Evaluation of Mono/Binocular Depth Perception Using Virtual Image Display

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Abstract. Augmented reality (AR) is a very popular technology in various applications. It allows the user to see the real world, with virtual objects composited with or superimposed upon the real world. The usability of interactive user interface based on AR relies heavily on visibility and depth perception of content, virtual image display particularly. In this paper, we performed several basic evaluations for a commercial see-through head mounted display based on those factors that can change depth perception: binocular or monocular, viewing distance, eye dominance, content changed in shape or size, indicated by hand or reference object. The experiment results reveal many interesting and fascinating features. The features will be user interface design guidelines for every similar see-through near-eye display systems.

Keywords: augmented reality, virtual image display, see-through near-eye display, user interface, depth perception.

1 Introduction

Augmented reality (AR) is one part of the general area of mixed reality according to the reality-virtuality continuum, as show in Fig.1, and it provides local virtuality [4]. Not like virtual environment (VE) technologies that completely immerse a user inside a synthetic environment and the user cannot see the real world around him, in contrast, AR allows the user to see the real world, with virtual objects composited with or superimposed upon the real world [5]. As a result, the AR technology functions by enhancing and enriching one's current perception of reality [3]. The natural and intuitional characteristics of AR increase its popularity in various applications, such as personal assistance, medication, education, industry, navigation and entertainment [1].

AR is also the technology to create a "next generation, reality-based interface" [6] and is moving from laboratories around the world into consumer markets. Current dominance head-worn AR technologies can be divided into three main types, projective AR, video AR and optical head-worn AR [1]. The optical head-worn AR (also known for see-through near-eye display) is the best choice of head-worn personal assistance for the advantages of delay-free (user can see the world around him without any transmission delay) and not required for special material for projection.

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However, see-through near-eye display has many disadvantages: low contrast, low brightness, low resolution, inaccurate depth perception, high power consuming and eye strain caused by dynamic refocus (changes from virtual objects and the real world). One difficult registration problem is accurate depth perception of virtual content. Naturally, stereoscopic has higher depth perception accuracy than that binocular has. However, additional problems including accommodation-convergence conflicts or low resolution and dim displays cause object to appear further away than they should be [1]. This is an essential issue for AR applications, since AR allows the user to see the real world and virtual objects simultaneously, and inaccurate depth perception will case the misalignment of the virtual objects.

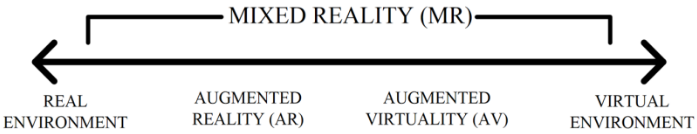

Fig. 1. Reality-virtuality continuum

In order to build a high usability user interface for optical head-worn AR system, factors that can change depth perception should be confirmed. We performed several basic evaluations based on those factors: binocular or monocular, viewing distance, eye dominance, content changed in shape or size, indicated by hand or reference object. The experiment results reveal many interesting and fascinating features. The features will be user interface design guidelines for every similar see-through near-eye display systems.

2 Depth Perception

2.1 Equipment

In this paper, we use the VUZIX (type STAR 1200) for depth perception evaluation. VUZIX is a mono/binocular see-through near-eye virtual image display and provides two separated and identical virtual screens for observer. It also provides a virtual screen (43 inches in diagonal) with high-resolution (852x480 WVGA) that appears in front of the user (3m). Since virtual screen is refracted from a very small LCD display through the well-designed optical apparatus, as show in Fig.2, it has very low power consumption.

2.2 Test Environment Set Up

In test environment of depth perception evaluation, as shown in Fig.3, moderator will display images in one or two screens in VUZIX and ask evaluator try to indicate the exactly location of the virtual floating object, using their finger (of their normal used hand) or a reference object (very small real object that connected to a sliding ruler). The location will be measured and recorded by a precision measuring device, which the scale can be read directly to 0.01mm. Evaluator will be fixed at a chin holder to the center of the background, which is a 22 inches screen in those evaluations. The field of view (FOV) through VUZIX will be limited inside the background. Ambient light will be fixed to the luminous recommendation of office lighting (320-500 Lux, under European law UNI EN 12464) to simulate indoor usage. For binocular test, we set the convergence angle of both eye to the viewing angle of a near eye object at distances of 30, 40 and 50 cm. The viewing angle is measured and confirmed by another precision eye-tracking device before evaluations.

