The University of Saskatchewan
Department of Computer Science

Technical Report #2009-03

UNIVERSITY OF SASKATCHEWAN

Investigation of Targeting-Assistance Techniques for Distant Pointing with Relative Ray Casting

Scott Bateman, Regan Mandryk, Carl Gutwin
Department of Computer Science
University of Saskatchewan
Saskatoon, Canada
{firstname.lastname}@usask.ca

Robert Xiao
Department of Computer Science
University of Waterloo
Waterloo, Canada
robert.bo.xiao@gmail.com

ABSTRACT
Pointing at displays from a distance is becoming a common scenario for controlling computers and entertainment systems. Several devices use direct-pointing methods, where the user points a hand-held device at targets on a screen, but these often suffer from accuracy problems. Many techniques have been explored for improving mouse-based pointing, but little is known about targeting assistance for distant pointing. We carried out experiments to test targeting assistance with a relative form of ray casting, common with devices such as the Nintendo Wiimote. We tested two motor-space techniques (sticky targets and target gravity), and three types of sensory-based acquisition feedback (visual, tactile, and aural). We found that the motor-space techniques were significantly more effective than control and that the sensory-based acquisition feedback. Overall, our studies provide initial results on the applicability of several previously uninvestigated targeting assists for distant pointing. Further, it shows the strong potential of motor space assists for improving target selection performance.

Author Keywords
Pointing, distant pointing, sticky targets, target gravity.

ACM Classification Keywords
H.5.2 [User Interfaces]: Graphical User Interfaces, Theory and methods, Interaction styles.

INTRODUCTION
Pointing from a distance is becoming common in both work and domestic environments, and for a variety of applications such as playing games, giving presentations, or working on large-scale visualizations. In these settings, traditional pointing devices often do not work well, and direct-pointing devices, such as the Nintendo Wii Remote (Wiimote), are becoming popular. Although these devices are successful, pointing in this fashion is still problematic – for example, researchers have reported difficulties with fatigue [29] and poor accuracy [26].

These problems suggest that targeting assistance can be valuable in distant-pointing settings where direct-pointing devices are used. A number of different assistance techniques have been proposed and tested for desktop environments which use mouse-based pointing: sensory-based acquisition feedback techniques [2,3,10,11,15,19,28], cursor-warping methods [1,4,18,20], expansions of the target in both visual space [7,24] and motor space [1, 7,10,11,20,24,37]), and reduction of target distances [1,4,6,18,31]. However, there is very little information available about whether any of these methods can be used with distant pointing.

To investigate targeting-assistance techniques for these situations, we carried out three preliminary studies. We focused on pointing that uses *relative ray casting*, in which there is a cursor on the screen that determines the selection location, but the position of the cursor is controlled by the left-right-up-down movements of the device in the user's hand. This differs slightly from *absolute ray casting*, where targeting is always determined by a direct line extending from a device (e.g. a laser pointer). Relative ray casting has fewer constraints than absolute ray casting, because cursor position is calculated – using a particular technology such as an infrared-based camera (e.g. the Wiimote), accelerometers, or gyroscopes (e.g., the Logitech MX Air Mouse). This means that there can be a difference between the pointing direction and the position of the cursor.

We tested two techniques that operate in motor space: *sticky targets*, which increase a target's effective width; and *target gravity*, which uses simulated gravity to increase effective target size and also decrease the effective distance to a target. In addition, we tested three different types of sensory-based acquisition feedback given when the cursor is over the target; we tested all combinations of visual, tactile and aural feedback. We performed three initial studies looking at variations of each approach to examine the individual techniques in depth, and to select the most appropriate versions for future study.

There are three main results from our studies. First, both motor-space techniques provided significant improvements over no assistance, reducing targeting time by almost one third and reducing errors by more than two thirds. Second, the sensory-based acquisition feedback techniques did not provide any improvements. Third, motor control techniques can provide high performance gains without being perceived by participants.

This technical report makes two specific contributions:

- The first demonstration that motor-space targeting assists work well with distant pointing and relative ray casting

- Further understanding of the effectiveness and perceptibility of these techniques

BACKGROUND AND RELATED WORK

Distant Pointing and Ray casting

In some computing environments (e.g., domestic settings, presentation rooms, or multi-display environments), traditional pointing devices often do not work well – users may be relatively far from the displays, and there is often no surface that can be used for a traditional mouse.

Researchers have proposed multiple techniques for supporting these different types of input environments, including 3D input devices such as flying mice and hand-held isometric input [22,38], absolute ray casting using devices similar to laser pointers [26,29,30,31], secondary displays that use world-in-miniature (or semantic snarfing) techniques [26], hand tracking and glove technology [33,35] and relative ray casting techniques [35], which are our main interest for this research.

Direct pointing techniques let people use natural pointing motions to interact with a display. The term *ray casting* is used to indicate the basic idea of these techniques – that a control spot on the display is projected as if it were a ray emanating from the user's finger or handheld device.

