原著論文

Increasing Efficiency in Information Seeking by Using Stereovision with Binocular See-Through Smart Glasses

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Abstract: Recently, binocular see-through smart glasses have become available. These glasses overlay a virtual image stereoscopically on a real world image and are used as a form of augmented reality (AR). People can utilize these working devices in many ways but are useful in industrial environments. The aim of this study is to quantitatively estimate the efficiency of information seeking when using the smart glasses. In the study, we employed a "Route Tracking Test (RTT)" uniquely developed in using 3D imaging and AR technologies. With the help of 142 volunteers participating with the RTT, we evaluated the ease and accuracy of informational seeking task while also checking for fatigue. A comparison was made between using the smart glasses and not using the devices. We found that the smart glasses used in the study significantly increased the ease and accuracy of the task while decreasing the visual fatigue of the participants. We finally confirm the advantage of the smart glasses compared to the conventional way of operational work with paper instructions.

Keywords: see-through smart glasses, work efficiency, information seeking, 3D imaging and augmented reality

1. Introduction

In 1997, Azuma defined augmented reality (AR) as an environment where the real world was supplemented by computer-generated virtual objects [1]. While AR has many potential applications [1-3] such as medical surgery [4] and aircraft maintenance [5], recent developments in the enabling technologies are remarkable [6]. Continued advances in micro-processing technology have brought about decreases in the size of electronic devices. At present, the stream of development of Internet of Things (IoT) which includes "wearable computing devices" is expanding greatly. A few examples of such devices with AR applications are head-mounted displays (HMDs) and eyeglass displays (smart glasses). The former are video see-through (VST) devices where real world images are captured with two video cameras mounted near the user's eyes and are rendered into 3D images. The device directly combines with computer-generated virtual information and then displayed to the user. The latter are called optical see-through (OST) devices where the real world is seen through semi-transparent screens placed in front of the user's eyes and is optically merged with computer-generated virtual information. When wearing HMD or smart glasses, observers can see additional information embedded in real environments.

The advantage of using such devices is that they give hands-free capability for various applications especially in industrial environments including manufacturing that requires picking things up and assemblage, maintenance and inspection, construction, warehouse operations, as well as retail solutions. The devices provide the potential to assist workers to follow work instructions as well as other information without disturbing their current work process [7]. On the other hand, the major disadvantage would be visual fatigue which may occur from a conflict with counter-intuitive depth perception cues that occur between the 3D real world image and the 2D virtual image overlaid in the flat displays [8-10]. The conflict is known as visual rivalry (for review, see [11]) and considered a crucial problem especially in wearing monocular devices. In contrast, such a conflict can diminish in a suitable environment in wearing binocular 3D devices. The latter statement is based on the experimental research evidence confirming that not only convergence but also lens accommodation of the viewers as they gaze at a virtual object presented on 3D LCD behaves like natural vision [12]. The experimental findings directly apply to binocular see-through smart glasses [13]. Therefore, we expect that a virtual image overlaid at an appropriate depth position upon an intended location in the real world image can be naturally perceived, leading to effective enhancement of task performance for industrial workers.

The aim of this experimental study is to estimate how much binocular see-through smart glasses with stereovision technology can increase the efficiency of information seeking

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as a work assisting device. The information seeking task that we adopted in the study was part of visual work process of assembly line workers who undergo considerable cognitive workload. Some benefits of AR to improve the visual assembly guidance to the workers were already pointed out in the experimental test-bed tasks using 3D puzzle pieces [14] or LEGO components [15-17]. However, those experimentations were devised and conducted by using either a 2D monitor [15, 16] or HMDs [14, 17] which presented virtual information in 2D at the fixed depth position of the display plane. Although the HMDs can also be used in 3D environment, it is not fully optimal in an industrial setting from a security perspective as the user's sight of the real world is completely blocked out on the hardware. On the other hand, see-through smart glasses have the advantage of leaving the view of the real world almost intact.

