Magic-Sense: Dynamic Cursor Sensitivity-Based Magic Pointing

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Abstract
MAGIC (Manual and Gaze Input Cascaded) pointing methods use eye gaze as a complementary input for the primary input device. This paper introduces a novel MAGIC pointing technique to provide fast and accurate selection. Cursor sensitivity is reduced near eye focus to allow fine selection, and increased away from target to improve selection speed. MAGIC-SENSE is tested against a traditional mouse and a gaze only pointing method using an ISO 9241-9 compliant circular Fitts' Law experiment. Using MAGIC-SENSE, subjects achieved lower error rates without compromising movement times compared to mouse-only method. A local calibration method that can boost all MAGIC pointing techniques is discussed.

Author Keywords
Magic; pointing; accuracy; eye; tracking

ACM Classification Keywords
H.5.2 [Information Interfaces And Presentation]: User Interfaces - Input devices and strategies (e.g., mouse, touchscreen);

General Terms
Performance, accuracy, evaluation, eye tracker, usability, adaptation, interface.

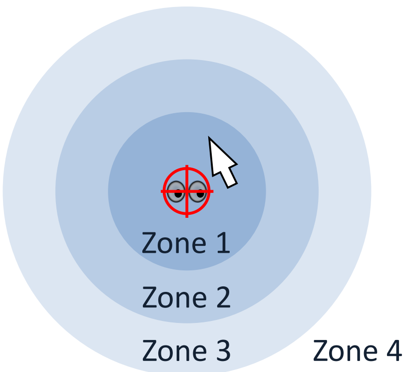

Figure 1. Sensitivity zones, gaze center, and target.

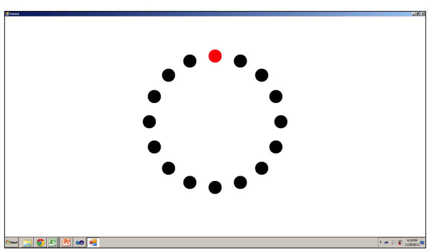

Figure 1. Circular Fitts' Law Experiment.

Introduction

Eyes move quicker than hands. Replacing traditional hand-held manual input devices, such as mouse, with eye tracking can greatly improve interaction speed [7]. While this replacement shows promise in faster interaction, the trade back is lower accuracy. Current eye tracking systems do not allow a high enough pointing precision for accurate selection of small targets. In this work, we aim to improve pointing performance by increasing selection speed and reducing selection errors via dynamically adjusting cursor sensitivity.

MAGIC pointing utilizes gaze input to aid manual pointing, instead of replacing it [12]. The idea is to let the user bring the cursor close to the target using gaze input, and then make the final selection by manual input. This combines the accuracy of our hands with the speed of our eyes.

In 1999, Zhai introduced the first two MAGIC pointing techniques, liberal and conservative, that warp the cursor to gaze center [12]. Liberal method continuously warped the cursor whereas conservative one triggered warping on hand movement. A pilot study showed that both methods significantly increased throughput, a combine measure of speed and accuracy, for an isometric joystick (TP[Liberal] = 4.76, TP[Conservative] = 4.55, TP[Joystick-Only] = 3.2).

Ten years later in 2009, three separate studies explored new directions in MAGIC pointing. Drewes combined the liberal method with a touch-sensitive mouse, activating continuous warping only when user touches the mouse [3]. The study reported some improvement of movement time when there is a complex background image.

On two separate studies, Blanch and Raiha investigated the use of gaze input to select between multiple cursors on screen [1, 8]. While both studies reported reduced error rates, Blanch also reported improvement in movement time.

Looking at the handful of studies that explored the benefits of combining manual and gaze input, we observe two important outcomes. One, users are able to complete tasks using MAGIC pointing techniques. Two, speed and accuracy improvements to the traditional manual-only interaction are possible by incorporating gaze input.

However, manual and gaze input have never been truly merged before. So far, all introduced methods break the pointing task into two discrete sub-tasks. The first sub-task is to bring the cursor to the vicinity of the target, and the second one is to make precise pointing. Eye gaze is assigned to the first task, while manual input is in charge of the latter, requiring a constant switching between input channels.