Absolute ray casting techniques conform exactly to this idea, and are exemplified by laser-based pointing techniques that have been proposed and tested in prior work [26,29,30,31]; other devices such as high-DoF trackers have also been used for absolute ray casting [35]. Researchers have looked at various issues in the use of these techniques, including the problem of reduced accuracy due to hand jitter [30] and fatigue [29].

Relative ray casting techniques are similar to absolute methods, but relax the exact correspondence between the control spot and the user's pointing direction [35]. This is a necessity with accelerometer-based tracking or tracking using external-to-display infrared light sources (such as that used in the Wiimote), since there is no absolute sensing of the user's actual pointing direction. In relative techniques, there is a cursor on the screen that determines the selection location, but the position of the cursor is controlled by the left-right-up-down movements of the device in the user's hand. In most situations relative ray casting feels the same as the absolute technique; however, in some cases there can be a difference between the absolute direction that the device is pointing and the location of the cursor.

Pointing with the WiiMote

The availability of the Wiimote as a low-cost and relatively high quality device has lead to new research in ray casting using the device. We provide a brief review of this work to highlight the differences between this and previous art.

Campbell, et al. investigated the differences between using the Wiimote as a zero-order (absolute ray casting) with its use as a first-order device (controlling cursor velocity) [8]**Error! Reference source not found.**, and found that direct pointing improved target selection times by a factor of 2.5.

Natapov, et al. compared the performance of different video game controllers including the WiiMote [27]. They found that the Wiimote had a throughput 31.5% lower than a standard mouse, which provided the best performance.

McArthur, et al., tested the difference performance of the Wiimote using different device buttons and attachments (e.g. a gun attachment), but found only small differences between the different devices [23].

Targeting Support

The goal of targeting-support techniques is to improve the user's ability to select on-screen targets quickly and effectively. Targeting has been widely studied in HCI, and the underlying principles of aimed movement are well understood. In particular, Fitts's Law [14] states that targeting difficulty is determined by the *index of difficulty (ID)*, which is calculated based on the size of the target and its distance from the starting location [21].

Selecting a target involves three phases [25]: a ballistic motion, a corrective phase, and a final acquisition phase where the pointer is moved into the target and the selection action is performed. Targeting support has been directed at all of these phases, and techniques can be organized into four groups: manipulation of amplitude, width, or both; and feedback during acquisition (see review in [5] for details).

Amplitude Manipulation

One class of techniques reduces targeting time by reducing the distance between the pointer and the target (i.e., the amplitude). Some techniques work by moving targets closer to the cursor [6]; the decision about which targets to move is determined by a command gesture or by the initial movement of the cursor. Other techniques warp the cursor closer to the target by predicting the end location of the targeting movement [4]. Both methods have been shown to work well for large displays, but prediction of the final position of a moving cursor remains a problem [5].

Width Manipulation

A second type of targeting support increases either the visual-space width or the motor-space width of the target. Visual expansion makes the target appear bigger (e.g., through the use of a fisheye lens), which can assist users in determining whether their pointer is on the target; however, visual-space expansion can also fool users into thinking that the target is larger in motor space than it really is, leading to errors. Even when the target size is increased in both visual and motor space, problems such as occlusion still exist [24].

Motor-space expansions involve increasing the effective area of a target. There are two main approaches: one that allows selection of the closest target even when the cursor is outside the target's original boundaries; and one that changes the movement of the cursor when inside the target.

When the space between targets is not needed for other purposes, it can be used to increase the effective area of the targets. One such technique, called Bubble Cursor [16], creates a mapping from every point in the display to the closest target; the technique allows the user to easily select the closest target to the cursor, regardless of the actual location of the cursor.

A second approach for increasing width, sometimes called 'sticky targets,' changes the control-to-display ratio (i.e., CD gain) of the input device when the cursor is over a selectable target [7]. This means that the user must move the mouse further to achieve the same cursor movement; the result is that the motor space of the target is increased. The amount of CD gain determines the degree of 'stickiness'; for example, an increase in CD ratio from 1:1 to 2:1 (a gain of 1.0) over the target results in an effective doubling of the width of the target (see Figure 1).

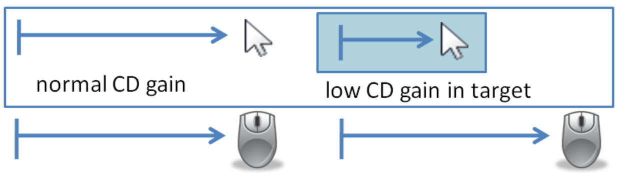

Figure 1. Sticky targets. When the cursor is on the target, more mouse movement is required to cross the same width.

Researchers have found that sticky targets can improve aiming time in both 1D [7,10,11,20] and 2D [37] tasks, particularly for small targets [11]. In addition, previous work has shown that users' perceptions of stickiness is not as strong as the effect itself – at low to moderate levels of the effect, users rarely notice it [20].

Manipulating both Amplitude and Width

A third class of techniques changes both the size of the targets and their distance. Some CD-manipulation techniques alter the cursor position throughout the targeting motion [11,18,37], rather than just over the target. Studies have shown improved targeting times with these techniques for older adults [37] and smaller targets [11].

