TractorBeam: Seamless integration of local and remote pointing for tabletop displays

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Abstract

This paper presents a novel interaction technique for tabletop computer displays. When using a direct input device such as a stylus, reaching objects on the far side of a table is difficult. While remote pointing has been investigated for large wall displays, there has been no similar research into reaching distant objects on tabletop displays. Augmenting a stylus to allow remote pointing may facilitate this process. We conducted two user studies to evaluate remote pointing on tabletop displays. Results from our work demonstrate that remote pointing is faster than stylus touch input for large targets, slower for small distant targets, and comparable in all other cases. In addition, when given a choice, people utilized the pointing interaction technique more often than stylus touch. Based on these results we developed the TractorBeam, a hybrid point-touch input technique that allows users to seamlessly reach distant objects on tabletop displays.

Key words: Input and interaction technologies, tabletop displays, user studies, pen-based UIs, quantitative empirical methods.

1 Introduction

While tabletop display research has become more prevalent in recent years, there is still no widely accepted standard input device for these displays. Researchers have used a wide array of both direct and indirect interaction techniques. For certain activities on a tabletop display, direct interaction with the display can provide benefits. However, users cannot easily interact with objects on the far side of the table using a direct input method without standing up and reaching, or walking around the display to bring the object within reach. It is important to provide users with an input technique that will allow them to seamlessly interact with far objects on tabletop displays without severely hindering interaction with close objects.

Remote pointing devices such as laser pointers have been proposed as input solutions for large wall displays with varying degrees of success [9-11]. While they allow input from various distances, they are problematic in terms of accuracy and speed. Given that the distances users typically need to reach on a tabletop display are much smaller, and the fact that people typically sit at a tabletop display with their arm supported, it is possible that a laser pointer style of interaction would perform better on a tabletop display than a wall display.

Table users are unique in that they are close to some parts of the display, but distant from others. The horizontal orientation of the tabletop also means that the "up-down" movement (shown to be problematic on a wall display) is very different on a tabletop display. A user may steady their arm by resting it on the table. Additionally, the hand/arm movement required to move the cursor is not linear – rather, it becomes smaller the closer the cursor gets to the far edge of the display.

We conducted a user study to compare three techniques for selecting objects on a tabletop display:

1. touch with stylus (touch)
2. pointing with stylus, arm kept stationary (point)
3. reaching and pointing with stylus (reach-and-point)

The results of this study, along with previous research, informed the design of the TractorBeam—a hybrid point-touch interaction technique which allows users to cast an invisible beam from the end of a stylus to select objects on a tabletop display. This is well suited for tabletop displays because it allows users to interact directly with nearby objects using a stylus as they normally would while also aiding them in reaching distant objects by providing a laser-style pointer.

This paper first reviews related work, then describes our experimental methodology to compare the effectiveness of the three proposed interaction techniques for tabletop displays. We next present the results and describe the TractorBeam interaction technique. Following this, we describe an exploratory user study we conducted to gain insight into usage of the TractorBeam. Finally, we present our conclusions and future work.

2 Related Work

Remote pointing on large wall displays

Remote interaction with vertical displays has been investigated in a number of studies [9, 10]. Several researchers have proposed laser pointer interaction as a possible solution [10], while others have examined solutions involving gyroscopic mice [9] or PDAs [10]. In most cases, these solutions performed poorly, with slow acquisition times and large error rates. For pointing tasks on large wall displays, laser pointers were worse than both mice [10, 11] and stylus touch [10] in terms of throughput and speed, and users found them difficult to operate [10]. In addition, using standard laser pointers required input to be tracked using a camera, and there were delays between a user pointing to a location and that action being processed by the computer, resulting in delayed feedback.

Reaching distant objects on large displays

Baudisch et al. [2] developed the drag-and-pop and drag-and-pick interaction techniques for reaching display items that are far away or otherwise out of the reach of the user. In drag-and-pop, as the user drags an icon across the display, potentially related target icons are stretched towards the icon being dragged. Drag-and-pick extends this idea by popping all (related and unrelated) icons located in the direction of the drag motion, and then allowing the user to pick the desired icon.

Interacting on tabletop displays

Past research on tabletop displays has used of a variety of input technologies including finger touch [5, 12], styli [7, 18], mice [15], and tangible input [16]. While most of this previous work has not evaluated input techniques, a few researchers have developed and tested input techniques for tabletop displays. Wu and Balakrishnan developed and evaluated a suite of hand and finger gestures for multi-touch tabletop displays [19]. Rekimoto and Saitoh explored two techniques – hyperdragging and pick-and-drop – to allow users to move files between a tabletop and other computing devices, including distant displays such as large wall screens [13].

