Magnetic Cursor: Improving Target Selection in Freehand Pointing Interfaces

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ABSTRACT
We present the magnetic cursor, a technique that aims to make distant freehand interaction with targets easier in large-screen public display applications. The magnetic cursor automatically warps to a selectable object that is close by, moves slower while on the object, and shows the relative cursor location visually to the user. Two designs of the magnetic cursor were compared to the snap-to-target technique in a 19 participant user study. Results indicate that the magnetic cursor design with weaker magnetism effect outperforms the other techniques in terms of target selection efficiency. Subjective feedback indicates that snap-to-target and the magnetic cursor design with weaker magnetism effect meet the participants' expectations for freehand pointing and are preferred to unassisted pointing and the magnetic cursor with stronger magnetism. Our findings suggest that the visual feedback of cursor location and short, static activation threshold for the magnetism effect can help users maintain the cursor within the active motor space of a target, especially when several selectable targets are situated in close proximity.

Categories and Subject Descriptors
H.5.2 **[User Interfaces]**: Interaction Styles; User-centered Design; I.3.6 **[Methodology and Techniques]**: Interaction Techniques

General Terms
Design, Experimentation, Human Factors.

Keywords
Freehand pointing, public display applications, target selection, user experience.

1. INTRODUCTION
Despite technological advancements and the unique potential benefits that gesture interfaces can offer, it is still uncommon to encounter gesture-controlled systems in public spaces, as many public display installations are either non-interactive or rely on touch or physical keys for interaction. In addition, real world studies of gesture-based interaction are still relatively rare in the context of public display systems, as many of the in-the-wild studies tend to focus on other aspects, such as the use (or non-use) of such systems. Also, only relatively few studies (e.g., [2, 7, 13, 14]) have investigated freehand pointing and the challenges associated with selecting on-screen objects.

The current research on target selection assistance is motivated by our initial usability findings of the use of Information Wall, a public display application that offers easy access through a freehand point-and-gesture interface to simple information like the latest news and events in nearby areas at the university campus. In freehand pointing systems, a simple pointing task requires focused hand-eye coordination and long term pointing based interaction is likely to result in physical fatigue faster than when using e.g. a mouse or handheld controller. These characteristics of freehand pointing, along with jitter and noise inherent in sensor-based detection, make it more difficult to hold the cursor steady than comparable methods utilizing physical input devices. Accurate freehand pointing can be especially challenging when multiple targets are in close proximity. Making the selection process as easy and intuitive as possible therefore aims to help reduce the cognitive and physical load of the users.

Our approach was to make target selection easier utilizing a novel assisting technique that is designed to work together with dwelling selection. This paper presents the results of an experiment where the two designs of the technique were compared to the snap-to-target technique, which has been previously proposed as an assisting method for target selection.

The rest of the paper is organized as follows. We will first introduce the context of our research, the Information Wall public display application. We then review related work on assisting methods for target selection in cursor-based pointing. Next, we introduce the Magnetic Cursor technique and describe the experiment conducted to study its effectiveness. Following, we report the results and discuss their implications for the design of targeting assistance techniques for freehand pointing.

2. INFORMATION WALL
In order to study gesture-based interaction in a public setting, we have developed a public display application called the Information Wall. Interaction with the Information Wall takes place via an on-screen cursor that moves according to where the user is pointing on the physical screen (Figure 1). The system utilizes the Microsoft Kinect sensor for detecting the users' hand coordinates, and maps these to the onscreen cursor location. Users can navigate the content with simple gestures, such as swiping to the cardinal directions to rotate the on-screen information cube in order to reveal new content. The rotation is triggered by selecting an edge of the cube, which involves hovering, or dwelling, the cursor over an active interface element for a short period of time. The same selection paradigm also applies to other objects, such as

buttons and list items. Dwelling was selected as the selection method because not only is it easy to provide immediate visual feedback but it also does not require any additional gestures, and has been found to be more intuitive than other selection methods such as grasping or gestures [7].