'Force fields' is one such approach, in which activation areas around a target attract the cursor towards the target [1]. When the cursor is inside the force field, the cursor is warped such that movements towards the target are increased, and movements away are decreased. A similar technique uses the metaphor of 'magnetic dust' that is left around windows and widgets as they are used. Dust accumulates over time and more frequently used interface elements become more attractive [18].

Acquisition-Phase Sensory Feedback

In the acquisition phase of targeting, the user needs to know whether their cursor is correctly positioned over the target. Most interfaces provide basic visual feedback to support acquisition (i.e., the visible pointer and target object), but this may not be enough, particularly when targets are small [10,11]. Researchers have investigated several types of additional sensory acquisition feedback including visual highlighting, changes to the cursor's appearance, or other modalities including sound, force, or vibration feedback.

Auditory and tactile acquisition feedback has been used in assistive technology for users with reduced visual acuity (e.g., [15]), and force-feedback mice have been used to implement gravity wells that pull the cursor into a target [28]. A comparison of four types of feedback (visual, auditory, tactile, and a combination) did not find a significant improvement in targeting time or error rates with a mouse, but did find an increased preference for the additional feedback [2]. A later study focused on very small targets and showed that both audio and tactile feedback can reduce targeting time with a mouse by about 4% each [10].

Targeting Support for Remote Pointing

Research into remote pointing has primarily focused on correcting problems with specific devices (e.g. the issue of jitter associated with laser pointers [29,30]), and on interaction techniques that improve overall usability and expressiveness [26,29,30]. There is very little research on assists for improving targeting with distant pointing. One study tested acquisition feedback and showed that haptic and aural information reduce targeting time compared with visual feedback [19]; another study showed that selection aids, including expanding cursors and targets, and snapping to a target, improved selection time for ray casting on tabletop displays [31].

The Speech-Filtered Bubble Ray investigated the application of the bubble cursor for wall displays, adding in the ability to filter out tightly clustered distracters using a speech interface [34]. The Speech-Filtered Bubble Ray outperformed both an unfiltered bubble ray and simple ray casting.

Work on TractorBeam for distant pointing on tabletop displays investigated several techniques that operated by increasing the target width or the distance to target (by snapping to the target when inside a set distance). While users performed equally between target width and distance to target techniques, they preferred the distance-minimizing snap-to-target technique [31].

STUDIES: TARGET AIDS FOR RELATIVE RAY CASTING

The goal of our experiments was to determine if targeting assist techniques would decrease movement time and errors for selecting targets in relative ray casting, and to determine the subjective perceptibility of the techniques. Studies 1 and 2 investigated motor control aids (sticky targets and target gravity); study 3 investigated acquisition feedback (visual, aural and tactile feedback).

In selecting the 'best' techniques in the three studies, we wanted to focus on those techniques that provided the best performance gains, while remaining relatively unnoticed by participants. This is because we believe that for targeting aids to be widely applicable and used they must provide real advantages in facilitating pointing and must not distract or interfere with existing interactions. This being said we acknowledge that different setups, configurations and tasks may lead to different 'best' levels for a technique. Our goal though is to inform our own future study of a cross-technique comparison in which the setup will be identical.

STUDY 1: STICKY TARGETS (MOTOR-SPACE ASSIST)

The first study investigated the effectiveness and perceptibility of the sticky-targets technique, and also determined which level of the effect provided the best mix of benefit and perceptibility, for later use in the comparison. We selected sticky targets for investigation because it has been shown to provide both performance gains [7,10,11,20, 37] and have low perceptibility [20]. Further, because it operates over the boundaries of target only, unlike bubble cursor [16], it does not change the basic method of target selection; meaning it is more widely applicable.

Methods

The Sticky Targets Technique

Target stickiness was applied when the cursor is over a target, by changing the CD ratio of the input device based on the desired stickiness. Stickiness levels were calculated as 1 – CD gain; so, the higher the sticky level, the more sticky the target is. For example, a sticky level of 0.4 means that while on the target, a movement will result in a 40% reduction in the normal cursor movement on screen. To achieve CD gain manipulations, the system cursor was hidden and a custom cursor was displayed in its place.

We used a sweep-test technique rather than a sampling approach: for every movement event from the device, we calculated whether the cursor had crossed a target since the last location, and adjusted the cursor position accordingly. This approach avoids the problem of missing targets due to low sampling rates [11].

Apparatus, Task and Participants

The study used a custom system built in C# that took input from a Wiimote input device, using the Wii Device Library (code.google.com/p/wiidevicelibrary). The system displayed output on a Dell 107cm plasma screen with a resolution of 1280x768 pixels. Participants sat in an office chair with armrests, 250cm from the screen.

The targeting task was the two-dimensional pointing task specified in ISO standard 9241 [12]. This task shows a ring of circular targets and asks participants to select each target one at a time; the next target is always directly across the ring (see Figure 2). The next target to be selected is coloured green and marked with a purple cross. Participants selected the target by moving the cursor into the target and clicking the 'B' button on the bottom of the Wiimote device.