3 First User Study: Pointing vs Touch

We conducted a study to compare the speed and accuracy of selecting a target by touching it with a stylus (touch) versus pointing to it (point, reach-and-point).

Experimental Design

Twelve right handed university students (7 male, 5 female) took part in our study. The hardware setup for our top-projected tabletop display consisted of a ceiling-mounted projector, mirror, desktop PC, and wooden table. The output from the PC was projected onto the mirror, which reflected the image onto the table (Figure 1). The projected display was 1200 x 900 mm, and inset 200 mm from the user's side of the table.

Input was received via a tethered stylus and receiver attached to a Polhemus Fastrak (six degrees of freedom 3D tracking system). The Fastrak receiver was secured to the centre of the underside of the table and provided our software with information about the current position of the stylus in relation to the display. We experienced no perceptible problems with lag in using the Fastrak system.

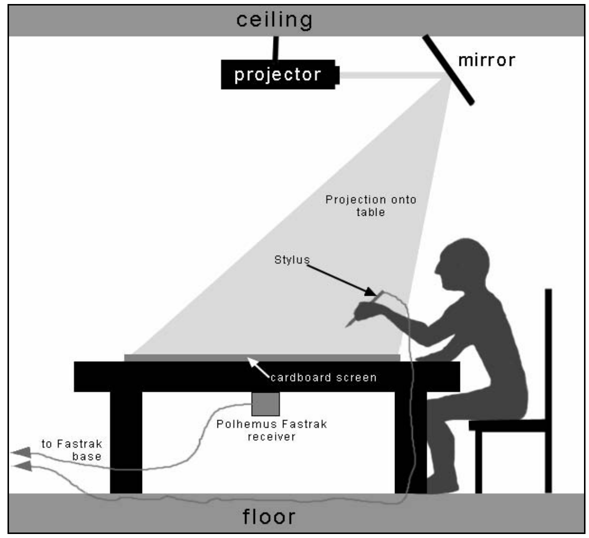

Figure 1: Top-projected table hardware configuration.

A multi-directional task (2D Fitts discrete task) was used to evaluate selection tasks in three conditions: *touch*, *point*, and *reach-and-point*. In the touch condition, participants selected objects by touching the stylus to an item on the table. In the point condition, users selected objects by pointing at them with a stylus (using it like a laser pointer, with a cursor appearing on the table). Participants were required to keep their upper arm stationary on the table and refrain from reaching towards the targets while pointing. In the reach-and-point condition, users selected objects by pointing at them (similar to the point condition) but were encouraged to reach out over the display to reduce the distance between stylus and target.

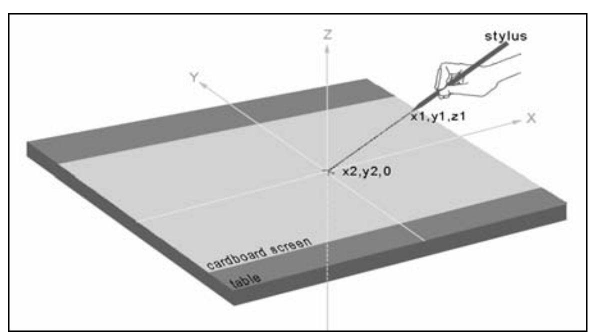

Figure 2: Pointing interaction technique.

Participants were presented with a series of trials that required them to first select a home square and subsequently select a target circle (Figure 2). The Polhemus stylus was used for all conditions, including touch, and visual feedback was provided via a cursor. In all conditions, selection was indicated by a cursor dwell of at least 300 ms inside a target.

A Java application was developed to implement the selection interactions required for each of the three conditions. Positional information (x, y, z, azimuth, and elevation) was received from the stylus and projection of the endpoint of the stylus onto the table was calculated (Figure 3: x2,y2). Each individual trial began when a user selected the home square, and ended when they selected the target circle. Software logged when a target appeared, when a user moved off the home square, and when a target circle was selected.

A within subjects design was utilized with each participant using all three techniques. To minimize order effects, condition order was counterbalanced.

After completing a background questionnaire, participants performed a series of trials using the experimental task software in each of the three conditions. Participants sat at the tabletop display and were asked to remain seated, unless it was necessary to briefly stand in order to reach distant targets.

