MAGIC Pointing for Eyewear Computers

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ABSTRACT
In this paper, we propose a combination of head and eye movements for touchlessly controlling the "mouse pointer" on eyewear devices, exploiting the speed of eye pointing and accuracy of head pointing. The method is a wearable computer-targeted variation of the original MAGIC pointing approach which combined gaze tracking with a classical mouse device. The result of our experiment shows that the combination of eye and head movements is faster than head pointing for far targets and more accurate than eye pointing.

Author Keywords
Eyewear computer; gaze tracking; head tracking; MAGIC pointing;

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces: Input devices and strategies

INTRODUCTION
Even if industry lately is trying to push Head-Mounted Display(HMD)-based wearable computers to the masses for everyday use, interaction challenges remain. The need for interaction on the move [11] and using eyewear devices in parallel with real world tasks require novel hands-free interaction techniques. For example, when hands are busy with real world tasks or in sterile environments such as operation theatre, providing touchless input modalities to the users is a big advantage for eyewear devices. Since eyewear computers sit on the users' head and in front of the users' eyes, head and eye movements are among the most interesting touchless input modalities. While head gesture-based interactions have already been supported by eyewear providers such as Google and Vuzix companies, eye tracking is not still available in commercial eyewear computers.

Just like previous mass-market user interface paradigms used in smartphones and PCs, interaction with eyewear devices relies heavily on the visual modality where point-and-select operations are fundamental. Previous studies of head and eye-pointing for eyewear computers [8, 4] have shown that while eye-pointing (letting eye movements control the mouse cursor) is faster than head pointing and mouse-pointing on HMD-based platforms, the inaccuracy of existing eye tracking methods limits eye-pointing to be used only for large targets on the display [3, 10]. On the contrary, head pointing has been found to exhibit higher accuracy [14, 8] but be limited by ergonomic challenges [4]. In this paper, we try to extend the old idea of the MAGIC (Manual And Gaze Input Cascaded)-pointing [17] to eyewear computers by combining head and eye movements for a target acquisition task. We conducted an experiment to compare the proposed MAGIC pointing approach with head pointing and eye pointing methods. We found that the proposed MAGIC approach benefits from both the speed of eye pointing and the accuracy of head pointing. In addition, the MAGIC method can decrease the amplitude of head-movements and thus ergonomic problems.

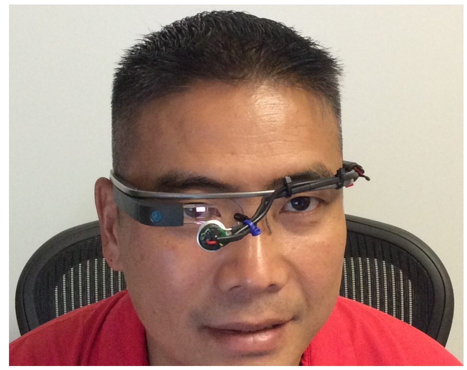

Figure 1. A participant performing the target acquisition task

RELATED WORK
Using eye gaze as an input modality has always been an interesting topic in the HCI community. The typical use of gaze in graphical user interface is a pointing mechanism to control the cursor position on the screen [4, 10]. Gaze pointing has also been explored for interaction with head-mounted displays [2, 8]; however, due to the inaccuracy of existing gaze tracking approaches and the subconscious jittery motions of eye [17], using eye-pointing is limited to the pointing towards large targets on the screen [3, 10, 4]. Aside from the target size limitation, eye-pointing has in several studies been found to be an inconvenient way of pointing [8, 4]. In fact, overloading the visual channel with a motor control task can be the main reason for eye-pointing to be recognized as an inconvenient pointing technique [17].

Another possible method for controlling the cursor is head tracking. The head movements can be detected by a camera [12, 9] or other wearable inertial sensors [7, 5]. Even if up-

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coming eyewear computers such as Google Glass and Vuzix Smart Glass are able to detect head gestures, the head movement as a pointing modality is not much explored for eyewear computers. Previous studies have proved that head pointing method is more accurate and convenient for users compared to eye pointing or trackball mice[8]. However, the mass of the head can reduce the speed of pointing, and it can be tiring for the neck muscles [4].