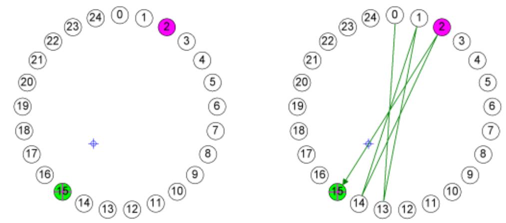

Figure 2. Examples of the study system and the ISO pointing task. Right image shows targeting sequence for first 5 trials.

Nine volunteers (six female) aged 19-30 years were recruited from a local university. All were right-handed and all were experienced users of computers (>7 hrs/wk), all were familiar with the Wiimote device and seven of the participants were regular users of this device (at least once/week).

Experimental Conditions, Design, and Procedure

Study 1 used a 10×3×3 repeated-measures design, with three factors: *stickiness* (ten levels from 0.0 to 0.9); *target width* (2cm, 2.8cm, 3.6cm); and *movement amplitude* (30cm, 35cm, and 40cm). In all conditions visual feedback was provided by changing the target's background colour to red when the cursor entered the target boundary.

The study was organized into 10 effect blocks (representing each level of stickiness). Users worked in a block completing one set of trials (25 trials or one trip around the circle) for each unique combination of amplitude and width. This equated to 10 blocks x 9 A/W sets = 90 conditions, and 90 conditions x 25 trials = 2250 trials/participant. Blocks were ordered using a Latin square design. Practice was given at the start of each effect block; after each block users completed a survey about the effect's perceptibility. The study took approximately one hour to complete.

Data Analyses

Movement time and errors for each targeting trial were collected through computer logs, and user perceptions of the effect were recorded in the surveys. Movement time (MT) was calculated as the time from selection of one target to selection of the next target. Errors were counted whenever a user clicked outside of the target prior to acquiring it. Outlier trials (when MT was more than 3 standard deviations above the mean) were removed (230 trials; 1.0%). Mean MT and the sum of errors for the 25 trials in each set were used in subsequent analyses.

Quantitative data were analysed using repeated-measures multivariate analysis of variance (RM-MANOVA) with α=0.05, and the Bonferroni adjustment was used for all pairwise comparisons. When the sphericity assumption was violated, the Huynh-Feldt method for adjusting the degrees of freedom was used. Survey data were analysed using the appropriate non-parametric technique.

Study 1 Results: Effects of Stickiness on Performance

We conducted a 10x3x3 RM-MANOVA on MT and errors with stickiness, width, and amplitude as factors. There were significant main effects of stickiness on both dependent measures (MT: $F_{9,72}$=11.31, p≈.000; Errors: $F_{0,72}$=5.83, p≈.000). As shown in Figure 3, increasing stickiness generally reduced MT and errors. However, with higher levels of stickiness both MT and errors plateaued, suggesting there is a point at which having stickier targets has decreased benefits for our task.

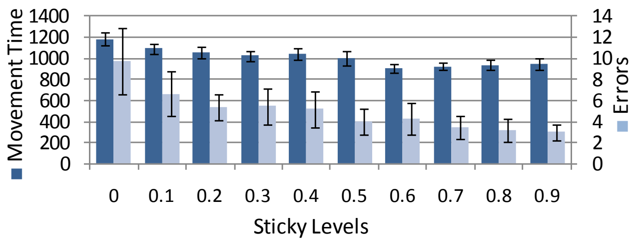

Figure 3. Mean MT and Errors ± SE, by level of stickiness.

There was no interaction between movement amplitude and stickiness for either measure (MT: $F_{18,144}$=1.6, p=.067; Errors: $F_{18,144}$=0.8, p=.746). There were, however, significant interactions between target width and stickiness (MT: $F_{18,144}$=3.6, p≈.000; Errors: $F_{18,144}$=2.8, p≈.000). Pairwise comparisons showed that stickiness had more of an effect on both time and errors when targets were small.

User perception of stickiness

After each block of trials, we asked participants rate the stickiness of the target on a scale from 0-6 (higher is more sticky – see Figure 4). There was a correlation between actual and perceived stickiness (Spearman's rho=.513, p≈.000). We did not test for differences in all levels of perceived stickiness, but did use this data to assist us in choosing the 'best' levels of stickiness for future study.

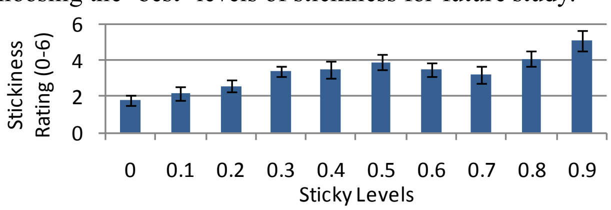

Figure 4. Mean ± SE of perceived gravity.