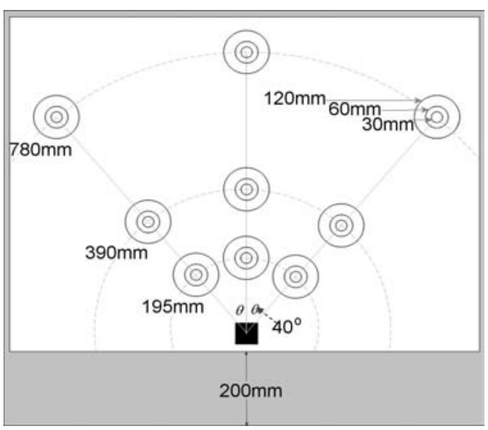

Figure 3: Software - The black square is the start point and the circles represent targets. Targets were 3 widths (30mm, 60mm, 120mm), on 3 angles (40˚ left, midline, 40˚ right), at 3 amplitudes (195mm, 390mm, 780mm).

For every condition, each participant first completed a warm-up session which required them to select 10 random targets. They then completed exactly five trials of each unique combination of amplitude, width, and angle, for a total of 135 trials. The ordering of the trials was randomized for each participant.

Following each condition users completed a post-task questionnaire to gather data on their comfort and perceived performance with the technique they had just used. Once finished all conditions, users were given a final questionnaire asking them to rank the techniques for satisfaction and perceived effectiveness.

Hypotheses

Given previous findings in pointing research using Fitts' Law, we expected effects of target width, angle, and amplitude on movement time (MT). Because users were required to lift their bodies from the chair to touch distant targets, we expected it would take longer to touch these targets than point to them. Although users are able to move much faster with a pointer, it would likely take them longer to home in on the target due to the amplification of their movements. For this reason we expected it would be faster to point to large targets than touch them. For the same reason we also expected it would take longer to point to small targets than touch.

Data analyses

Computer logs were used to determine movement time, error rate, and entry rate (number of times a target was entered in a single trial). MT data were calculated from when the cursor exited the home square until the user selected the target. This method of computing movement time does not include reaction time. We chose to measure MT in this manner because it was important that the time required to visually scan the large tabletop display did not influence the time taken to actually perform the movement. In addition, the 300 ms dwell time (required to determine a selection) was not included in the movement time measure.

Since participants were required to select a target before moving on to the next trial, there were no missed targets. Errors occurred in one of two ways: either the cursor left the home square before the target appeared (anticipatory error); or the participant did not complete the trial within 4 sec (timeout error). We removed 69 (1.4% of total trials) anticipatory errors and 24 (0.5% of total trials) timeout errors from the analysis.

Outliers were removed for each participant by calculating each individual's mean movement time for all trials, and removing any individual times that were more than three standard deviations from this mean.

Welford's extension to Fitts' Law [17] was used to recognize the potential separable effects of width and amplitude: $MT = a + b_1 \log_2 A - b_2 \log_2 W$, where, $b_1 \log_2 A$ may correspond to the initial impulse towards the target, while $b_2 \log_2 W$ may correspond to the feedback based final adjustment.

Participants may have entered the target circle more than once as a result of overshooting, especially for smaller targets. We logged each time a user entered the target to get an indication of the degree of overshooting (entry rate).

Movement time and entry rate data for the five repeated trials at each unique combination of target variables were averaged. Repeated Measures Analysis of Variance (ANOVAs) were performed on the mean MT and mean entry rate data. All main effects and interactions were tested at α=.05. We also performed multiple regressions on means for MT (averaged across all subjects) using ID, or A and W as predictors, separately for each technique. Questionnaire data were analyzed using non-parametric statistics.

Results and Discussion

Movement time data for the midline, separated by interaction technique, amplitude, and width are presented in Table 1. Entry rates (the number of times the cursor entered the target prior to selecting it) separated by interaction technique, amplitude, and width are shown in Table 2. Note that an entry rate of 1.0 would signify that participants never overshot the target.

Amp (mm)	Width (mm)	Touch Mean (SE)	Point Mean (SE)	Reach Mean (SE)
195	30	438 (36)	513 (35)	543 (44)
	60	341 (27)	310 (22)	311 (23)
	120	296 (25)	176 (15)	179 (17)
390	30	582 (52)	711 (44)	827 (56)
	60	573 (65)	557 (33)	561 (35)
	120	463 (37)	376 (26)	404 (29)
780	30	1027 (68)	1480 (98)	1433 (68)
	60	975 (98)	938 (63)	1038 (68)
	120	829 (76)	682 (46)	770 (58)

Table 1: Mean movement time (MT) for each technique.