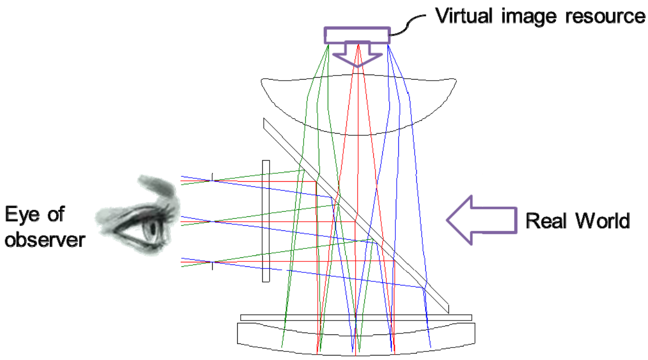

Fig. 2. Sample of optical configuration of virtual image display

2.3 Binocular and Monocular Setup on See-Through Near-Eye Display

With properly content design, we can simulate the viewing distance changing of virtual objects for depth perception evaluations. Since the convergence angle of eye will be automatic adjusted when viewing distance changed, when we focus on a near object, the convergence angle of eye is bigger than that we focus on a far object. In VUZIX, the virtual image is seen by two eyes separately, and the convergence angle of eyes will be fixed into a predefined angle, as a result, a floating virtual screen appeared in front of user at predefined viewing distance (43-inch virtual screen at 3m). In order to create a virtual object at particular position in front of user, we change the location of virtual images on both virtual screens. For example, shift the image in left screen toward to right and shift the image in right screen toward to left, the virtual object will be visually closer to user, since the convergence angle is going bigger. The image in tests is a simple white circle or white square on black background without any textures or other monocular depth perception cues. For monocular tests, we display only one image in left screens or right screens.

2.4 Participations

Total 30 evaluators (10 females) with age 18-35 participated in this study. We verified that no one was color blind and all evaluators have normal or corrected-to-normal vision. We also confirmed that none of them were stereo blindness.

2.5 Evaluations

Factors that could affect the depth perception will be evaluated in tests: binocular or monocular, viewing distance of virtual objects, eye dominance, content changed in shape or size, indicated by hand or reference object. The evaluation includes 9 stages, which are 5 stages in monocular and 4 stages in binocular, and performed in randomly order. Fig.4. shows one example of task list for evaluation. At first and second stage, we display one white circle on left (1st) and right (2nd) virtual screen in VUZIX and ask evaluator to indicate the location of the circle by finger. At third stage, we display one white circle on left screen and then display one bigger white circle at the same location and ask evaluator to indicate the location of the bigger circle by finger. At fourth stage, we display one white circle on left screen and then display one white square with the same size at the same location and ask evaluator to indicate the location of the square by finger. At fifth stage, we display one white circle on left screen and ask evaluator to indicate the location of the circle by moving a reference object. At sixth to ninth stages, we display one white circle on both screens to simulate seeing a near eye object at viewing distances of 30, 40 and 50 cm. Then we ask evaluator to indicate the location by their finger (at 30, 40 and 50 cm) or by a reference object (at 40 cm).