Choosing stickiness levels for the comparison study

For future cross-technique comparison, we want levels of stickiness that combine improved targeting and low perceptibility. We selected two levels: a low-perceptibility level (the highest level that was not perceptibly different than no stickiness as determined by Wilcoxon signed ranks tests), and a high-assist level (the highest level before performance plateaued). These criteria indicated stickiness of 0.2 for the lower level and 0.6 for the higher.

STUDY 2: TARGET GRAVITY (MOTOR-SPACE ASSIST)

Study two duplicated the sticky targets study, but with target gravity as the assist technique. Methods and analyses were identical to study one, with exceptions as noted below. We created the target gravity technique for study, as we wanted to explore a technique that worked by both effectively decreasing target amplitude and increasing target width (recall sticky targets works only on target width). Plus in creating target gravity we wanted to address shortfalls we saw in similar techniques (described below).

Methods

Target Gravity

Our implementation of target gravity is similar to the 'force field' technique [1]; but instead of restricting a target's attraction to a limited range around the target, we calculate the gravity effect for all targets at all times, regardless of the position of the cursor. However, because target gravity is inversely proportional to the square of the distance between the cursor and the target, the influence of a target decreases rapidly at greater distances.

Our gravity effect is calculated as follows. For n targets, let $p_1, p_2,..p_n$ be the positions of the targets with radii $r_1, r_2,..r_n$. Let p_0 represent the true position of the cursor (i.e., without any gravity effect applied), and let p_w be the warped position. Let G be the 'gravitational constant' (i.e., weight multiplier). Then, for each target $i=1..n$, compute the target weight with Equation 1. Finally, compute the warped position of the cursor using Equation 2.

$$w_i = \frac{G r_i^2}{|p_0 - p_i|^2 + 1}, \text{ with } w_0 = 1 \qquad \text{Equation 1}$$

$$p_w = \frac{\sum_{i=0}^{n} w_i p_i}{\sum_{i=0}^{n} w_i} \qquad \text{Equation 2}$$

The warped position is a weighted average of the true cursor position and the positions of each target. The weight for the cursor position is fixed at 1.0, and the weight for each target is inversely proportional to the square of the distance between the cursor and that target. The weights for each target are proportional to the area of the target, and are multiplied by the gravitational constant G. Manipulating G in the study changed the strength of the gravity effect.

Participants and Study Conditions

Nine volunteers (seven female) aged 20-29 and who did not participate in study 1 were recruited from a local university. All were experienced computer users (>7 hrs/wk), all were familiar with the Wiimote device, and four participants were regular users of the device (at least once/week).

Study 2 used the same 10x3x3 design as above, but with *target gravity* (ten levels: 0.0, 0.01, 0.03, 0.08, 0.22, 0.63, 1.76, 5.0, 14.1, 39.8). These values were chosen by selecting values of an equal distance (on a log base 10 scale) between 0 and an upper bound of 39.8 (selected as a highest reasonable value through pilot testing).

Study 2 Results: Effects of Gravity on Performance

A 10x3x3 RM-MANOVA on time and error data (347 outliers removed, 1.7%) showed main effects of gravity level on both dependent measures (MT: $F_{9,72}$=25.8, p≈.000; Errors: $F_{0,72}$=9.3, p≈.000). Figure 5 shows that increasing gravity reduced MT and errors.

There was no interaction between movement amplitude and gravity for either measure (MT: $F_{18,144}$=0.5, p=.972; Errors:

$F_{18,144}$=0.5, p=.971). There was a significant interaction between target width and gravity for MT, but not for errors (MT: $F_{18,144}$=5.1, p≈.000; Errors: $F_{18,144}$=1.4, p=.120). The effect of width on MT was reduced for high gravity levels.

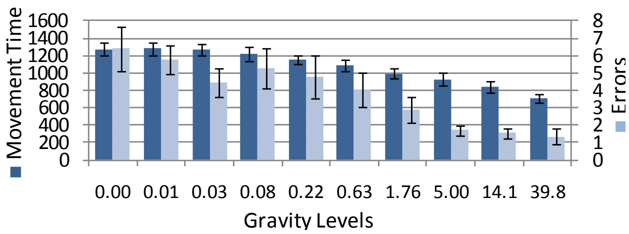

Figure 5. Mean MT and Errors ± SE, by level of gravity.

User perception of gravity

We recorded participant perceptions of the level of gravity after each block (see Figure 6). There was a correlation between actual and perceived gravity levels (Spearman's rho=.464, p≈.000). We did not test for differences in all levels of perceived gravity, but did use this data to assist us in choosing the 'best' levels of gravity.

Choosing gravity levels for the comparison study

Based on the performance and perception results, we wanted to choose a low-perceptibility and a high-assist level of gravity. Wilcoxon signed ranks test showed that users did not perceive a difference between no gravity and gravity until the two highest levels. For the low-perceptibility level, we chose gravity of 0.03 to correspond with the choice for stickiness from Study 1. For the high-assist level, we chose a gravity of 5.0 (high assistive benefit without high perceptibility).