Amp (mm)	Width (mm)	Touch Mean (SE)	Point Mean (SE)	Reach Mean (SE)
195	30	1.08 (0.04)	1.56 (0.06)	1.55 (0.06)
	60	1.03 (0.01)	1.29 (0.05)	1.34 (0.05)
	120	1.01 (0.01)	1.28 (0.03)	1.26 (0.03)
390	30	1.06 (0.03)	1.52 (0.08)	1.82 (0.12)
	60	1.03 (0.01)	1.56 (0.09)	1.42 (0.07)
	120	1.00 (0.00)	1.26 (0.05)	1.31 (0.07)
780	30	1.12 (0.03)	3.43 (0.23)	3.14 (0.20)
	60	1.07 (0.04)	2.18 (0.15)	2.37 (0.15)
	120	1.02 (0.01)	1.65 (0.12)	1.63 (0.05)

Table 2: Mean entry rate for each technique.

Hypothesis 1a: Fitts' Law would be upheld using all 3 interaction techniques.

Research has shown that movement times for similar indices of difficulty will differ for varying combinations of target amplitude and width [8], and that target amplitude and width are better predictors of movement time than the index of difficulty (ID) alone [6]. Using a multiple linear regression, our data was fit across subjects for MT using ID, or A and W as predictors for each technique (Table 3).

	Regression	R^2
Touch	MT (ms) = -90 + 199 ID	.67
	MT (ms) = -1801 + 330 $\log_2$A - 67 $\log_2$W	.97
Point	MT (ms) = -433 + 290 ID	.88
	MT (ms) = -738 + 331 $\log_2$A - 249 $\log_2$W	.90
Reach	MT (ms) = -512 + 326 ID	.91
	MT (ms) = -895 + 375 $\log_2$A - 278 $\log_2$W	.93

Table 3: Linear regressions for prediction of movement time (midline data only)

Consistent with previous work, Welford's two-part model provided a better fit than ID alone. Note that for touch on the midline, Fitts' Law only accounted for 67% of the variance, while the two-part model accounted for 97%. Although the Welford model provides two parameters, which would generally provide a better fit than one parameter, the unusually low fit for the Fitts model speaks to the unique issues in non traditional computing environments. When aiming with a remote pointer on an oblique surface, the cursor movements are amplified further from the pointer source. As such, a straightforward log linear model would not account well for performance. Welford's model revealed that for similar IDs, movement times were more sensitive to changes in target amplitude than target width when touching. For pointing, the relative contribution of target width was much higher.

Since participants had to lift completely off their chair to reach distant targets, we thought MT for these targets would be disproportionately slower than MT for targets within reach. Plotting both predicted MT from a model of close and middle targets and actual MT as evidenced in the data reveals this to be the case. Figure 4 shows that for close and middle target distances, predicted and actual MTs are similar. For distant targets, actual MT is larger than predicted MT for all three widths. For pointing, the difference between predicted and actual is particularly large for small, distant targets.

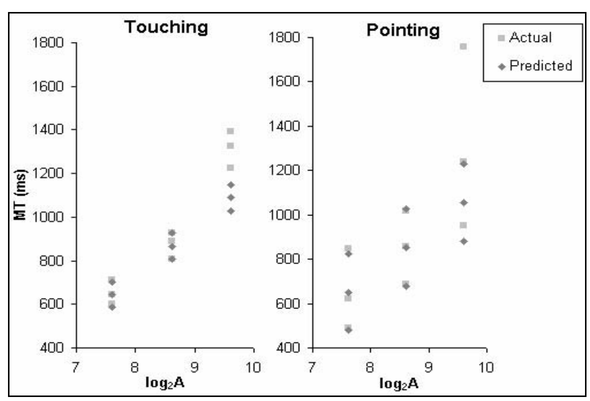

Figure 4: Predicted and actual MTs based on models of close and mid targets. For each $\log_2$A the three vertical symbols represent small, medium, and large target widths (top to bottom).

Hypothesis 1b: It would be faster to point along the midline and towards the right, than towards the left.

Repeated measures ANOVAs were performed on the movement time data for the 3 (interaction technique) by 3 (target angle) design. Consistent with our hypothesis, there was a main effect for angle ($F_{2,22}$ =15.74, p=.000, η2=.59), but no main effect for interaction technique ($F_{2,22}$=1.55, p=.240, η2=.12). Pairwise comparisons revealed that movement times were significantly faster for targets on the right than targets on the midline ($F_{1,11}$=12.66, p=.004, η2=.54) or on the left ($F_{1,11}$=24.64, p=.000, η2=.69).

Hypothesis 2: Pointing would be faster for distant targets but not different for close.