MAGIC-SENSE is a new direction in MAGIC pointing where manual and gaze input channels are truly merged. The pointing task is not broken into subtasks. Rather, gaze input is used to determine the user's *precision requirements*, and then cursor sensitivity is adjusted accordingly. This work, to the best of our knowledge, is the first attempt to design and evaluate such a method. To shed light in the direction of the MAGIC-SENSE development, a pilot Fitts' Law experiment was conducted using a webcam-based eye tracker.

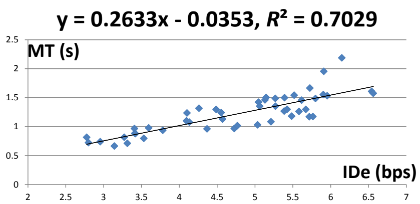

Figure 2. Mouse-only results before averaging the MT and ID_e values for each ID condition.

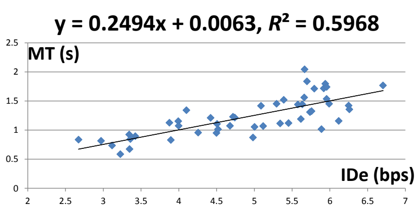

Figure 4. MAGIC-SENSE results before averaging the MT and ID_e values for each ID condition.

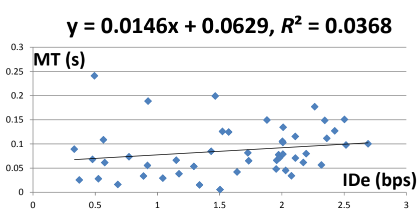

Figure 5. Gaze-only results before averaging the MT and ID_e values for each ID condition.

Background

The human capability of carrying out rapid aimed movements is described by Fitts' Law [5, 10]. The performance measure throughput (TP) is related to index of difficulty (ID) and movement time (MT) as shown in equation 1.

$$TP = ID / MT \tag{1}$$

The first application of Fitts' Law in HCI was by Card in 1978 [2]. Since then, different formulations of ID was proposed. ISO 9241-9 suggests the use of Shannon formulation of index of difficulty with an adjustment for accuracy as in equation 2 [10, 13].

$$ID_e = log_2(D_e / W_e + 1) \tag{2}$$

Next, equation 3 describes how W_e is calculated.

$$W_e = 4.133\sigma \tag{3}$$

Finally, adjusted distance (D_e) is calculated as the mean distance travelled. Soukoreff and Mackenzie provided an in-depth, step-by-step guide to designing Fitts' Law experiments for HCI [10].

Design & Implementation

Eyes have higher resolution near gaze center [4]. Therefore, accurate pointing can only happen near gaze center, since our vision is limited further away. This implies that there is a higher need for accuracy near gaze center compared to the rest of the screen.

To take advantage of this biological limitation, we break the screen into four distinct zones as shown in Figure 1. Cursor sensitivity is decreased to a low sensitivity setting at Zone 1, where cursor is closest to target. As the cursor falls into further zones, sensitivity is increased to higher values.

Most Microsoft Windows platforms offer a sensitivity range between 0 and 20, going from lowest to highest. In our implementation of MAGIC-SENSE, we chose to set the zonal sensitivities as the following - Zone 1: 8, Zone 2: 13, Zone 3: 17, and Zone 4: 20. For the mouse-only method, sensitivity was set to 13. In future implementations of MAGIC-SENSE, these numbers can be optimized, or the users can be allowed to fine-tune them to their liking. Likewise, the number of zones can be adjusted to achieve better performance. The accuracy of eye tracking should be considered while making such modifications. For example, a very narrow Zone 1 may be off the target if there is a large gap between the reported gaze coordinates and the actual target coordinates.

One of the advantages of MAGIC-SENSE over the previously introduced MAGIC pointing techniques [1, 3, 8, 12] is that reliance on accurate eye tracking is reduced. In other words, the worst thing that can happen is an uncomfortable sensitivity setting. While this can possibly get annoying, we do not think it would make the interaction impossible.

In this paper, we conduct a pilot study to test the performance of MAGIC-SENSE against a mouse-only and a 1 second dwell time-based eye gaze-only method.

Evaluation Methodology

Equipment

As the cost of commercial eye tracking systems remain in four to five figures, more affordable webcam-based

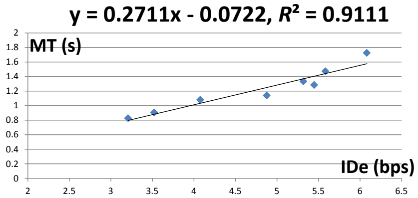

Figure 6. Mouse-only results after averaging ID_e values.