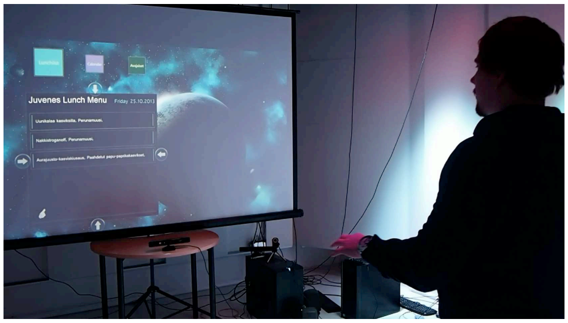

Figure 1. The Information Wall.

3. RELATED WORK

Several different targeting assistance methods have been proposed in previous research, although very few of them have been developed or evaluated specifically with distant freehand pointing in mind. These techniques can be broadly divided into ones that reduce the distance from the cursor to the target, either by moving the cursor closer to the target or the target closer to the cursor, or by increasing the size of the cursor or target [11].

Kabbash and Buxton [8] presented the area cursor, which is a static rectangular area, and to interact with a target the cursor only needs to touch it, not completely contain it. The area cursor is problematic with small and dense targets, as several targets may touch the cursor simultaneously. Worden et al [15] improved the area cursor by adding a crosshair to the center of the area. When several targets are contained within the cursor, the one closest to the center is selected. Grossman and Balakrishnan [6] developed the bubble cursor where the ellipse-shaped cursor dynamically resizes itself based on surrounding targets. Resizing is made so that the cursor always touches the closest target, but – thanks to its shape - never touches multiple targets at the same time.

Several targeting assistance approaches are based on expanding the target size in motor space, typically by manipulating the control-display (CD) gain. In semantic pointing [4] the CD gain is adapted according to cursor distance from nearby objects. Objects can have a unique size in motor space as well, and so it would be possible to have for example the most commonly used buttons larger than others in motor space. König et al [9] presented the adaptive pointing technique, which smoothly adjusts the CD gain of the cursor based on the speed and direction of movement, so that pointing appears more precise while still maintaining the feel of absolute pointing, e.g. the cursor appears where the input device is pointing, which makes the technique possibly suitable for distant freehand pointing, too. Ahlström et al [1] presented the force field technique, which works by creating an area around a target, inside which the CD gain for the cursor is lowered whenever the cursor moves towards the target (force point), making the cursor move faster than normal. While moving away from the target, the CD gain is increased again until it reaches the default value. In essence, the user is supposed to feel that the cursor is “attracted” to the target.

With sticky targets (or sticky icons) [1, 5, 15], the cursor moves slower than normal when it is on top of an object. In traditional desktop environments sticky targets have been found to be efficient in simple pointing tasks, but in real-world situations sticky icons might increase acquisition times as users would need to pass through several icons that make the cursor slower to get to the desired target. Some methods combine both at distance and while on the object. For example, Bateman et al [3] proposed a technique called target gravity, which makes the cursor attracted to objects from a distance and makes the cursor move slower while on an object. All gravity-enabled objects affect the cursor’s location at the same time.

Relatively few studies have addressed the effectiveness of targeting assistance in non-desktop environments. Bateman et al [3] compared several different techniques with the Nintendo Wiimote as the input device. The target gravity technique was found to be the fastest and most preferred by users. Parker et al [12] compared different targeting assistance methods for stylus-based pointing in tabletop interaction. Their first proposed technique was expand-cursor, in which a circular area surrounds the cursor whenever a selectable object is close enough. The circle grows bigger as it nears an object and shrinks and vanishes when it moves away from the object. The object can be selected when the circle overlaps it, similar to the area cursor. Expand-target works the other way around – the object itself grows bigger when the cursor is moving closer, and shrinks back to its original size when the cursor moves away. In snap-to-target, the cursor “snaps” to the center of an object when it is close by. The cursor moves out of the object when the “real” cursor position moves further away. Snap-to-target was found to be the most efficient, accurate and subjectively preferred. All of the techniques proposed by Parker et al activate when the cursor has travelled 90% of the distance between the starting point and the target.