2. Materials and methods

In the experiment, we investigated the work performance of participants carrying out visual search tasks. We used binocular see-through smart glasses (EPSON MOVERIO Pro BT-2000) where virtual information was projected in 3D; that is, at an appropriate depth position in the real environment through the semi-transparent screens. Having only recently been produced, there are only a limited number of studies on such a device. For example, the initial study on calibration of the device for AR was carried out in 2015 [18], and the first measurement of accommodative response when viewing a virtual image moving in depth through the device was made in 2016 [19].

As a visual search task for the experiment, we used the Route Tracking Test (RTT), a uniquely developed test that allows 3D imaging and AR technologies to evaluate the ease and accuracy of operational work. We suppose that the RTT models a part of an assembly process where a worker has to fabricate a product. An assembly manual is typically used to guide the tasks requiring the worker to gather assembly parts from all over the containers placed on a storage shelf and integrate them into a product following assembly procedure instructions. The RTT does not involve any practical manual work process which likely depends on skill of each worker. However, it possibly replicates visual perception process of the instructions given to the worker who is to move promptly to the next operation such as identifying the location of the container where the next required assembly part should be picked up or directing attention from the container to the place to attach the part on an assembly base. In the process, we expect positive effects on human workload and performance if we suitably use smart glasses compared to the conventional way of instructions by paper which requires both holding it by hand and frequent shift of view line during the work [20].

The RTT was set up with a "virtual" path guidance overlaid on a "real" numerical table such as a *sudoku* puzzle (Fig. 1). The path guidance was made in such a way that red arrows accompanied a red circle and a red square. The path aligned uni-directionally on a virtual square plane 20cm on a side and was presented at a visual distance of 70cm in front of participant's eyes through the glasses. This distance was estimated for activities within an arm's reach of a worker.

The numerical table was a square 20cm on a side and consisted of a 9x9 grid of columns and rows with random numbers assigned on each cell of the grid. The size and number of the cells as well as the range of their alignment on the table were designed such that a worker sitting on a chair may easily see the whole of parts installation site. The grid was presented on a 24-inch LCD (G2420HD, BenQ) which was placed at a distance of 70cm straight in front of participant's eyes, where the guiding path was also to be presented as described above.

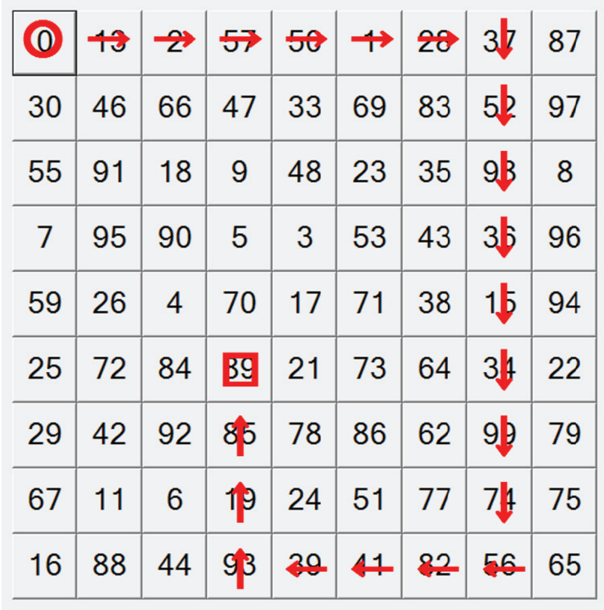

Fig. 1. RTT used in the experiment. The "virtual" path guidance (red figures) is overlaid on the "real" numerical table (black grid with random numbers) through the smart glasses. The path guidance consists of a circle (start), arrows (tracking directions) and a square (goal).

In the experiment, participants maintained a sitting posture. They were asked first to wear the glasses and adjust their face position to the visual distance (~70cm) where each cell of the grid on the real table contained no more than one virtual arrow overlaid. Then, at the start, they were promptly asked to find a circle set to the corresponding starting cell in the upper left corner (i.e., "0" in Fig. 1) of the table, track a sequence of arrows from the starting cell and find the number assigned on a goal cell marked with a square. We note that all the participants were advised in advance not to directly read the number assigned on the goal cell but to necessarily track the arrows one by one to find the number.

