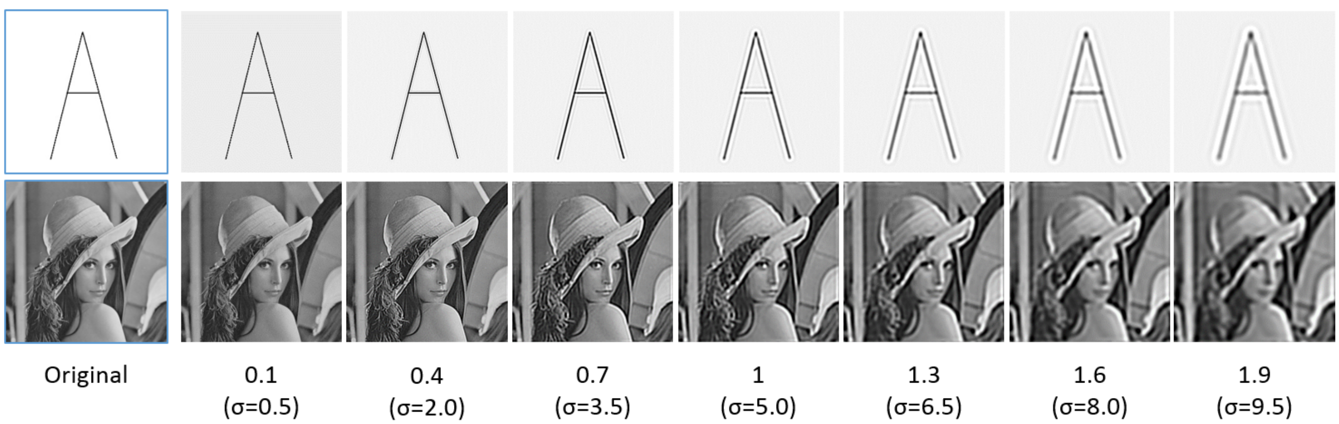

Fig. 5. PP Exp Images