4. MAGNETIC CURSOR

Based on existing research, we recognized attributes that we wanted to have in a technique that assists in selecting targets in gesture interfaces. First, gesture-based interaction especially in public spaces is a relatively novel domain to most users. For this reason, the cursor should appear familiar from other environments, and thus its visual attributes should not be significantly altered during runtime. Second, distant freehand pointing is an absolute pointing technique, which means that targeting assistance methods that significantly alter the behavior or location of the cursor are not preferable. However, it has been found that small position changes may improve targeting time without being perceptible to the user [10]. Third, it is important to note that in most other types of input devices it is a trivial task to keep the cursor stationary. To achieve the same in distant freehand pointing, users have to focus to maintain their arm stationary. Also, typically interaction with targets happens by gesturing with the same hand that is used for pointing, like forming a fist or making a pushing motion. While performing the gesture, the cursor can easily move around unintentionally. Thus, the assisting technique’s task in freehand pointing interfaces is twofold: make *acquiring* the desired target faster and easier, but also make *staying* on the target easier.

As a solution, we developed the Magnetic Cursor technique, which combines the snap-to-target and sticky icons approaches. To achieve the basic requirements outline above, the cursor has two functions; when it moves close enough to a selectable target, it automatically jumps onto that target, and while it is on the target, it moves slower than normal, requiring more movement to jump out of the target. When the cursor jumps onto an object, its position is calculated relative to the actual point where the user is pointing, i.e., pointing at the very edge of the area where magnetism is in effect will move the cursor to the corresponding edge of the object. The dynamic positioning tells the user whether one is actually pointing at the desired target or if one is barely inside the effective area.

The cursor's position is calculated as

$$c \pm a * r / m$$

where *c* is the (x,y) center of the target, *a* is the distance between the target center and the point where the user is actually pointing, *r* is the radius of the target, and *m* is the radius of the area where magnetism is in effect, calculated from the center of the target. In the case of the cursor being inside several magnetic areas, the closest object is always chosen.

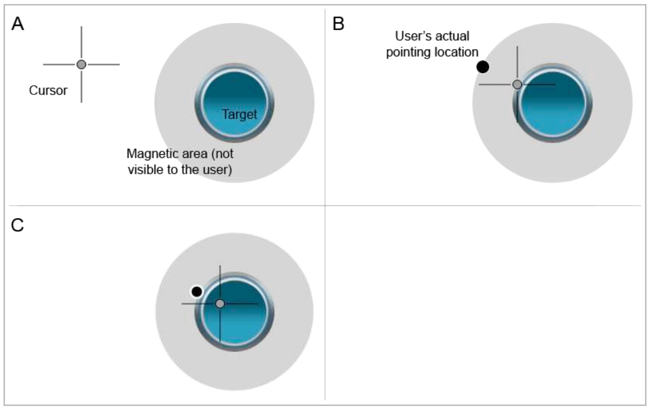

Figure 2. The Magnetic Cursor. A: While outside magnetic areas, the cursor follows the user's pointing location. B: At the edge of a magnetic area, the cursor warps onto the corresponding edge of the target. C: When pointing closer to the target, the cursor moves closer to the target relative to the radius of the magnetic area and the distance between the actual pointing location and the center of the target.

The magnetic cursor's behavior is demonstrated in Figure 2. In Figure 2C, the actual pointing location has travelled 50% of the distance between the edge of the magnetic area and the center of the target, and thus the visual cursor is positioned halfway between the center and the edge of the target.