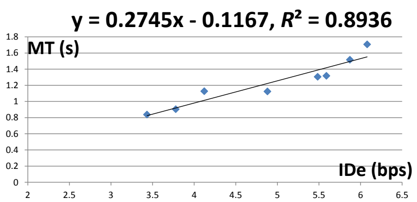

Figure 7. MAGIC-SENSE results after averaging ID_e values.

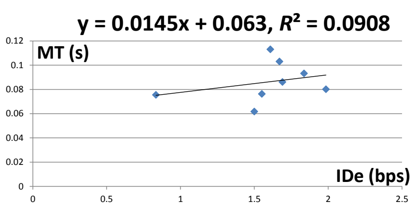

Figure 8. Gaze-only results after averaging ID_e values.

options appeal to a wider community. Skovsgaard compared a webcam-based option that uses ITU Gaze Tracker, an open source eye tracking software, to two commercially available systems [9]. Skovsgaard reports that while one of the commercial systems resulted in lower error rates, the webcam-based solution offered highest accuracy. In our experiment, we used a similar setup.

- Sony Playstation 3 EYE Camera (Modified)
  - 75 fps @ 640x480 pixels
  - 4.3mm m12 Lens (Replaced original)
  - 850nm Visible Light Filter (Added)
- Clover Electronics IR010 Infrared Illuminator
- Intel Core i3 @ 2.13 GHz, 4.0 GB RAM
- ITU Gaze Tracker 2.0b 64-bit
- Chinrest

Fitts' Law Experiment

Figure 2 shows the circular Fitts' paradigm used in our experiment. A range of ID conditions between 2 to 8 should be used in Fitts' Law experiments [10]. For all three pointing methods, the experiment consisted of 8 conditions with indexes of difficulties (ID) ranging from 2.7 to 7.5. Each condition included 17 targets. Shannon formulation was used to calculate ID values. To comply with ISO9241-9, we measured the end-point scatter and movement times to perform adjustment for accuracy. Then, we plotted the data and investigated goodness of fit. We calculated the throughput of each pointing method using mean of means.

Our pilot study involved 6 subjects, 5 male and 1 female, between the ages of 19 and 35. All subjects received one training session for gaze-only and MAGIC-SENSE, and one recording session for all three methods. We asked subjects to click on targets as quickly as possible. Recording sessions were balanced using Latin square to counter learning effects.

Results

Calibration

All subjects attained reasonable accuracy with the eye tracker. Tracking accuracy varied between 0.1 and 1.2 degrees of the visual angle as reported by the ITU Gaze Tracker software.

Goodness of Fit

Results for mouse-only and MAGIC-SENSE methods revealed a relatively poor fit to Fitts' Law, whereas the gaze-only results showed no relationship. Figures 3, 4 and 5 illustrate the linear regression plots.

As suggested in the Soukoreff and Mackenzie paper [10], adjustment for accuracy assigned a unique ID_e for each condition completed by each user. Plotting all 48 ID_e values against respective movement times resulted in relatively low R^2 values. However, when we averaged the ID_e values assigned for each ID with their respective average movement times, we observed a much better fit with all three conditions. Figures 6, 7 and 8 display the regression plots after averaging ID_e values.

Gaze-only method has been shown to follow Fitts' Law [11, 14]. In our experiment, the very low R^2 value for the gaze-only method was most likely due to very small target widths (4, 6, 8, 10, 12, 20, 50 and 100 pixels). A large difference between ID and ID_e values may indicate that the tasks were not suited for the pointing device [10]. While we used a variety of ID values between 2.7 and 7.5, they shrank to a narrow range of ID_e values from 0.33 to 2.69 because of the expected high

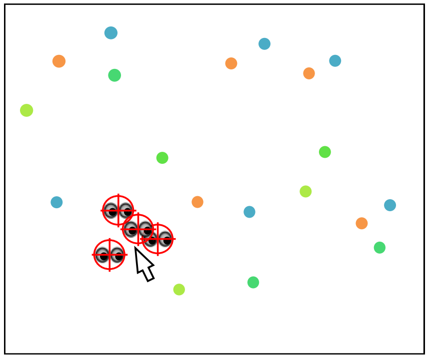

Figure 9. Nearest local calibration point changes with jittery eye gaze center coordinates. An offset vector is associated with each point.