Repeated measures ANOVAs were performed on the movement time data for the 3 (interaction technique) by 3 (target amplitude) by 3 (target width) design. A significant 3-way interaction between width, amplitude, and interaction technique was found ($F_{8,88}$=8.0, p=.000, η^2=.42). Since our hypothesis stated that MTs between techniques would differ as a function of target amplitude, we separated this by amplitude.

For distant targets there was a significant interaction effect of width by interaction technique ($F_{4,44}$=21.2, p=.000, η^2=.66). To further explore this interaction effect we separated by width and performed ANOVAs on movement time data for the 3 (interaction technique) design. This revealed that the first part of our hypothesis was validated for large targets but not for medium or small targets. For large distant targets, we found a main effect of interaction technique ($F_{2,22}$=4.6, p=.021, η^2=.30) and pairwise comparisons revealed the point technique was significantly faster than both the touch and reach-and-point techniques ($F_{1,11}$=5.4, p=.040, η^2=.33 and $F_{1,11}$=5.6, p=.038, η^2=.34 respectively).

For medium-sized distant targets there was no significant difference between interaction techniques ($F_{2,22}$=1.9, p=.173, η^2=.15).

For small distant targets, a main effect of interaction technique was found ($F_{2,22}$=13.8, p=.000, η^2=.56), and pairwise comparisons revealed touch was significantly faster than point and reach-and-point ($F_{1,11}$=12.7, p=.004, η^2=.54 and $F_{1,11}$=36.35, p=.000, η^2=.77).

For close targets there was also a significant interaction effect of width by interaction technique ($F_{4,44}$=9.5, p=.000, η^2=.47). To further explore this, we separated by target width and performed ANOVAs on movement time data for close targets in the 3 interaction technique design. We found the second part of our hypothesis was validated for small and medium targets but not for large targets. For small and medium targets there was no significant difference between the three techniques ($F_{2,22}$=1.98, p=.163, η^2=.15 and $F_{2,22}$=1.15, p=.334, η^2=.10 respectively). For large targets there was a main effect of interaction technique ($F_{2,22}$=28.7, p=.000, η^2=.72) and pairwise comparisons revealed both the point and reach-and-point techniques were significantly faster than the touch technique ($F_{1,11}$=28.2, p=.000, η^2=.72 and $F_{1,11}$=37.0, p=.000, η^2=.77 respectively).

For small targets at medium distances there was a main effect of interaction technique ($F_{2,22}$=17.3, p=.000, η^2=.61) and pairwise comparisons revealed touch was significantly faster than both point and reach-and-point ($F_{1,11}$=6.9, p=.023, η^2=.39 and $F_{1,11}$=38.9, p=.000, η^2=.78, respectively), and point was significantly faster than reach-and-point ($F_{1,11}$=10.3, p=.008, η^2=.48).

For small targets at close distances no significant difference was found between the three interaction techniques ($F_{2,22}$=1.98, p=.163, η^2=.15).

Entry rate analyses

In general, when pointing, users overshoot the target then make compensatory movements. This overshoot can happen more than once, which may indicate that a target is difficult to acquire. We expected that pointing to small targets would yield higher entry rates than touch (subsequently causing MTs to be slower).

ANOVAs were performed on entry rate data for the smallest target width for the 2 (interaction technique) by 3 (target angle) by 3 (amplitude) design. This revealed a significant interaction effect between amplitude and technique ($F_{2,22}$=114.25, p<.000, η^2=.91). Exploring this interaction effect further, we separated on technique and ANOVAs were performed on the 3 (target angle) by 3 (amplitude) design.

We found a significant effect of amplitude on entry rate for the point technique ($F_{2,22}$=93.8, p=.000, η2=.90). Pairwise comparisons revealed a significantly higher entry rate at the distant amplitude than at either close or medium amplitudes ($F_{1,11}$=95.16, p=.000, η2=.90, and $F_{1,11}$=109.06, p=.000, η2=.91).

For the touch interaction technique no significant difference was found for amplitude ($F_{2,22}$=1.36, p=.275, η2=.11) but a significant main effect was found for angle ($F_{2,22}$=3.77, p=.039, η2=.26). Pairwise comparisons revealed a significantly higher entry rate at the left and right angles than on the midline ($F_{1,11}$=7.65, p=.018, η2=.41, and $F_{1,11}$=5.21, p=.043, η^2=.32).

Questionnaire response analyses

After each condition, participants rated a number of factors related to effort, comfort, and effectiveness on a five-point scale. To determine differences between the interaction techniques, results from these questionnaires were analyzed using a Friedman test. The means are summarized in Table 4.