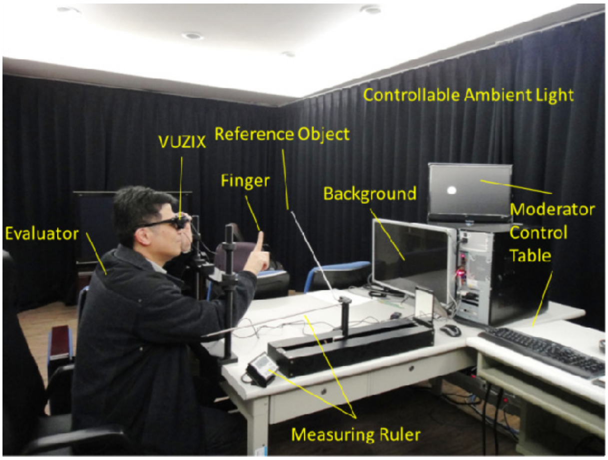

Fig. 3. Test environment set up for depth perception evaluation

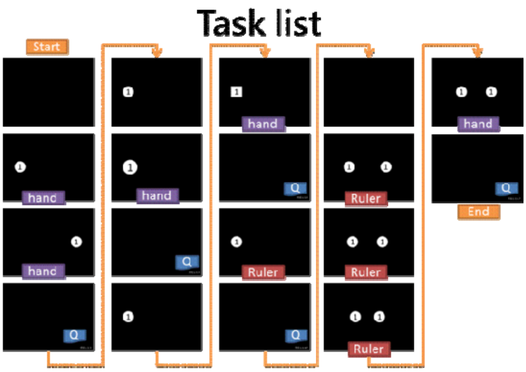

Fig. 4. Task list example for depth perception evaluation

3 Experiment Results

3.1 Monocular and Binocular

The experiment results of depth perception evaluations reveal many interesting and fascinating features, as shown in Fig.5. In monocular tests, it displays only one small circle or square in one eye, the observer can't sense the viewing distance directly from the virtual object in those monocular stages. The depth perception might come from the user experience of observer by compared their finger size and the size of virtual circle. It is obviously and naturally that the binocular depth perception is more accurate than monocular, as show in Fig.6. The standard deviation is smaller in binocular than that in monocular, as show in Table.1.

Table 1. Results of paired samples t-test for different property

Property		Paired Differences				t	df	Sig. (2-tailed)
		Mean	Std. Deviation	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Size change	**small - big**	44.15167	89.46459	10.74504	77.55829	2.703	29	**.011**
Shape change	circle - square	-9.34233	94.70232	-44.70476	26.02009	-.540	29	.593
Binocular	**hand - ruler**	-34.73067	63.62760	-58.48960	-10.97173	-2.990	29	**.006**
Monocular	**hand - ruler**	-83.25967	135.22556	-133.75372	-32.76561	-3.372	29	**.002**
Eye domination	left - right	-5.97700	109.00321	-46.67947	34.72547	-.300	29	.766

3.2 Viewing Distances

The binocular depth perception accuracy is various at different viewing distances, as show in Fig.5. Depth perception is accurate at viewing distance 400mm when it was

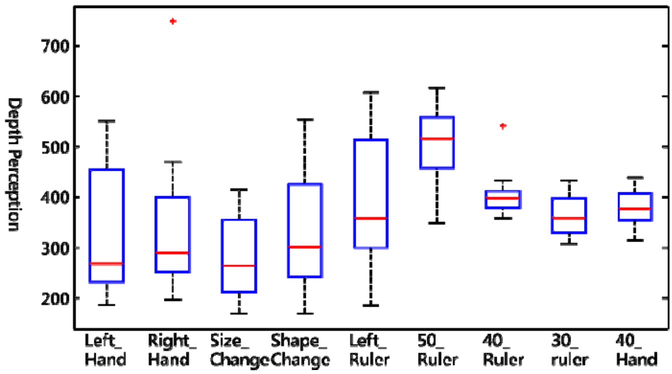

Fig. 5. Experiment results of depth perception evaluations

indicated by finger or reference object. Only one of the evaluators says that he cannot make well convergence of the binocular images at viewing distances 500 mm and 300 mm. Depth perception is very inaccurate at viewing distance 500 mm and 300 mm, 500 mm particularly. This result may be contributed by hand lengths of evaluators. The usual and comfortable location caused by hand length will change the depth perception at different distances. It requires further tests to determinate the best operation zone for virtual objects interactive user interface.

3.3 Eye Domination

Since approximately two-thirds of the population is right-eye dominant and one-third left-eye dominant [2], we need to confirm the influence of eye domination on depth perception. Paired sample t-test was used for eye domination (image on left screen only and image on right screen only), as show in table.1. The experiment result indicated that there was no different in eye domination (Eye domination, $p > 0.05$) for depth perception in our tests.

3.4 Content Change in Size or Shape

Content change may affect the depth perception. We use paired sample t-tests for content change in size (small to big) and shape (circle to square), as show in table.1. Significant differences between small circle and big circle were noted (Size change, $p < 0.05$). Depth perception will naturally increase when virtual image going bigger, as show in Fig.7. Experiment result also indicated that there was no different in change shape (Shape change, $p > 0.05$).

3.5 Indicated by Hand or Reference Object

The tools for distance measurement of virtual object will affect the depth perception. In this study, we let evaluator use their finger to indicate the location of virtual object or operate a sliding ruler for indication in both monocular stage and binocular stage. The reference object attached on sliding ruler is a small needle that smaller than virtual image and that will not cover or overlapping with virtual object. Otherwise, finger can cover on or overlap with virtual object in those tests. Paired sample t-tests were used for indicator change in monocular (hand to ruler) and binocular (hand to ruler), as show in table.1. Significant differences between hand and ruler in binocular and monocular ($p < 0.05$) were noted. The results revealed that depth perception on ruler was further than that on finger. Depth perception will increase when it was indicated by a reference object, as show in Fig.8. Therefore, we can confirm the collision of virtual objects will affect the depth perception. Even the virtual image should be closer than real world or finger for user's eye, as show in Fig. 2.