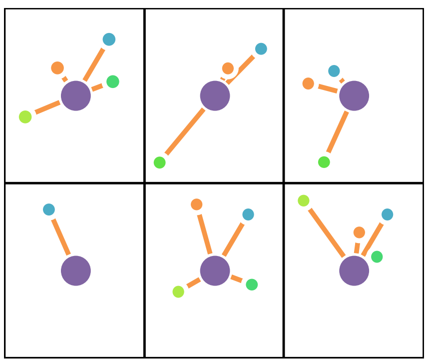

Figure 10. Local calibration points averaged for each window. An offset vector is associated with each point.

offset between target center and end points. In other words, subjects not only made too many errors using gaze-only, they made very large errors. These large errors resulted in a high standard deviation of end point scatter, decreasing ID_e values substantially. This suggests that MAGIC pointing techniques should be compared to gaze-only methods using larger, more suitable targets.

Error Rates, Movement Time, and Throughput
The error rates were significantly lower with MAGIC-SENSE at 18% compared to mouse-only method at 22% (t-paired(47) = 2.15, $p < 0.05$). Gaze-only had the highest error rates at 83%. The improvement in error rates was most likely because of the lower sensitivity setting (8) near the target compared to the fixed sensitivity for mouse-only (13).

After removing dwell time, gaze-only had the lowest average movement time at 0.086 seconds, Mouse-only and MAGIC-SENSE achieved similar results at 1.22, and 1.23 seconds respectively.

While the increase was not significant (t-paired(47) = 1.84, p = 0.07), MAGIC-SENSE showed a slight improvement in throughput. The results were: TP[MAGIC-SENSE] = 4.1, TP[Mouse-Only] = 4.0, and TP[Gaze-Only] = 1.5 bits per second.

Discussion

We observed a difficulty users had with MAGIC-SENSE. Subjects seemed to have more over-shoots compared to the mouse-only method. This particular problem was also observed in the initial MAGIC pointing paper [12]. This is most likely because of the difference between the reported gaze point and the actual target location. MAGIC pointing guides the manual interaction in a slightly wrong direction.

We propose a local calibration idea that all MAGIC pointing techniques can benefit from. Jacob introduced local calibration as a means for the user to improve calibration accuracy [5]. The idea was that user brings the cursor to a desired location on the screen. Staring at the cursor, user clicks on a button. The offset between cursor and gaze locations are recorded as a local calibration point. Reported future gaze points are then adjusted according to the nearest local calibration point.

An inherent strength of MAGIC pointing yet to be explored is that every click can be considered as a local calibration point. We applied this automated version of Jacob's method, and observed that the reported gaze center points were warped closer to the cursor location. However, there was a problem when gaze location was between multiple local calibration points; the jittery gaze coordinates were affected differently by multiple local calibration points. This problem is illustrated in figure 9.

To possibly overcome this variable offset problem in future research, we propose a weighted local calibration method. First, we divide the screen into a grid of 12 windows with 3 rows and 4 columns. An average offset vector for each window is calculated by the mean offset of the n latest local calibration vectors within its borders as shown in figure 10. Then, we dynamically adjust the gaze coordinates by the weighted average of each window's offset, where the weight is the inverse of the distance between the current gaze center and the window center.

This method allows us to smoothen the dynamic offset adjustment, limit the number of points for which we have to calculate the weighted offset in real time, and keep the most current calibration offset for different parts of the screen. After implementing the weighted local calibration, we no longer observed the variable offset problem. We are planning to investigate this method in more detail in our future work.

Conclusions & Future Work

This paper explored the possibility of using cursor sensitivity as a means to cascade manual and gaze inputs. The findings support previous work in that users are able to use MAGIC pointing techniques, and there is a potential to achieve higher speed and accuracy compared to traditional manual-only pointing.

As future work, we are planning to employ the weighted local calibration to MAGIC-SENSE, liberal and conservative MAGIC pointing methods. We will test all three MAGIC pointing techniques against mouse-only and gaze-only methods, using more subjects and more suitable ID conditions.

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