4.1 Pilot study

A pilot study with seven participants was conducted to study the feasibility of the magnetic cursor technique. Our research questions were: (1) How does the magnetic cursor compare to the normal, unaltered cursor? (2) Does the magnetic cursor increase error rate? (3) What is a suitable activation threshold for the magnetic cursor? The *threshold* refers to the distance from which the magnetic cursor activates and moves onto a target. Thresholds of 100 and 200 pixels were evaluated, while the target radius was a static 100 pixels. In the 2D target acquisition experiment, the participants' task was to select the indicated button while balancing speed and accuracy. An early version of the Information Wall system was used as the interface.

The results showed that both magnetic cursor designs were almost twice as fast as the normal cursor, with the stronger (200-pixel threshold) version being the fastest. Subjectively, 5 out of 7 participants chose the 100-pixel version to be more pleasant to use. The error rates were higher with the magnetic cursors compared to the normal cursor (0.5%). At 2.4% and 3.3%, respectively, they are in line with error rates reported in previous research. Given the low absolute level of errors across conditions, the magnetic cursor can be considered more efficient than a normal cursor in practical terms.

5. EVALUATION

The objective of our user study was to examine both the objective (pointing performance) and subjective (user experience) properties of the proposed Magnetic Cursor technique in comparison to another similar technique, snap-to-target [12]. As discussed earlier, we wanted a cursor that does not visually alter itself or the objects, but instead changes the way it moves based on its and the objects' locations. Also, in the study by Parker et al [12], snap-to-target not only emerged as the most efficient and also the most preferred technique, but was also evaluated on a pen-based distant pointing system with similar characteristics to a freehand pointing interface. The target gravity technique evaluated by Bateman et al [3] shared many of the features, however it was concluded to be too subtle for the experiment as the cursor still requires movement towards the target after crossing the gravity threshold. In addition, given the inconclusive results on the activation threshold in the pilot study, we decided to include both versions of the magnetic cursor in the user study. Considering the results from previous studies and the pilot, the normal cursor was included in the study to serve as an introduction to freehand pointing and as a warm-up session.

Given the characteristics of the assisting techniques, our main hypothesis was that, owing to its visual feedback of pointing location, with magnetic cursor it would be easier for users to maintain focus on the selected element because they get visual feedback of the relative pointing location compared to techniques that do not provide such feedback, such as unassisted pointing or snap-to-target. Further, we were interested in examining the tradeoffs between ease of selection and susceptibility to erroneous selections in the presence of multiple targets. Finally, we were interested in investigating whether the differences in the techniques would be perceptible enough to users to result in differences in subjective feedback.

5.1 Participants

A total of 19 participants took part in the study, 3 women and 16 men. Their age varied from 19 years to 57 years (mean = 24). Most participants had some experience with gesture-based systems, all from the gaming domain using the Nintendo Wii, Microsoft Kinect, or PlayStation Move. Participants were recruited from a basic first-year interactive technology course held at a local university. Participation in the user study counted towards the completion of their course credit.

5.2 Apparatus

The study was carried out in a laboratory setting in October 2013. The interface was displayed on a 1920 x 1080 full HD projection screen. Participants were instructed to stand 2.4 meters away from the screen center.

An experiment application utilizing Microsoft Kinect as the input device was implemented specifically for the study. The default smoothing algorithm of the Kinect SDK was used to filter out minor input jitter. Calculation of the pointing coordinates is based on the Physical Interaction Zone data provided by the SDK.

Snap-to-target was implemented the same way as in the study by Parker et al. Thus, with levels of 400 and 800 pixels we used for distance, snapping would activate when the cursor was either 40 or 80 pixels away from the edge of the target. Similarly to the magnetic cursor, if multiple targets were inside the snapping threshold, the closest target was chosen.

5.3 Task

We used a 2D target acquisition task, where participants pointed at and selected targets positioned around the screen. One highlighted button would appear at a time, surrounded by four, visually different distractors (Figure 3). Distractor targets were added around the target button to investigate the performance effect of different magnetic cursor thresholds on selection time in scenarios where multiple targets appear within the activation threshold. Accidentally selecting a distractor was counted as an error and task progress required the correct button to be selected.