The MAGIC pointing concept was firstly proposed by Zhai et al [17] to utilize eye movements for a mouse pointing task. In their proposed approach, the cursor is initially placed within the boundary of gaze area, and after the cursor appears, the user completes the target acquisition using a mouse. In this method, users do not need to know that the initial point is tied to their eye gaze; therefore, the whole pointing task seems more intuitive to the users compared to the gaze-pointing method [17]. MAGIC pointing have been explored in different ways in the HCI community. For instance, the combination of MAGIC pointing with a touch-sensitive mouse in the MAGIC-Touch System [6], is proved to be faster for a pointing task on a complex background compared to a normal mouse. Also in the Satellite Cursor System [16], the MAGIC pointing approach has been implemented without gaze tracking with the help of multiple cursors. Stellmach and Dachselt [13] extended the "conservative" method presented in [17] by introducing MAGIC Touch and MAGIC Tab pointing techniques. Their proposed techniques require extra input from users to activate the cursor. On the contrary, we used a "liberal" [17] method where the cursor moves to the new gaze location whenever the eye gaze moves more than a predefined distance from the initial point.

The most relevant work to our study is [15] where the benefits of using head movements to adjust gaze cursor position in a desktop settings is investigated. However, we investigate head-assisted gaze pointing on wearable_ and _near_to_eye_ displays that cover a small portion of the users field of view. While [15] compares a version of MAGIC pointing with gaze-only pointing, we compare MAGIC pointing with head-only pointing. In [15], head movements are directly derived from eye movements obtained from the eye tracker which is not applicable to the eyewear computers without using an additional scene camera. In our study we used the Google Glass' inbuilt inertial sensors for head tracking. The main novelty in our work is to apply MAGIC pointing technique to an eyewear computer setting, while previous works have mainly explored desktop settings. We believe that MAGIC technique can be even more useful for interaction with an eyewear device compared to stationary screens. Because the size of the display is relatively small in an eyewear device which increases the inaccuracy problem of the eye pointing.

EXPERIMENT DESIGN

In this paper, we investigate whether the combination of gaze and head tracking (MAGIC pointing) can reduce the limitations of eye and head only pointing modalities. To answer this question, an experiment is designed where the user accomplishes a target acquisition task by head only and MAGIC methods. In this experiment, we have two different target sizes (30 and 70 pixels) since the accuracy of our gaze tracker is about 1 degree, and the minimum selectable target using only our gaze tracker is about 50 pixels. The design of our experiment covers both larger and smaller targets than this limit. Also we defined two different distances (280 and 100 pixels) for the pointing task.

METHOD

Participants

16 participants (mean age = 29, 2 females) were recruited among local university students to participate in the experiment. Most of the participants were highly skilled computer users ($\bar{X} = 4.62$, $\sigma = .5$, where the range was 1 to 5), and all of them had perfect visual acuity or wearing contact lens. Two participants had the experience of using gaze-tracker systems before.

Apparatus

Since the main focus of our study is developing a novel interaction technique for new eyewear computers, we developed a prototype on the Google Glass platform (see Figure. 1). The inbuilt inertial sensors of the Glass was used to track head movements. While to detect the eye gaze, an external infrared camera was added to the Glass and positioned under the display. The camera sends the eye image wirelessly to a remote server [1]. The server analyzes the eye image in real-time and calculates the eye gaze in two dimensions. The server sends the calculated gaze to the client application on the Google Glass through WiFi connection. The client application receives the gaze data and adjusts the user interface accordingly (see Figure. 2). The accuracy of our home-made gaze tracker system is about 1 degree.