Participants felt touching the table required significantly more physical effort than pointing or reaching and pointing (χ^2=7.2, p=.027), however, they experienced less wrist fatigue when touching the than when pointing or reaching and pointing (χ^2=9.4, p=.009).

At the end of the experiment we asked the participants to rate the three interaction techniques according to how effective they were and how much they liked each technique. There were no significant differences between the three conditions for either variable.

	Touch Mean(SD)	Point Mean(SD)	Reach Mean(SD)
Mental Effort	2.7 (1.0)	2.3 (1.0)	2.9 (1.0)
Physical Effort*	4.8 (0.5)	3.7 (1.2)	3.8 (1.3)
Perceived Accuracy	4.5 (0.7)	4.1 (0.9)	3.9 (0.9)
Perceived Speed	4.0 (0.9)	4.0 (0.7)	3.8 (0.9)
Wrist Fatigue*	2.7 (0.9)	3.2 (1.3)	3.7 (1.0)
Arm Fatigue	3.7 (1.2)	3.7 (1.0)	3.5 (1.4)
Shoulder Fatigue	3.7 (1.6)	3.5 (0.7)	3.1 (1.4)
Neck Fatigue	2.8 (1.4)	2.8 (1.2)	2.4 (1.2)
Comfort	2.8 (1.3)	3.3 (0.9)	3.3 (1.3)
Ease of Use	3.8 (1.2)	4.3 (0.5)	3.8 (1.0)

Table 4: Mean responses from the condition questionnaires on a five-point scale where 1 is low and 5 is high. (denotes p<.05)*

Participant feedback provided additional evidence that it was more difficult to point to small, far targets. One participant commented: "significant effort was required … to select small objects that were further away" while another noted "I often over-shot the target and it required more movement in my arm to select."

Questionnaire comments also revealed participant fatigue caused by reaching for distant targets in the touch condition: "When the target was close [touching] was fine… But when I had to actually get up from my seat to reach the target it was AWFUL!" Furthermore, some participants noted the tradeoff between speed and comfort, stating their preference for the pointing technique for far targets even though it was slower: "I don't think I was as accurate but I liked it better because I didn't have to keep standing and sitting over and over."

4 Second User Study: TractorBeam Usage

Our first study showed that touch and pointing both have speed advantages in certain situations. Additionally, participant feedback suggested that users would accept the tradeoff between technique and speed for distant targets, if it allowed them to select objects without moving from their seats. Keeping this in mind, we designed an interaction technique that combines close touch and distant pointing, allowing users to interact with nearby parts of the display more naturally with a stylus, and use the pointing functionality when they need to select an item that is beyond their reach.

One of the main benefits of the TractorBeam interaction technique is that it allows users to interact with both close and distant items on a tabletop display without having to switch modes or devices. To interact with a close object, the user simply touches the stylus to the table, as one would normally use a stylus. To interact with a distant object, the user simply points the stylus towards their desired target, casting a virtual beam which positions the cursor where the user is pointing.

When pointing from a distance, it may be harder for a user to control the cursor. However, Scott et al. noted that users primarily select distant objects in order to bring them closer, and typically perform more complicated interactions such as manipulation once the items are close [14]. By allowing users to touch locally and point remotely, the TractorBeam provides the means for direct manipulation of close objects, and quick selection of distant objects, allowing users to switch seamlessly from selecting to moving to manipulating.

We ran a follow-up study on our TractorBeam interaction technique to determine which input techniques users would choose for selecting various size objects at various locations on the tabletop display.

Experimental Design and Data Analyses

Six participants, two male and four female, took part in this study. All had participated in our previous user study and were familiar with the tabletop display and the three different input techniques.

A simple pointing task was used to observe participants' use of the TractorBeam technique to select targets on a tabletop display. Participants were instructed to use their preferred combination of touch, point, and reach-and-point to make selections. A second Java application was developed, and was run on the same tabletop display. It presented a series of selection trials in which target circles appeared in one of 9 locations on the display (Figure 6). Each participant completed exactly five trials of every possible combination of location and width, for a total of 135 trials. The ordering of the trials was randomized.

The focus for this study was on choice of technique, rather than target acquisition time. As such, we used a coding sheet to record which input technique (touch, point, reach-and-point) participants used on each target. We classified touch as any selection where the stylus touched the table, point as any selection where the user's arm remained stationary, and reach-and-point as any selection where the user's arm moved forwards or sideways to get closer to a target prior to pointing. The counts were totaled for each user and percentages calculated for each size and table location. Friedman tests were then used to evaluate the counts for each of the hypotheses.