In the case without the glasses, we set an instruction sheet of ordinary white paper to the immediate right of the LCD placed on the flat desk. The paper simply contained the same kind of path guidance (i.e., a sequence of a circle, arrows, and a square) printed on it in the range of squared 20cm grid.

The study included a total of 142 volunteer participants. There were 73 males and 69 females covering a wide range of ages between 14 and 88 years old. They undertook the tasks with either naked eyes or a pair of glasses (including contact lenses) depending on their need. Following a few rehearsals by using a smaller numerical table of a 5x5 grid and corresponding path guidance, we asked each participant to complete a real task of RTT and investigated their visual search performance with and without the smart glasses. In order to remove any form of visual bias, we randomized the order of experimental trials with and without the glasses for each participant. The horizontal illuminance at the position of participants was 755*lx*.

We obtained informed consent from all the participants, and the experiment in this study was approved comprehensively by the Ethics Review Board in Graduate School of Information Science, Nagoya University.

3. Results

In the experiment, we measured search time, accuracy of answers, ease of search, and degree of fatigue at each trial for all the participants. The former two measurements were done by objective evaluations while the latter two by subjective evaluations using Visual Analogue Scale (VAS) [21, 22]; each participant was asked to place a mark on the scale between “extremely difficult (0)” and “extremely easy (100)” for ease of search and between “not at all fatigued (0)” and “extremely fatigued (100)” for degree of fatigue. We used VAS to indicate how the participant was feeling right after each trial.

As a result, we found that the see-through smart glasses used in the study could significantly increase the efficiency of information seeking (Fig. 2). That is, the search time decreases to approximately one third and the percentage of correct answers increases by approximately 20 points in the case of the smart glasses compared when only looking at the paper. In addition, the ease of search prominently increases and the degree of fatigue dominantly decreases in the case of the smart glasses compared to the paper. In each graph in Fig.2, we also carried out a t-test to compare the means of two groups, i.e., the paper and the smart glasses. Then we obtained t-value, degrees of freedom (df) and significance probability (p-value) as (a) $t=16.356$, $df=141$, $p<0.00001$, (c) $t=17.209$, $df=141$, $p<0.00001$, and (d) $t=12.380$, $df=141$, $p<0.00001$. As we see $p<0.05$, we confirmed a significant difference between the paper and the smart glasses in each analysis (Fig. 2).

4. Discussion

Binocular see-through smart glasses that enable stereovision can overlay a virtual image at an appropriate depth position as a real world image. Such images can be naturally perceived without visual conflict between viewing a real object of interest and the additional virtually inserted information on the device. Manufacturers of the glasses expect the devices to effectively enhance task performance for industrial workers or others undertaking dual tasks.

The results from this study present key evidence that binocular see-through smart glasses that overlay a virtual image stereoscopically on a real world image are useful for industrial applications since they can increase ease and accuracy of information seeking. Such glasses are also found to cause less fatigue compared to the conventional way of operational work with paper instructions. We consider the main reasons as follows: With the smart glasses, we no longer need frequent shift of view line between the instructions and the real target during the work, resulting in the reduction of human workload and performance.

In the experiment, we employed a number of participants covering a wide range of ages. Nevertheless, standard error of the mean is rather small for each graph in Fig. 2. In addition to the clear difference between the tasks with and without the glasses, we can take the following reason into consideration for the case with the glasses. The virtual images were created and presented 70cm in front of the participants while assuming that their pupil distance (PD) was always fixed to the standard value of 65mm. The situation can be a little problematic especially for those who have smaller values of PD because they may have difficulty in fusing the images in the right depth of the real target in front of them. That is, such participants have a disadvantage to fuse far images in front and may cause visual fatigue, mistakes in their work, etc. [23] However, in our experiment, the images were presented 70cm in front, which we consider is not far enough to cause such a problem. As a result, standard error of the mean is rather small for each graph in Fig. 2.