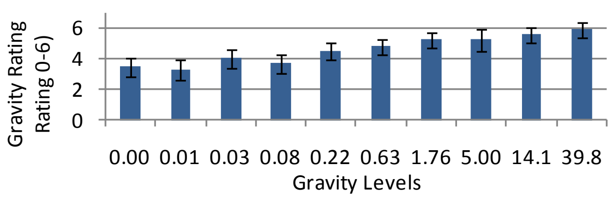

Figure 6. Mean ± SE of perceived gravity.

STUDY 3: ACQUISITION FEEDBACK

The third study tested the effects of acquisition feedback (tactile, visual, and aural) on targeting. The study was again identical to study one with exceptions outlined below.

Methods

Acquisition Feedback Types

We tested tactile, aural, and visual feedback; all forms were given continuously when the cursor was over the target.

- *Tactile* feedback was provided with the Wii vibration motor. We note that Krol et al. [19] found a 70ms delay in the start of the vibration motor, but did not determine the effect on targeting. In our pilot testing, the vibration appeared to be coincident with target entry, so we assume a negligible effect on our results.
- *Aural* feedback was provided by playing a continuous 130Hz sine-wave tone through external speakers placed beside the display (as used by Cockburn & Brewster [10]).
- *Visual* feedback was provided (as in the previous two studies) by changing the target's colour to red.

Participants and Study Conditions

Eight volunteers (3 female) who had not been in other studies, aged 20-29 years participated; all were experienced computer users (>7 hrs/wk) and all were familiar with the Wiimote device. Study 3 used an 8×3×3 repeated-measures design, but with *sensory feedback* as the main factor (all combinations of visual, aural, and tactile, plus no feedback).

Study 3 Results: Effects of Feedback on Performance

An 8x3x3 RM-MANOVA on time and error data (231 outliers removed, 1.6%) showed no significant main effects of feedback on either measure (MT: $F_{2.6,18.7}$=1.0, p=.412; Errors: $F_{3.1,21.4}$=1.4, p=.275). As shown in Figure 7, no feedback type led to a clear improvement in time or errors.

There was no interaction between movement amplitude and feedback type for either measure (MT: $F_{14,98}$=0.7, p=.740; Errors: $F_{14,98}$=1.1, p=..348), or between width and feedback type (MT: $F_{14,98}$=1.2, p=.262; Errors: $F_{14,98}$=0.5, p=.928).

Choosing sensory feedback for the comparison study

Because there was no one feedback technique that outperformed others, we chose the combination of all feedback types for the comparison study. Previous work has shown that while the sensory techniques do not have an additive benefit, they also do not interact negatively [2].

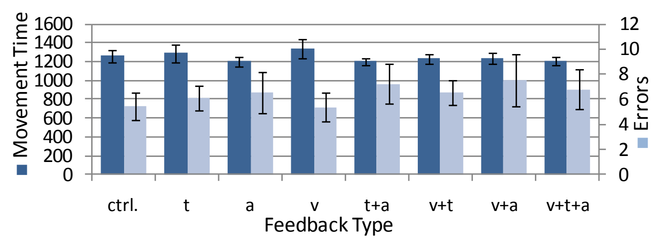

Figure 7. Mean MT and Errors ± SE, by feedback type (ctrl = no feedback, t = tactile, a = aural, v = visual).

DISCUSSION

There are seven main results from our studies:

1. Motor-space targeting assists have significant positive effects on relative ray casting performance, reducing targeting time by almost one third, and reducing errors by more than two thirds.
2. Participants preferred high-levels of the motor space techniques, and gravity the most of all.
3. The divergence of the pointing device from the cursor was not a major problem for any participant.
4. Both sticky targets and target gravity can be operated at fairly high levels without the effect being obvious.
5. Target gravity was the fastest of all techniques.
6. Acquisition feedback did not show any advantages.
7. Multiple intermediate targets did *not* cause major problems for any of the techniques, and the speed-coupled variant of sticky targets did not outperform ordinary sticky targets in this condition.

Below, we explain the results for each technique, and discuss how they can be applied and generalized.

Figure 8. Mean user ratings ±SE; 0-6 scale (higher is better).

Review of Techniques

Sticky Targets

Sticky targets provided significant and substantial reductions in time and errors compared to standard pointing and feedback techniques. The technique is effective even with small CD gain changes, and is not highly perceptible.

Target stickiness has an important advantage – that the effect is limited to the target regions. This means that controlled actions outside the targets (such as drawing or steering) are not affected by the technique.

Target Gravity

Target Gravity was significantly faster control even at lower levels, and it also performed will in terms of errors. Like sticky targets, participants did not perceive a strong effect, even when the gravity was higher. The technique works well because it acts both during movement (drawing the cursor towards a target) as well as over the target (by reducing cursor movement as the cursor moves away).

