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A Display for Supporting Ownership of Virtual Arms

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Abstract

To enable convincing first-person interactions involving object manipulation, virtual reality systems need to represent the user's body in the virtual environment. Virtual body parts, particularly the arms and hands, must appear in the correct perceived spatial positions in a first-person view so that users can "take ownership" of them. One current method to achieve this goal is head-mounted displays, but they have cost and motion sickness problems. Other methods such as table-top projections have problems with image occlusion by the user's own limbs. In this paper we describe a low-cost alternative using a mirrored horizontal display which places virtual arms in the correct position relative to the user on a table top. We hypothesized that, compared to a normal monitor, our display provides improved subjective ownership of virtual limbs while maintaining equivalent ease of use. Questionnaires on healthy subjects showed that they found it easier to induce self-ownership of virtual arms using our display. We also compared a virtual rubber hand illusion using our display with a real rubber hand illusion and found comparable ownership results. We conclude that our display can support improved ownership of virtual arms compared to a normal vertical display.

Keywords--- Virtual reality, ownership, rubber hand illusion, mirrored display

1. Introduction

A primary objective of virtual reality (VR) systems is to provide users with realistic visual input, while not compromising on comfort or usability. While normal displays presenting virtual environments on vertical monitors or projection screens are familiar and well accepted, the image produced is displaced away from the user and thus cannot represent the user's body parts – particularly arms and legs – in the correct position relative to the user's viewpoint. This drawback may limit the extent to which users can imagine the virtual arms to be their own. Simple devices such as a mirror box [1, 2] can be used to achieve the desired effect for a single arm, but this box does not support manipulation of the viewed image or integration with tasks that are possible with VR.

Fully immersive head-mounted stereo displays (HMDs) can produce virtual environments in which virtual limbs appear in the correct position relative to the user's viewpoint. However, their use has been limited by concerns of cost and motion sickness, e.g. in computer gaming [3]. Shutter glasses, eyeglass displays and stereo glasses cause fewer motion sickness problems than wrap-around HMDs due to better peripheral vision [4], but they also provide correspondingly less convincing immersion. There is also conflicting data about the extent to which HMDs provide benefits for tasks in virtual navigation [5] and virtual search [6, 7].

Because of the disadvantages of HMDs and stereo glasses, many systems use alternative methods to achieve subject immersion. Some use large displays to achieve immersion by showing a live video image of the subject's arm on the screen [8-10]. While easy to implement and quickly understood by users, it provides a representation of the user's body that is "out there" rather than situated in the user's frame of reference. Another system combines magnetic tracking of an arm moving on a table with a back-projected image of the arm on the table [11]. This arrangement allows the image of the virtual arm to be placed in the correct position relative to the user, but suffers from the potential disadvantage that the real arm can occlude the image of the virtual arm. The same table projection setup has been used to test the rubber hand illusion (RHI) [12] in virtual reality [13], where the virtual versions of the RHI was found to be weaker than the real (unmediated) RHI. Another system comprising a half-mirror, a flat CRT display, shutter glasses, a pen-type haptic phantom display and eye trackers allows users to virtually manipulate sushi on a plate [14]. In this system users see and manipulate the virtual sushi on a plate in stereo as if it was in front of them, but they see only representations of chopsticks rather than virtual arms.

Here we constructed and tested a VR system for displaying correctly positioned virtual arms that aims to optimally trade off fidelity of immersion against cost and usability. Subjects place their arms and hands on a table, which are tracked using digital compasses and data gloves. They look down into a horizontal mirror placed between the eyes and the arms on the table, in which they see a reflected image from a LCD monitor displaying a pair of virtual arms. The monitor can be placed in two positions: a vertical position for normal use (normal position), and a horizontal position to be used with the mirror (mirror position) (see Figure 1). In the mirror position, the virtual arms appear to float and move in space at the same location as their real arms without occlusion by the real arms. We compared the usability and efficacy of the monitor in the

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mirror position with the normal position for generating a feeling of ownership of the virtual arms. Our hypothesis was that our system is as easy to use (or easier) than a conventional display and improves subjective feelings of ownership.