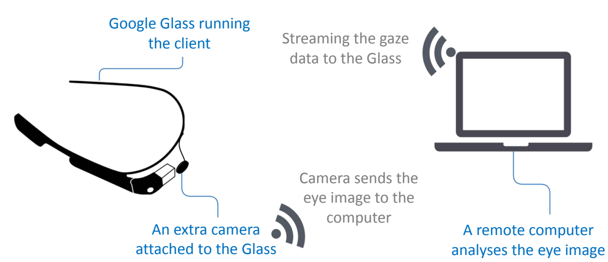

Figure 2. The system architecture of the prototype

Head only pointing technique

To control the cursor by head movements, we used the internal fusion function of the Google Glass ($RotationVector$). This function combines the data from accelerometer, gyroscope, and magnetometer to calculate yaw, pitch, and roll. The yaw value is used to calculate the horizontal position of the cursor (X), and the vertical position of the cursor (Y) is calculated based on the pitch value. The yaw and pitch values are converted to degree and multiplied by 10 to increase the sensitivity of the cursor motion. When the experiment starts the head position of the participant is in neutral state and the cursor is positioned in the middle of the screen. But after performing some head pointing tasks, the user's head might move from the neutral position. The participants were asked to return their head to the neutral position whenever they needed. In such situations, the cursor follows the screen borders.

MAGIC pointing technique

Our MAGIC pointing technique is similar to the Zhai's "liberal" approach [17]. In the MAGIC pointing condition, the gaze data is used as an implicit input to adjust the initial position of the pointer as close as possible to the target. After appearing the target, the user immediately moves the eye gaze towards the target. The gaze tracker calculates the gaze position, and the cursor appears close to the target in the area of 3° around the target. At this point the user is able to control the cursor by head movements to reach the target.

Procedure

The experiment started with a short introduction to the purpose of the experiment and the use of the apparatus. After preparing participants for the experiment, they were asked to use the system for a while until they felt comfortable with all conditions. This usually took 2-3 minutes for each condition. Then each participant was asked to complete the task in three different conditions. The task was a simple target acquisition in which the targets were displayed sequentially on the Glass prism, and the users were asked to point to the targets by combined head and eye movements (1st condition) and head movements (2nd condition), after which the target was conclusively selected by tapping on the Glass touchpad. The targets were red circles with two different diameters of 30, 70 pixels (equal to $0.6°$ and $1.4°$) displayed randomly on a black background one after each other. Since the new target appears immediately after selecting the previous one, the previous target is taken as the start point for the next pointing task. The pointer was illustrated by a white cross controlled by head and eye movements. When the pointer was on the target, users had to tap on the Google Glass touchpad, to select the target and accomplish the task. After the experiment, the participants were asked to complete a short questionnaire with 5-point likert scale questions to reflect on their experience in each condition. The conditions were counterbalanced to avoid the learning effect.

Design

The experiment was an within-subjects design with 16 participants, and each participant completed all conditions in one experimental session that lasted for approximately half an hour. In each condition (head pointing and Magic pointing), participants completed the task for two target sizes (30 and 70 pixels) and two different distances (100 and 280 pixels equal to $2°$ and $5.6°$). In order to remove outliers from the experiment, the participants were asked to repeat each task for 15 times and the median of the 15 trials was taken.

RESULT

We recorded the task completion time and error rate (average of the number of misses by tapping off the target) for each target acquisition task. Figure 3 (a and b) illustrates the mean and standard deviation of the task completion time and error rate for each condition. A repeated measure ANOVA is used to investigate the differences in task completion time and error. Post-hoc paired samples t-tests with a Bonferroni correction were used for pairwise comparisons. (α = .05)

Pointing Modality. The result of statistical analysis showed that the task completion time significantly varied with pointing technique: F(1, 15) = 9.27, $p < .008$. The post-hoc t-tests revealed that head pointing is significantly faster than MAGIC pointing for the short distance (100 pixels) where target = 30 t(15) = 2.42 $p < .029$ and target = 70 t(15) = 5.196 $p < .0001$. However, participants were faster in MAGIC pointing condition when they pointed to the far distance (280 pixels) for target = 30, t(15) = 7.15 $p < .0001$ and target = 70, t(15) = 3.014 $p < .009$.

Target size. As expected, the effect of target size was significant in task completion time in all conditions: F(1,15) = 285.92, $p < .0001$. Participants selected smaller targets at the same distance significantly slower in both conditions.