Our technique is based on Ahlstrom's force fields [1], but contains two noteworthy improvements. First, force fields allow influence from only one target at a time, and at a limited distance around a target. Target gravity allows all targets to attract the cursor at all times, making increasingly strong corrections as the cursor nears a target. Second, target gravity provides a parameterization which governs how attractive a target should be. While this was not a factor in our experiments (all targets were treated equally), it would allow more important targets to exert more gravity. For this reason it could be valuable to couple target gravity with 'semantic pointing' widgets [7], which would allow interface elements to occupy greater area in visual and motor space, and also increase the attractiveness they have over the cursor. Further, unlike magnetic dust techniques [18], our approach does not require any user-specific interaction history before its use.

Acquisition Feedback

We expected that sensory-based acquisition feedback techniques would perform better than no feedback, but there was no improvement in either time or errors. Previous literature shows mixed results for acquisition feedback in general, and in our study participants neither performed well with these techniques nor did they prefer them. Several participants stated that they found tactile frustrating, because the vibration made it more difficult to stay on the small targets (also reported in [2]). Other participants said that they found the tone used for aural feedback annoying. It is possible, however, that our targets were not small enough for perceptual feedback to make a major difference.

CONCLUSIONS AND FUTURE WORK

Remote pointing is now common in many home and work environments, and relative-ray casting devices such as the Nintendo Wiimote are popular choices for controlling on-screen interfaces. To start an investigation of how remote pointing might be improved, we investigated several targeting-assist techniques that can be used with relative ray casting. Ours is the first investigation of the motor-space manipulation techniques sticky targets and target gravity in this new domain. Through several studies, we determined appropriate settings and variants for the three different approaches that we plan to use in future study.

In future work, we plan to compare our motor-space techniques and the acquisition feedback techniques, now that we have identified appropriate 'best' performing levels. In this future study we wish to also investigate the issue of passing through non-target distractors.

To get a better idea of how are techniques might be used in the real world, we will add to our testing system non-target distracters that participants will be required to passthrough on their way to selecting a target. This will simulate the real world scenario of passing through icons or buttons that also have employed a targeting assist. This will provide important understanding on two issues. First, how distracting is it for participants and how does it affect participant performance. In the case of our sensory-based acquisition feedback techniques, users may mistakenly select the incorrect target more often if they are basing their target selections on the feedback alone, and not the actual location of the intended target. In the case of our motor space techniques, participants cursors may become 'stuck' on the distractor targets as they are passed through, this might become a great annoyance and/or hamper completion time greatly.

Finally, in the case of passthroughs for our motor space techniques there is an important related issue that will likely result, which is the issue of ongoing changes of the pointing direction of the device and the onscreen cursor. In the case of passing through a distractor target for our gravity technique, the user's cusor would first be attracted to the target and then become increasingly stuck to the target as it approaches the center of the target. This will result in the user's hand moving faster or slower, and the speed of this movement will change as the user moves the cursor on way to a final target. It will be important to understand this issue of 'cursor divergence' for motor space targeting assists to be applied at all in distant pointing scenarios. It will be common in this scenario for the direct straight line from the end of the pointing device to diverge (maybe dramatically) from the direct line to onscreen cursor; further, this divergence will be changing all the time, as the cursor is pulled or sticks to potential targets. Providing some insight on how users experience this issue will be crucial for understanding the applicability of motor-space targeting assists, such as sticky targets or gravity, to real world scenarios.