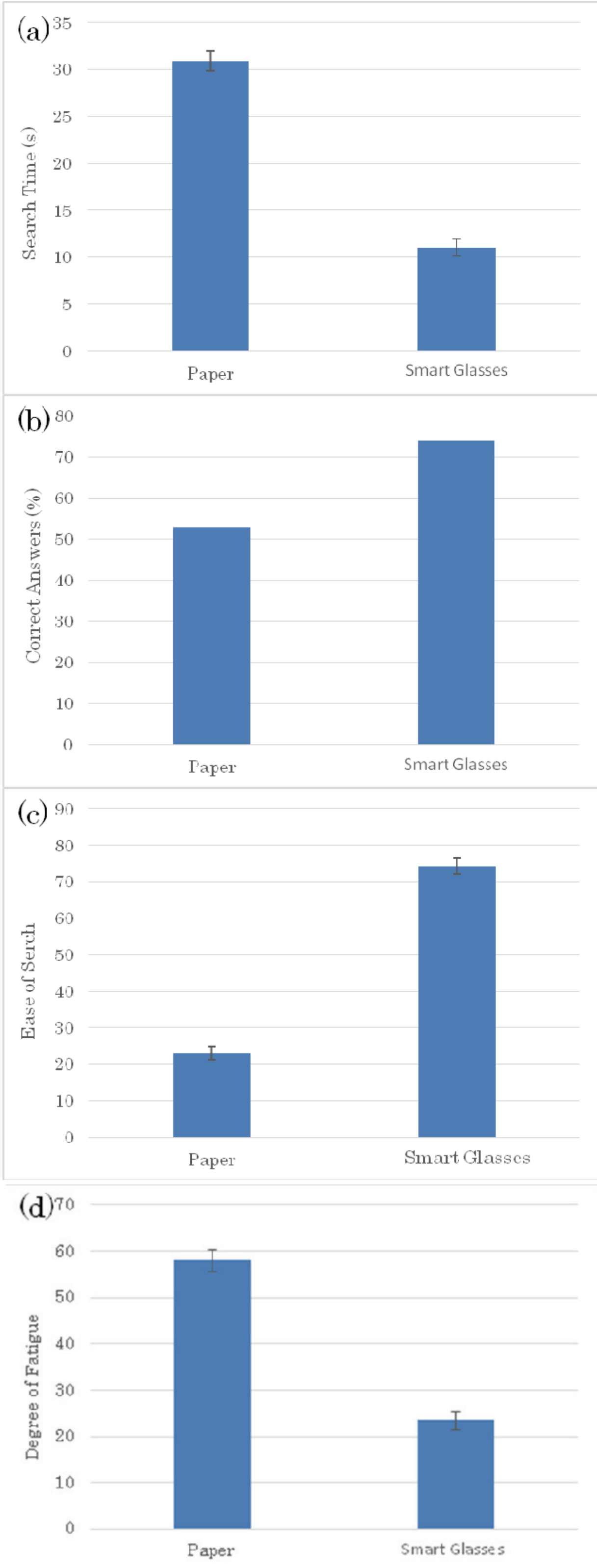

Fig. 2. Average value of all participants (142 males and females): (a) search time (second), (b) percentage of correct answers (%), (c) ease of search (VAS: extremely difficult (0) - extremely easy (100)) and (d) degree of fatigue (VAS: not at all fatigued (0) - extremely fatigued (100)). Each error bar indicates standard error of the mean.

One may also think that not only binocular but also monocular see-through smart glasses can be of similar advantage for such a simple task as RTT. However, apart from the visual conflict described above, monocular see-through smart glasses have essential difficulty in adjusting the depth position and hence the scale of the virtual image to those of the real target since we can hardly find a clue for such adjustment. Further investigation, such as comparison between smart glasses with and without stereoscopic vision, will strengthen the results presented in this paper. Inflexibility of head posture caused by wearing the smart glasses can also be an important factor to be taken into account because it may rather lead to lower performance [20]. We expect that our study presented here will promote and expand a variety of industrial applications of such devices.

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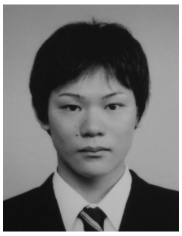

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