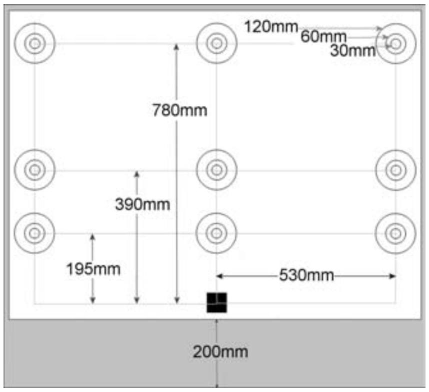

Figure 6: The black square is the start point and the circles represent targets, which were 3 widths (30mm, 60mm, 120mm), and appeared at 9 locations.

Hypotheses

Results from our first study revealed that for distant targets, pointing was faster for large targets and touching was faster for small targets. However, our participants expressed appreciation for the point and reach-and-point techniques because they required less physical effort. Based on this we thought that for distant targets, users would use the point or reach-and-point techniques and for close targets they would use touch.

Results and Discussion

The counts and percentages for the number of times participants chose to use each interaction technique were recorded. For each table location there are a total of 90 trials (5 trials x 3 sizes x 6 participants). Figure 7 presents a visual representation of the data, showing use percentages for each of the three interaction techniques.

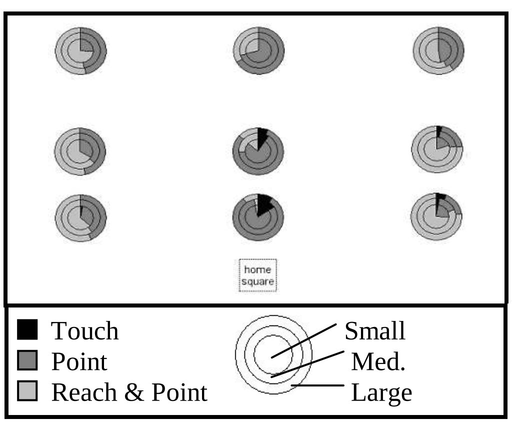

Figure 7: Percentages by size and target location. Nested graphs show amounts techniques were used.

Hypothesis 1: For distant targets, users will choose to use point or reach-and-point.

For far targets, no participant ever used the touch interaction technique. Results from a Friedman two-way ANOVA revealed that the first hypothesis was validated in that users **always** chose to use point or reach-and-point for far targets ($\chi^2_{2,N=6}$=8.087, p=.018). On average, the point technique was used 51% of the time and the reach-and-point technique 49%.

Hypothesis 2: For close targets users will choose to touch targets directly with the stylus.

For close targets, only one participant used the touch interaction technique (18 times out of 45 trials). The remaining five participants **never** used the touch interaction technique. For these five participants, the results from a Friedman two-way ANOVA revealed that hypothesis two was not validated in that the users always chose to point or reach-and-point to close targets ($\chi^2_{2,N=5}$=6.421, p=.040). These five participants used the point technique 54% of the time and the reach-and-point technique 46% of the time. The one participant who did use the touch interaction technique used it 40% of the time, the point technique 4% of the time and the reach-and-point technique 56% of the time.

Further analyses revealed that the choice of whether to point or reach-and-point depended more on the angle than the amplitude of the target. For both the point and reach-and-point techniques, the results from a Friedman two-way ANOVA revealed a significant difference between the interaction technique used for the left, centre, and right targets (point: χ^2(2, N=6)=8.32, p=.016 and reach: χ^2(2, N=6)=7.90, p=.019) while no difference was found based on target amplitude. Users tended to use the point technique more for centre targets and used the reach-and-point technique more for targets on the left and right hand side of the table.

5 Conclusions and Future Work

Although previous research has found that remote pointing is a poor input technique for large wall displays, our studies found it to be a highly effective technique for tabletop computer displays. It is appropriate for reaching distant objects, and would be effective for users who want to select distant items to move them closer into their personal space for manipulation. The TractorBeam capitalizes on the benefits offered by both pointing and touch, allowing the user to use both techniques seamlessly and without the need to switch between different modes.

When selecting an interaction technique, user comfort must also be considered. The results from our second user study clearly indicated that users preferred to use a pointing interaction style to select distant objects. Thus, although our first experiment revealed that touching was faster for small, far targets, the touch input technique was fatiguing, and not preferred by users (and never utilized for far targets in our second study).