REFERENCES

1. Ahlström, D., Hitz, M., and Leitner, G. An evaluation of sticky and force enhanced targets in multi target situations. *Proc. NordicCHI,* (2001), 58-67.
2. Akamatsu, M., and MacKenzie, I.S. Movement characteristics using a mouse with tactile and force feedback. *IJHCS, 45*, (1996), 483-493.
3. Akamatsu, M., MacKenzie, I. S., & Hasbrouq, T. A comparision of tactile auditory, and visual feedback in a pointing task using a mouse-type device. *Ergonomics, 38,* (1995), 816-827.
4. Asano, T., Sharlin, E., Kitamura, Y., Takashima, K., and Kishino, F. 2005. Predictive interaction using the delphian desktop. *Proc. UIST*, (2005), 133-141.
5. Balakrishnan, R. "Beating" Fitt's law: virtual enhancements for pointing facilitation. *IJHCS, 61*, (2004), 857-874.
6. Baudisch, P., Cutrell, E., Robbins, D., Czerwinski, M., Tandler, P. Bederson, B., and Zierlinger, A. Drag-and-Pop and Drag-and-Pick: Techniques for Accessing Remote Screen Content on Touch- and Pen-operated Systems. *Proc. Interact*, (2003), 57-64.
7. Blanch, R., Guiard, Y., Beaudoin-Lafon, M. Semantic pointing: improving target axquisition with control-display ratio adaptation. *Proc. CHI* (2004), 519-525.
8. Campbell, B., O'Brien, K., Byrne, M., Bachman, B. Fitts' Law Predictions with an Alternative Pointing Device (Wiimote®). Proc. of Human Factors and Ergonomics Society Annual Meeting, 52, 5 (2008), 1321-1325.
9. O. Chapuis, J.B. Labrune and E. Pietriga. DynaSpot: Speed-Dependent Area Cursor. Proc. CHI, (2009), 1391-1400.
10. Cockburn, A. and Brewster, S. Multimodal feedback for the acquisition of small targets. *Ergonomics, 48*, 9 (2005), 1129-1150.
11. Cockburn, A. and Firth, A. Improving the acquisition of small targets. *Proc. British HCI Conf.,* (2003), 181-196.
12. International Organisation for Standardisation, *ISO Standard 9241: Ergonomic requirements for office work with visual display terminals (VDTs)*, Part 9, 1998.
13. Elmqvist, N., Fekete, J-D. Semantic Pointing for Object Picking in Complex 3D Environments. Proc. of GI, pp. 243-250, 2008.
14. Fitt, P. M. The Information Capacity of the human motor control system in controlling the amplitude of movement. *J. Exp. Psychology, 47,* (1954), 381-391.
15. Fraser, J., Gutwin, C. The Effects of Feedback on Targeting Performance in Visually Stressed Conditions. *Proc. Graphics Interface*, (2000), 203-210.
16. Grossman, T. and Balakrishnan, R. The bubble cursor: enhancing target acquisition by dynamic resizing of the cursor's activation area. *Proc. CHI,* (2005), 281-290.
17. Guiard, Y., Blanch, R., and Beaudouin-Lafon, M. Object pointing: a complement to bitmap pointing in GUIs. *Proc. Graphics Interface* (2004), 9-16.
18. Hurst, A., Mankoff, J., Dey, A. K., and Hudson, S. E. 2007. Dirty desktops: using a patina of magnetic mouse dust to make common interactor targets easier to select. *Proc. UIST,* (2007), 183-186.
19. Krol, L. R., Aliakseyeu, D., and Subramanian, S. Haptic feedback in remote pointing. *Proc. CHI* (2009), 3763-3768.
20. Mandryk, R. L., and Gutwin, C. Perceptibility and Utility of Sticky Targets. *Proc. GI,* (2008), 65-72.
21. MacKenzie, I. S. Fitts' law as a research and design tool in human-computer interaction. *HCI, 7*, (1992), 91-139.
22. MacKenzie, I. S. and Jusoh, D. An evaluation of two input devices for remote pointing. *Proc. INTERACT,* (2001), p. 235-249.
23. McArthur, V., Castellucci, S. J., & MacKenzie, I. S. An empirical comparison of "Wiimote" gun attachments for pointing tasks. Proc. EICS (2009), 203-208.
24. McGuffin, M., Balakrishnan, R. Acquisition of Expanding Targets. *Proc. CHI, (2002),* 57-64.
25. Meyer, D.E., Smith, J.E., Kornblum, S., Abrams, R.A., Wright, C.E. Optimality in human motor performance: ideal control of rapid aimed movements. *Psychological Review, 8,* (1988), 340-370.
26. Myers, B., Bhatnagar, R., Nichols, J., Peck, C.H., Kong, D., Miller, R., and Long, C. Interacting at a distance: measuring the performance of laser pointers and other devices. *Proc. CHI,* (2002), 33-40.
27. Natapov, D., Castellucci, S. J., & MacKenzie, I. S. ISO 9241-9 evaluation of video game controllers, Proc. GI, (2009), pp. 223-230.
28. Oakley, I., McGee, M., Brewster, S., Gray, P. Putting the feel in 'Look and Feel' *Proc CHI*, (2000), 415-422.
29. Oh, J.-Y. and Stuerzlinger, W. Laser pointers as collaborative pointing devices. *Proc. GI,* 2002, 141-149.
30. Olsen, D.R. and Nielsen, T. Laser pointer interaction. *Proc. CHI*, (2001), 17-22.
31. Parker, J.K., Mandryk, R.L., Nunes, M.N., and Inkpen, K.M. TractorBeam Selection Aids: Improving Target Acquisition for Pointing Input on Tabletop Displays. *Proc. INTERACT*, (2005), 80-93.
32. Rodgers, M.E., Mandryk, R.L., and Inkpen, K.M. Smart Sticky Widgets: Pseudo-haptic enhancements for multi-monitor displays. *Proc. SmartGraphics* (2006), 194-205.
33. Sturman, D. J., Zeltzer, D. A survey of glove-based input. *Comp. Graphics and Appl., 14*, 1 (1994), 30-39.
34. Tse, E., Hancock, M., and Greenberg, S. Speech-filtered bubble ray: improving target acquisition on display walls. Proc. ACM ICMI (2007), 307-314.

35. Vogel, D. and Balakrishnan, R. Distant freehand pointing and clicking on very large, high resolution displays. *Proc. UIST*, (2005), 33-42.
36. Wilson, A., and Pham, H. Pointing in intelligent environments with the World Cursor. *Interact*, 2003.
37. Worden, A., Walker, M., Bharat, K. and Hudson, S. Making computers easier for older adults to use: area cursors and sticky icons. *Proc. CHI,* (1997), 266-271.
38. Zhai, S. User performance in relation to 3D input device design. *Computer Graphics*, *32*, 4 (1998), 50-54.