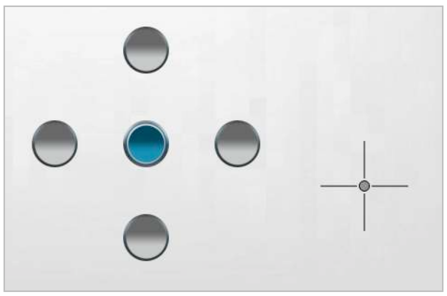

Figure 3. Screenshot of the application.

The buttons were selected using dwelling with the same visual feedback we used in the Information Wall. Dwell time for triggering a selection was set to 1.2 seconds for every condition after a dwell time of 1.5 seconds used in the pilot was reported to have been too slow by the participants.

5.4 Design

The user study was organized as a repeated measures within-subjects experiment with factors:

- **Technique**. Three levels: low-power magnetic cursor (100-pixel activation threshold, referred to as MC1), high-power magnetic cursor (200 pixels, referred to as MC2), and snap-to-target.
- **Distance**. Distance to the target from the previous target with two levels: 400 pixels and 800 pixels
- **Target size**. Size of the target and distractor buttons with two levels: 50-pixel and 100-pixel diameter.
- **Density**. Distance between the target and the distractors with two levels: 50 and 100 pixels.

The participants completed six target selections per each factor level combination, resulting in 2736 total selections.

The dependent variable was target selection time, which was decomposed in the analysis phase into *time to land on target* (first time the user brought the cursor on top of the correct target) and *target selection time* (including dwelling and possible reacquisition of target). In addition, the number of *hovers on target* (i.e., leaving target area and reacquiring it) and *error rate* was calculated for each technique.

5.5 Procedure

The participants started by reading a short introduction and by filling out a background questionnaire. All participants started with the normal cursor to acquaint themselves with the pointing system. The order of the three assisting techniques was counterbalanced and the participants were randomly assigned to one of the counterbalanced orders. Completing each pointing technique block was divided into two sessions, between which participants were able to rest if they desired. Each session contained 25 selections, the first of which always started from the center of the screen and was excluded in the analysis of the study. Values for distance, target size and density were randomized so that all eight possible combinations would appear six times for each technique.

Subjective feedback was collected using 11 questions related to the user of the pointing technique (Table 1). Participants answered the questions four times, once after each technique. Each question was answered on a 7-point bipolar scale.

Table 1. User experience statements.

Q1	Gesture control works very roughly/smoothly
Q2	Pointing requires me to focus too little/much
Q3	Pointing requires physical effort too little/too much
Q4	Pointing accurately is easy/difficult
Q5	Selecting targets by pointing is too fast/too slow
Q6	My arm gets tired when pointing not at all/a lot
Q7	Pointing feels very uncomfortable/ comfortable
Q8	Altogether pointing is very difficult/easy
Q9	I control pointing very poorly/well
Q10	The process of selecting the desired target is slow/fast
Q11	When the cursor is on a target, the target is selected too fast/slowly

Participants were not informed of the actual behavior of the techniques or of the differences between them. This is comparable to a realistic setting – a first-time user of a freehand pointing system will not be aware of the possible assisting techniques. When all the selection sets were completed, participants filled out the last questionnaire comparing the techniques.

6. RESULTS

Outliers were removed before analyzing the results. An entry was considered to be an outlier if total selection time (acquisition time included) differed more than 1.5 times standard deviation from the average selection time. Outliers formed around 9% of the data.