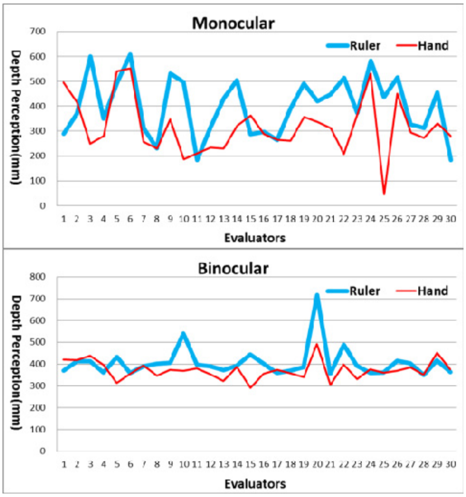

Fig. 6. Experiment results from monocular stage with image on left eye and binocular stage with virtual object at 400 mm

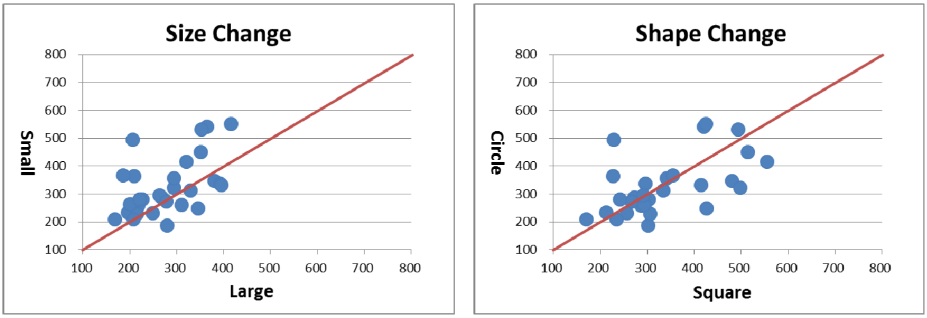

Fig. 7. Correlation of size and shape changing

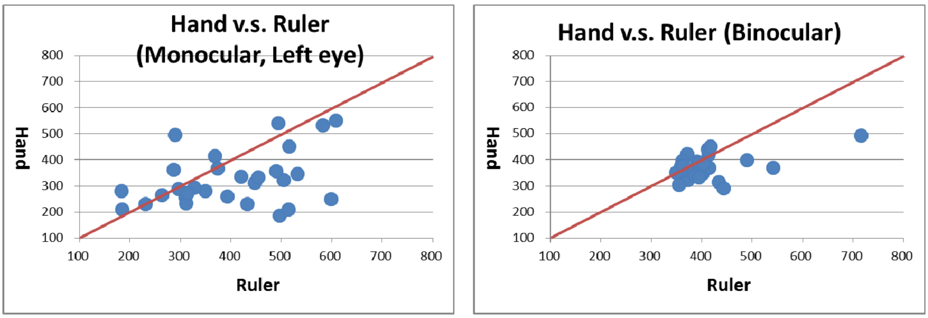

Fig. 8. Correlation of measurement tool changing for monocular and binocular test

4 Conclusions and Future Works

Augmented reality is a very popular technology in various applications. The usability of user interface based on AR relies heavily on visibility of content and depth perception of interactive surface. In order to build a high usability user interface, factors that can change depth perception should be confirmed. We performed several basic evaluations based on those factors. The experiment results reveal many interesting and fascinating results. Significant differences between binocular or monocular, content changed in shape or size, indicated by hand or reference object were noticed. Otherwise, depth perception is accuracy at viewing distance 400 mm that indicated by finger or reference objects.

Here we list several suggestions for user interface design:

1. Displaying content in binocular optical head-wear AR with properly design based on convergence angles can simulate viewing distance changing.
2. The viewing distance of interactive virtual floating control panel should be not too close or too far from user, 400 mm is recommended.
3. Applications of optical head-wear AR that require precision depth perception, binocular is recommended.
4. Fault tolerance design for depth perception of binocular applications at viewing distance 40cm, offset ± 5cm is recommended.
5. The size of virtual object is a better cue for depth perception rather than shape.
6. Multi-dimensional control panel is required on monocular virtual image display since the low precision depth perception.

Those suggestions can not only be the user interface design guidelines for VUZIX but also for every similar see-through near-eye display system. In the future, there still remain various properties, such as content color, texture gradient, contrast, resolution, stereoscopic rendering, object motion and real time feedback that might affect the usability of UI and all should be confirmed through a lot of work.

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