Distance. Also the distance factor affected the task completion time significantly: F(1,15) = 274.16, $p < .0001$. However, there was no significant difference between pointing to a big target (70) located in different distances in the MAGIC pointing condition t(15) = .037 $p = .971$.

Error rate. Analysis of error rate showed no significant difference between different modalities, target sizes, and distances. The result of questionnaire is represented in the Figure 3 (c). In the MAGIC pointing condition, we also calculated the portion of gaze in the total task completion time. In average only 8% of the total pointing time was spent by gaze tracker to detect the eye gaze and move the cursor close to the target. Moreover, in 33% of the MAGIC pointing trials with big target (70) the gaze point was exactly on the target, while for the small targets (30) just in 4% of the trials the detected gaze point was on the target.

DISCUSSION AND CONCLUSION

In this paper we empirically evaluated a pointing modality for eyewear devices using a combination of head and eye movements. All of the participants were able to complete the task. Using our gaze tracker for pointing, users would be able to select only targets larger than 50 pixels, while in our experiment all of the small targets were successfully selected using MAGIC pointing. This means MAGIC pointing technique makes it possible to select targets smaller than accuracy of our gaze tracker system.

Findings from the experiment, showed that MAGIC pointing is faster than Head pointing just for long distances. One reason for this can be the delay of the gaze tracker system to detect the gaze coordinate and communicate it to the eyewear device. If the target is too close, the head only pointing can start immediately, but in the MAGIC pointing condition, user should wait until the gaze point is detected close enough to the target. This means MAGIC pointing is faster than Head pointing only for the far targets which is in line with our initial goal which was to reduce amplitude of head-movements and its ergonomic problems. In fact, for pointing to the close targets the head does not need to move a lot. Another observation is the fact that the speed of MAGIC pointing method

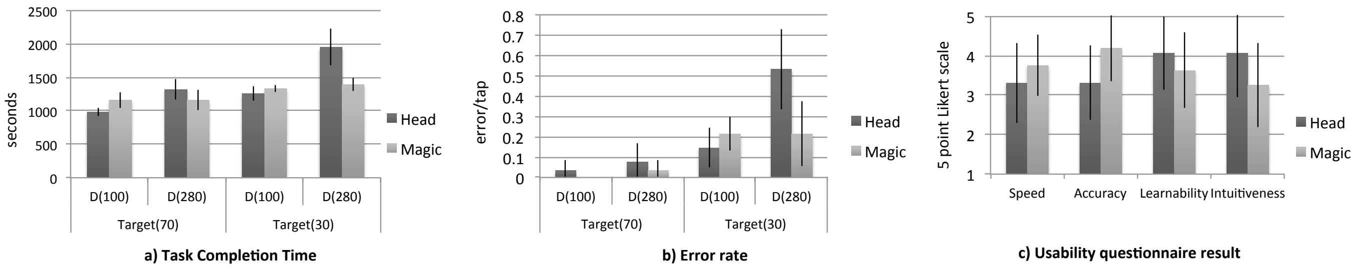

Figure 3. a) Mean of the task completion time for two distances: D(100) & D(280), two target sizes: T(30) & T(70), and two modalities: Head & MAGIC pointing, b) Mean of the error rates for all conditions, c) Results of the usability questionnaire

does not depend on the distance for big targets. This can be due to the fact that in MAGIC pointing condition, most of the distance between initial position of the pointer and the target is gone by eye movements, and the manual part of the pointing task is the distance from warped cursor position to the target. Which means the manual part of the pointing task is independent from the initial position of the pointer.

Our prototype is based on the state of the art technology in eyewear computers (Google Glass) to evaluate practicality of the MAGIC pointing as a novel target acquisition technique for these devices. Our findings indicate that 1) the MAGIC pointing looks very promising technique for target acquisition in eyewear computers, 2) probably in the emerging gaze informed (attention-aware) user interfaces, the traditional design guidelines based on the Fitts' Law (e.g. minimizing the cursor movements etc.) cannot be directly transferred to this new interface paradigm.

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