The Fitts' Law evaluation on the results of our first study raised interesting questions about the use of pointing on tabletop displays. Pointing was slower than touching for small, distant targets. Since a pointer can travel faster than a user's arm, we speculate that the extra movement time is contained within the percent time after peak velocity, or the home-in phase of the movement. The acquisition is further complicated for distant targets because of the non-linear mapping between distance and angle – i.e. the further the distance, the greater the physical movements of the stylus are amplified in the cursor. We plan to collect positional data at a high frequency to further investigate this issue.

While the studies discussed in this paper test target acquisition only, we envision the TractorBeam – with the addition of a button for selection – being used to drag and manipulate items on a tabletop display. With this in mind we plan to evaluate our technique using a suite of tasks such as tunneling [1] docking [3], and tracing [4] to provide a better overall indicator of the TractorBeam's performance on the tabletop. In addition, we would like to test the use of the TractorBeam in ecologically valid tasks using robust applications. Since pointing to small, distant targets was slow and users overshot the target several times before selection, we would also like to consider methods of improving a the ability to select these targets.

Finally, we would like to examine the impact of multiple TractorBeams on co-located collaboration around a tabletop display. We are interested in how this interaction technique affects task work, and whether teamwork will be affected. For example, we think that the TractorBeam might aid in the awareness of other people's activities over traditional indirect methods of input such as mice.

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References

[1] Accot, J. and Zhai, S. (1997). Beyond Fitts' Law: Models for trajectory-based HCI tasks. In *Proc. of CHI '97*. p. 295-302.

[2] Baudisch, P., Cutrell, E., Robbins, D., Czerwinski, M., Tandler, P., Bederson, B., Zierlinger, A. (2003). Drag-and-Pop and Drag-and-Pick: Techniques for accessing remote screen content on touch- and pen-operated systems. In *Proc. INTERACT 2003*. p. 57-64.

[3] Boritz, J. and Booth, K.S. (1998). A study of interactive 6 DOF docking in a computerised virtual environment. In *Proc. of VRAIS '98*. p. 139-146.

[4] Cohen, O., Meyer, S., and Nilsen, E. (1993). Studying the movement of high tech rodentia: Pointing and dragging. In *Ext. Abstracts of CHI '93*. p. 135-136.

[5] Deitz, P. and Leigh, D. (2000). DiamondTouch: A multi-user touch technology. In *Proc. of UIST 2000*. p. 219-226.

[6] Graham, E.D. and MacKenzie, C.L. (1996). Physical versus virtual pointing. In *Proc. CHI'96*. p. 292-299.

[7] Krueger, W. and Frohlich, B. (1994). The Responsive Workbench. *IEEE Computer Graphics and Applications*, *14*(3): p. 12-15.

[8] MacKenzie, C.L., Graham, E.D., Trip, A., and Wang, Y. (1996). Pointing to virtual targets with the left and right hand. *Journal of Sport and Exercise Psychology*, *18*: p. S55.

[9] MacKenzie, I.S. and Jusoh, S. (2001). An evaluation of two input devices for remote pointing. In *Proc. of EHCI 2001*: Springer-Verlag. p. 235-250.

[10] Myers, B.A., Bhatnagar, R., Nichols, J., Peck, C.H., Kong, D., Miller, R., and Long, A.C. (2002). Interacting at a distance: measuring the performance of laser pointers and other devices. In *Proc. of CHI 2002*. p. 33-40.

[11] Oh, J. and Stuerzlinger, W. (2002). Laser pointers as collaborative pointing devices. In *Proc. of Graphics Interface 2002*. p. 141-149.

[12] Rekimoto, J. (2002). SmartSkin: an infrastructure for freehand manipulation on interactive surfaces. In *Proc. of CHI 2002*. p. 113-120.

[13] Rekimoto, J. and Saitoh, M. (1999). Augmented Surfaces: A spatially continuous work space for hybrid computing environments. In *Proc. CHI '99*. p. 378-385.

[14] Scott, S.D., Carpendale, M.S.T., and Inkpen, K.M. (2004). Territoriality in collaborative tabletop workspaces. In *Proc. of CSCW 2004*.

[15] Scott, S.D., Lesh, N., and Klau, G.W. (2002). Investigating human-computer optimization. In *Proc. of CHI 2002*. p. 155-162.

[16] Ulmer, B. and Ishii, H. (1997). The metaDESK: Models and prototypes for tangible user interfaces. In *Proc. of UIST '97*. p. 223-232.

[17] Welford, (1968). *Fundamentals of Skill*. London: Methuen.

[18] Wellner, P. (1993). Interacting with paper on the Digital Desk. *Comm. of the ACM*, *36*(7): p. 87-96.

[19] Wu, M. and Balakrishnan, R. (2003). Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays. In *Proceedings of UIST 2003*. p. 193-202.