2. Method

2.1. Apparatus

The display system is illustrated in Figure 1, showing the two possible monitor positions. When the monitor is in the vertical position the mirror is removed. Figure 2 shows the data gloves used to transfer movements from the real arms to the virtual arms. The gloves measure angular rotation of the arm in three dimensions and the bending of the thumb, index finger and middle finger. The bending of the virtual ring and little fingers was set to be the same as the virtual middle finger.

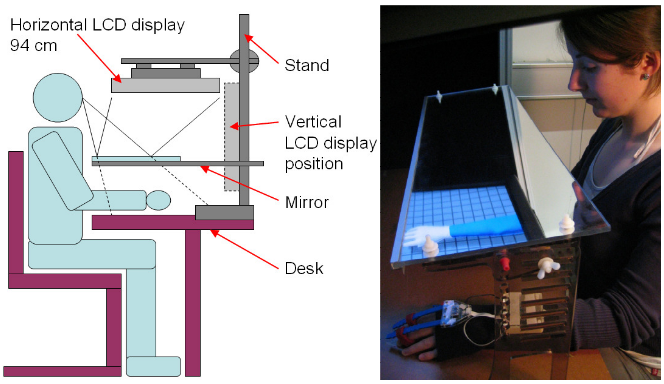

Figure 1: Mirrored arm display. (Left) Schematic of arrangement of mirror and monitor, showing the two possible positions of the monitor. (Right) Test subject wearing data gloves and viewing screen reflected in the mirror. The arms of the subject are lying on the table below the mirror. Due to the mirror reflection, the virtual arms appear to be level with the table.

2.2. Subjects

Forty right-handed healthy participants (19 male, 21 female; 20-73 years, age 42.8±17.0 years [mean ± standard deviation]) took part in the study. Participants were rewarded with the equivalent of USD 20. All procedures were approved by the ethics commission of [[Name withheld for anonymity]].

2.3. Usability testing

Each subject was tested with the screen in the normal (vertical) and mirrored (horizontal) position, assigned randomly for each subject. Subjects put on the data gloves and sat at the table with the screen set to the first position. They then moved their arms, hands and fingers, watching the corresponding virtual movements on the screen until they felt that they understood the correspondence between their own movements and those of the virtual arms. The screen was then moved to the second position. Subjects moved their arms again until they felt that they understood the movement correspondence. Finally, they completed the questionnaire (Table 1).

2.4. Virtual and Real Rubber Hand Illusion

All healthy subjects were tested based on the well-known rubber hand illusion [12]. Subjects sat at the table as before. Their left arm was hidden behind a wall and wore a disposable latex glove. To the right of the arm a clothed rubber arm was placed, also wearing a latex glove.

Real and virtual versions of the rubber hand illusion were applied in an inter-subject randomized order (Figure 2). In the real version, the mirror was moved to the virtual (horizontal) viewing position. A ruler appeared on the screen, and subjects reported where they thought their (non-visible) middle finger was located. Then the mirror was moved backwards to reveal the real rubber arm. Using two identical paintbrushes, the experimenter then simultaneously stroked the middle finger of the rubber arm and the subject's hidden finger at about 0.5 Hz. Subjects were asked to concentrate on the strokes on the rubber hand. Stroking continued for four minutes, as in a previous study [15]. The mirror was then moved forwards again, and a ruler appeared again, this time in a different lateral position so that subjects could not remember the previous number they had reported. Subjects again reported where they thought their hidden middle finger was; the relative lateral shifts were documented as drifts. After the test subjects filled out a RHI psychophysical questionnaire (Figure 5, from [12]). The virtual version of the test was similar, except that the mirror stayed in the virtual viewing position and subjects viewed a pre-recorded video of the rubber arm in the mirror being stroked. The rubber hand in the video was shown at the same position on the table as the real rubber hand.