6.1 Time to land on target

A significant main effect of pointing technique was not observed for target acquisition time whereas significant effects were found for pointing distance, target size and target density. This is intuitively clear, given that the assisting techniques operate in close proximity to the targets and the bulk of the acquisition time is made up by the physical pointing motion from the previous to the current target. We did find a three-way interaction pointing technique * distance * density and four-way interaction pointing technique * distance * target size * density. However, interpreting such complex interactions is conceptually challenging within the context of this experiment. Given the experimental setup, the high effect size for pointing distance (partial $\eta^2 = 0.889$), and low effect size of the interactions (partial $\eta^2 = 0.293$ and 0.161, respectively), it appears that the main contributor to target acquisition time is the distance rather than differences in pointing behavior between the techniques.

6.2 Target selection time

Target selection time was calculated from the time when the user first acquired the target to the time when the target was selected. Repeated measures ANOVA showed a significant main effect of pointing technique on target selection time ($F_{2,36} = 11.445$, $p < 0.001$), with MC1 performing significantly faster (1.6 seconds) than MC2 (1.7) and snap-to-target (1.8). Unsurprisingly, also target size and density had a significant effect on selection time. The selection of larger targets was faster than smaller targets and similarly less densely packed targets were faster to select than more densely packed targets.

6.3 Target hovers

Repeated measures ANOVA showed a significant interaction between pointing technique and target density ($F_{2,36} = 3.644$, $p < 0.05$), as well as significant main effects for pointing technique, target size, and target density. As Figure 4 shows, when distractors were in close proximity to the target (50 pixels), MC1 had significantly fewer target hovers on average (1.6) than the other techniques (1.8 for MC2 and 1.9 for snap-to-target). At higher distance (100 pixels) the difference was not significant.

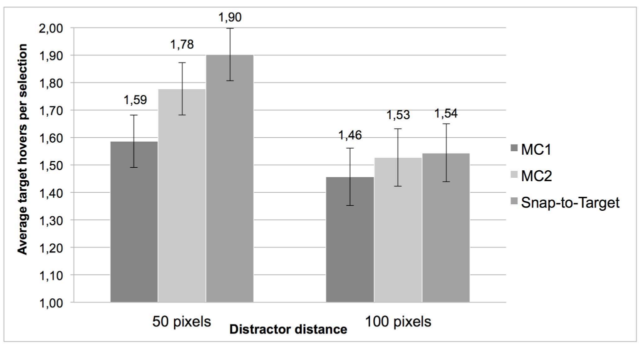

Figure 4. Average target hovers per selection.

6.4 Error rate

According to repeated measures ANOVA, there was also a significant effect of pointing technique on error rate ($F_{2,36} = 14.043$, $p < 0.001$), whereby MC2 had a higher error rate (8.6%) than MC1 (2.4%) and snap-to-target (3.2%). Also, an interaction between target size and density was found. Selecting tightly packed smaller targets was significantly more challenging than selecting larger targets, but when target density is lower, the effect of target size effectively disappears. Although the normal cursor condition was not a part of this comparison, it should be noted that similarly to the pilot study, its use was in practice error free.

6.5 User experience

The user experience responses did not show many significant differences between the pointing techniques (Figure 5) based on pairwise comparisons. Normal cursor ratings are shown as a reference. MC2 was found to require more mental effort to operate (Q2) and less controllable (Q9) than its low-power counterpart. Snap-to-target and MC1 were also perceived to be faster to use for selecting the desired target (Q10). Our participants' subjective preferences are in line with their experience ratings. Out of the 19 participants, nine participants chose MC1 as the most pleasant technique, and nine chose the snap-to-target technique. Only one participant preferred MC2, while the normal cursor was not preferred by anyone. Conversely, eight participants chose both the normal cursor and MC2 as the least pleasant technique. The snap-to-target was chosen least favorite by three participants. MC1 did not receive any votes.