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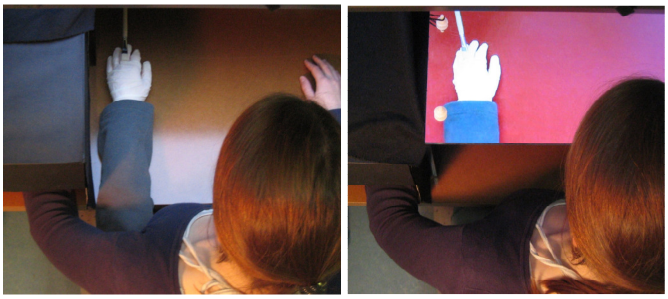

Figure 2. Rubber hand illusion test. (Left) Real rubber hand illusion, showing rubber arm being stroked with a paintbrush. (Right) Virtual rubber arm illusion, showing video of rubber arm being viewed in mirror.

2.5. Data analysis

SPSS was used for all analyses; the RHI and drift analysis was analogous to that used by Ijsselstein, de Kort and Haans [13].

For the usability test a univariate general linear model (univariate ANOVA) was applied for each statement of the usability questionnaire to assess effects of experimental order, gender and age. The data were also checked for interactions between the fixed factors, i.e. first presented screen position and gender. T-tests were conducted to evaluate significant deviations from the neutral response (4 on the scale) towards either the normal position or the mirrored position.

The RHI questionnaires and the drift data were evaluated using repeated measures ANOVA (within-subject effects, between-subjects effects and comparison of real and virtual situation). For the drift calculation the lateral shifts of the ruler were subtracted from their corresponding positions reported by the participants, and the pre-stroking positions were subtracted from the post-stoking positions to quantify the drift.

3. Results

3.1. Usability test

The subjects showed a significant deviation from the neutral response for three statements (Table 1): 2) more enjoyable ($p=0.001$, mean=4.85), 4) more interesting to use ($p<0.001$, mean=5.03) and 6) easier to imagine that the arms on the screen belonged to me ($p<0.001$, mean=5.25). For each of these statements subjects preferred the mirrored position.

Gender influenced two responses: men thought the normal position was more comfortable (statement 1, $F(1,36)=4.588$, $p=0.039$) whereas women judged the mirrored position as easier to use (statement 3, $F(1,36)=4.31$, $p=0.045$).

Age had an influence ($F(1,36)=4.698$, $p=0.037$) on statement 6 in the form of a weak negative linear trend. There were no significant interactions between fixed factors and no significant influences of experimental order or computing experience (statements D1 and D2).

#	Usability statement	Mean	SD	p
1	More comfortable	3.90	1.71	N.S.
2	More enjoyable	4.85	1.56	0.001
3	Easier to use	4.33	1.37	N.S.
4	More interesting to use	5.03	1.49	<0.001
5	Easier to move my arms freely	4.10	1.58	N.S.
6	Easier to imagine that the arms on the screen belonged to me	5.25	1.58	<0.001
7	Prefer to use in the long term	4.48	2.09	N.S.
D1	I use computers regularly	6.35	1.25	-
D2	I am experienced with playing computer games	2.70	1.84	-

Table 1. Usability questionnaire mean and standard deviations of responses of healthy subjects. For statements 1-7, 1 = strong preference for normal position, 7 = strong preference for mirrored position, 4 = neutral. Values of p indicate significance of difference from 4 (neutral). For the demographic statements (D1 and D2) the response scale ranges from 1:'I disagree strongly' to 7:'I agree strongly'.

3.2 Rubber hand illusion and drift

For the RHI questionnaire no significant difference in response was found between the real and the virtual situations for any of the nine statements (Table 2). In both the real and virtual situations age had a significantly positive effect on the response to statement 2 ('RH paintbrush') – older people gave higher answers ($F(1,33)=5.22$, $p=0.029$). Additionally, men gave significantly lower answers than women for this statement ($F(1,33)=4.96$, $p=0.033$). A separate comparison of the real and virtual RHI for the first-presented situation found no significant response differences, and the same was the case for the second-presented situation. Hence we concluded that the order of presentation did not affect our overall result showing that the real and virtual RHIs were indistinguishable.

As reported in previous studies [13], many subjects experience a perceptual drift of their arm position towards the rubber arm, although the drift direction can also be away from the rubber arm. In our results the RHI drifts did not show significant differences between the real and the virtual conditions (real drift = 1.6±6.5 cm, virtual drift = 2.8±6.4 cm, mean±SD), within-subject or between-subject effects. The drift in the real and virtual conditions were positively linearly correlated, $R^2 = 0.47$.

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#	Rubber Hand Illusion Statement: "It seemed as if…"	Real		Virtual	
		Mean	SD	Mean	SD
1	… I felt the paintbrush in the same location as where I saw the rubber hand being touched.	5.34	2.02	5.85	1.71
2	… the touch I felt was caused by the paintbrush touching the rubber hand.	4.84	1.85	5.62	1.76
3	… the rubber hand was my hand.	3.37	2.28	4.59	2.20
4	… my (real) hand was drifting towards the right (towards the rubber hand).	2.29	1.56	2.69	2.01
5	… I might have more than one left hand or arm.	1.68	1.12	1.69	1.15
6	… the touch I was feeling came from somewhere between my own hand and the rubber hand.	2.18	1.78	1.79	1.28
7	… my (real) hand was turning 'rubbery'.	1.87	1.44	1.97	1.66
8	… the rubber hand was drifting towards the left (towards my hand).	1.71	1.29	1.79	1.28
9	… the rubber hand began to visually resemble my own (real) hand.	3.53	2.20	3.74	2.09

Table 2. Real and virtual rubber hand illusion statements and mean responses. The response scale ranged from 1: 'I disagree strongly' to 7: 'I agree strongly'.

4. Discussion

Overall, our mirror-based VR display with its specially designed horizontal mirror placed between the eyes and the arms of the user was reported to be as good or better than a normal (vertical) screen position. The mirrored position was reported to be more enjoyable, more interesting to use and easier to imagine that the arms on the screen were one's own arms. Slight gender differences were seen in which men preferred the normal position being more comfortable and women preferred the mirrored position as being easier to use.

Likewise, the RHI test showed that the virtual mirrored image may be as good as using a real live hand. Both the RHI questionnaire and the measured drift revealed that using a virtual mirror presentation did not measurably affect the illusion. However, despite the fact that the RHI is well known, the small number of studies published to date have widely varying protocols that could have affected our results. For example, when measuring the drifts we chose not to pre-select subjects with strong RHI responses as has been done in other studies, which we felt could bias the results. Furthermore, compared to [13] and [12] which stroked the rubber hand fingers for approximately 7 min. and 10 min. respectively, the stroking in our experiments lasted only 4 min. (as in [15]). Nevertheless, our results for both the real and virtual RHI are remarkably similar to these previous studies, indicating a reliable induction of the RHI in our subjects.

Compared to Ijsselsteijn, de Kort and Haans, who reported significantly lower answers for a virtual condition [13], our results showed similar answers in the real and the virtual conditions. This discrepancy may indicate that the immersion and ownership induced by the virtual environment using our mirror-based method could provide for easier induction of the RHI.

The questionnaire that we used for evaluating user preferences was designed specifically for comparing our mirrored display with a normal display. While it has the advantage of allowing a direct comparison of the two displays in a single series of questions, it may have been useful to additionally apply a standardized questionnaire such as the Questionnaire for User Interface Satisfaction (QUIS) [16] to allow comparisons with other studies. This evaluation will be one of the topics of future work.

Conclusions

Our results suggest that, compared to a conventional large-screen display, our mirror-based VR display provides improved immersion and/or induced ownership of virtual limbs. Further studies on specific subject groups are required to assess its suitability for particular target VR applications.

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