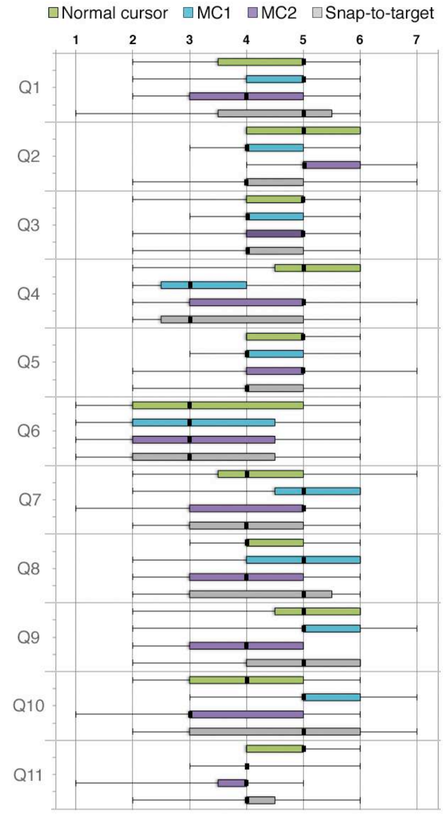

Figure 5. User experience ratings as boxplots (showing median and interquartile range) for each pointing technique.

7. DISCUSSION

Our research questions were concerned with how well the assisting techniques can help users maintain selection on the target during dwelling, what the tradeoffs are between activation threshold and errors in the presence of multiple targets, and how the participants subjectively perceive the different techniques. The results show that the low-power magnetic cursor design provided the best pointing performance in terms of target selection time. This benefit derives primarily from its ability to help the users keep the selection on target in densely packed target arrangements, where it outperformed the other techniques. This can be explained by the visual feedback of relative cursor position within the target, which we believe helped correct the pointing closer to the center to maintain position on the target.

The poor performance of high-powered magnetic cursor, both objectively and in subjective feedback, can be explained by the relationship between the computer cursor location and the strength of the magnetism effect. As the actual pointing location is further from the computed location, inaccuracies with pointing can result in the cursor warping to the wrong target more easily than with the low-power cursor. Participants' difficulties in controlling the cursor at high degree of magnetism are especially evident in the inflated error rate for high-power magnetic cursor.

This study evaluated assisting techniques for freehand pointing interfaces by investigating the tradeoffs between two design variables – visual feedback of cursor location and activation threshold of the warping effect. The magnetic cursor designs utilized a fixed activation threshold whereas the snap-to-target technique was dependent on the pointing distance. Similarly, the magnetic cursor designs showed the relative position of the cursor within the target's expanded motor space whereas snap-to-target placed it into the middle of the target irrespective of location in motor space. Our results suggest that while the visual feedback appears to help the user maintain the cursor on the target, it also needs to be coupled with a relatively low, static activation threshold. While this makes pointing less effective at a distance, it also reduces the chance of sliding off target during dwelling.

The use of dwelling, while practical for novice users, is fairly inefficient. In future studies we are planning to study how different simple gestures, just as grab or pinch, could be used to speed up target selection in conjunction with cursor warping. Increasing the motor space of targets could be beneficial in alleviating targeting issues that can arise as a result of hand gestures affecting the pointing coordinates. Furthermore, it might be beneficial to take the magnetic cursor concept further; instead of the cursor having a predefined magnetic area, targets could have their own magnetic areas with varying sizes and shapes.

8. CONCLUSION

We investigated different means for improving target interaction for freehand pointing in large display environments. We proposed the magnetic cursor technique, which automatically warps the cursor onto a target, makes the cursor move slower on target, and visually shows its relative position in the motor space. We evaluated the performance and user experience of two versions of the magnetic cursor and compared them to the snap-to-target technique. The low-power version of the magnetic cursor was found to be the fastest of all techniques in target selection; however differences between the assisting techniques were mostly small in practical terms. In terms of user experience, all techniques were mostly equal, although slight preference towards the low-power magnetic cursor was found. However, it is clear that too aggressive an activation threshold can negatively affect error rate and user experience, as was observed with the high-power magnetic cursor.

9. ACKNOWLEDGMENTS

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