Large display interaction via multiple acceleration curves on a touchpad

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University in

partial fulfillment of the requirements for the degree of

Master of Science

in

Computer Science and Applications

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December 9, 2013

Blacksburg, Virginia

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Abstract

Large, high resolution displays combine high pixel density with ample physical dimensions. Combination of these two factors creates a multi-scale workspace [2] where object targeting requires both high speed and high accuracy for nearby and far apart targeting. Modern operating systems support dynamic control-display gain adjustment (i.e. cursor acceleration) that helps to maintain both speed and accuracy. However, very large high resolution displays require broad range of control-display gain ratios. Current interaction techniques attempt to solve the problem by utilizing multiple modes of interaction, where different modes provide different levels of pointer precision. We are investigating the question of the value of allowing users to dynamically choose granularity levels for continuous pointing within single mode of interaction via multiple acceleration curves. Our solution offers different cursor acceleration curves depending on the targeting conditions, thus broadening the range of control-display ratios. Our approach utilizes a consumer multitouch touchpad that allows fast and accurate detection of multiple fingers. A user can choose three different acceleration curves based on how many fingers are used for cursor positioning. Our goal is to investigate the effects of such multi-scale interaction and to compare it against standard single curve interaction.

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Chapter 1

Introduction

1.1 Motivation and background

Figure 1: Conceptual image depicting the mechanism of switching acceleration curves by varying the number of contacting fingers

With large, high resolution displays users are expected to perform cursor movements over a wide range of distances, ranging from precise near target adjustments to fast long distance displacements. Such displays are capable of displaying small objects far apart from each other. Fast and accurate acquisition of such objects imposes two main requirements on the pointing device: fast cursor movement for long distances [17] and high precision for fine-grained refinement of cursor position.

Multiple studies show [5, 18, 19] that dynamic control-display (CD) gain adjustment (i.e. cursor acceleration) improves pointing performance by dynamically adjusting CD gain depending on the physical movement speed. As a result, lower speeds decrease CD ratio for precision and higher speeds increase the ratio for faster cursor movements. This provides users with implicit device pointing granularity control.

Casiez et al. [18], investigated various acceleration curves and determined that OSX curve is significantly better than Windows XP and Xorg curves at small target acquisition tasks, however for large target acquisition Xorg and Windows curves outperform the one in OSX. They concluded that *there is no single acceleration curve that is better than others for all types of tasks.*

Nancel et al. [24] studied utility of an optimized single acceleration curve for multiscale continuous, target-agnostic pointing on large, high resolution displays. The authors concluded that such acceleration curve performs poorly with targets of size less than 7mm.

In a different paper Casiez et al., determine [19] a usable range of control-display values, and the relationship of this range to screen size, resolution, target dimensions and other parameters. An increase in screen resolution and physical dimensions implies change of the usable range of control-display ratios. Acceleration curves offer the ability to vary control-display ratios by varying the motor movement speed, thus offering a range of CD gain ratios within the usable range for a given screen. It has been shown that techniques with fixed CD gains perform poorly [28] on large, high resolution displays.

Large, high resolution screens create a multi-scale targeting environment where efficient continuous cursor positioning requires very diverse range of CD gain ratios. This creates a situation where a single acceleration curve is insufficient for all scales of interaction that are possible with very large, high-resolution screens. For example, Windows OS allows [30] user selectable multipliers ("Cursor speed" in Control Panel) for an acceleration curve, which is equivalent to changing the range of usable CD gain ratios. Some input devices (upscale gaming mice for example) feature user selectable setting for sensitivity which is effectively another multiplier for an acceleration curve. The purpose of these customization features is to fit user preferences which vary depending on the environment they are working in. However, none of these approaches allow explicit, dynamic and instantaneous alteration of the pointing precision and speed.

With very large, high resolutions screens users deal with multiple scales of interaction which is effectively a variable environment that implies a very wide range of possible targeting conditions. With such screens user preference for the pointer speed dynamically varies depending on the targeting conditions of the current task. It is logical to assume that in order to match dynamically varying tasks the acceleration curve multiplier setting should be dynamically changeable in real time.

Dasiyici et al. [5] attempt to accommodate the multi-scale environment of very large, high resolution screens by allowing users to manually alternate between predefined fixed CD gain ratios by employing a button as a switching mechanism. Their study showed that the interaction with the switching mechanism created a cognitive and a physical barrier that negatively affected performance. Also the lack of acceleration curve deteriorated results.

1.2 Research problem

The main challenge with an interaction technique that features dynamically switchable pointing granularity settings is to ameliorate the cognitive and physical obstacles introduced by the mechanism of switching as well as mental dissonance associated with the potential switch between different modes of interactions. This raises a question of what interaction mechanism to use that would minimize the cognitive and physical efforts while allowing on demand, dynamic and instantaneous switching of pointer granularity setting.

1.3 Contribution

We address the problem of continuous pointing on Large, High Resolution Displays (LHRD) by providing fast and accurate pointing with minimal cognitive barriers through:

- Single mental mode of interaction.
- Combining the benefits of explicit and implicit pointing granularity controls.
- Rapid and fluid switching mechanism for the explicit device granularity control.

In order to support manual selection of acceleration curve multipliers we implement an access mechanic that we think reduces the effort that is required for manual switching. In

order to lower the cognitive and physical efforts we decided to incorporate user selectable explicit pointer granularity settings into a single interaction mode. We leverage the multitouch capabilities of the touchpad that is used in recent Apple laptop computers, to enable selection of different pointing speed and precision settings by simply altering the number of fingers in contact with the capacitive surface of the touchpad.

This implementation allows users to dynamically select three different multipliers for our acceleration curve by using one, two or three fingers to move the cursor (Figure 1). Thus, with different number of fingers it is possible to shift the range of CD gain ratios that the acceleration curve can offer. One finger has the lowest acceleration curve multiplier (L) which offers optimal CD gain range for the smaller area of the screen and small targets, two fingers have greater multiplier (M) that offers CD gain range for medium distances and medium sized targets, and finally three fingers produce largest (H) multiplier offers range of CD gain ratios that is aimed at coarse long distance movements. This technique could extend to all 5 fingers on one hand. For convenience we will be referring to this technique as LMH.

A study is conducted to explore how users leverage the ability to dynamically switch acceleration curve multipliers as they move the cursor around.

Chapter 2

Current techniques

The challenges of large display interactions are acknowledged and addressed through

diverse range of devices and design philosophies [31] (Figure 2).
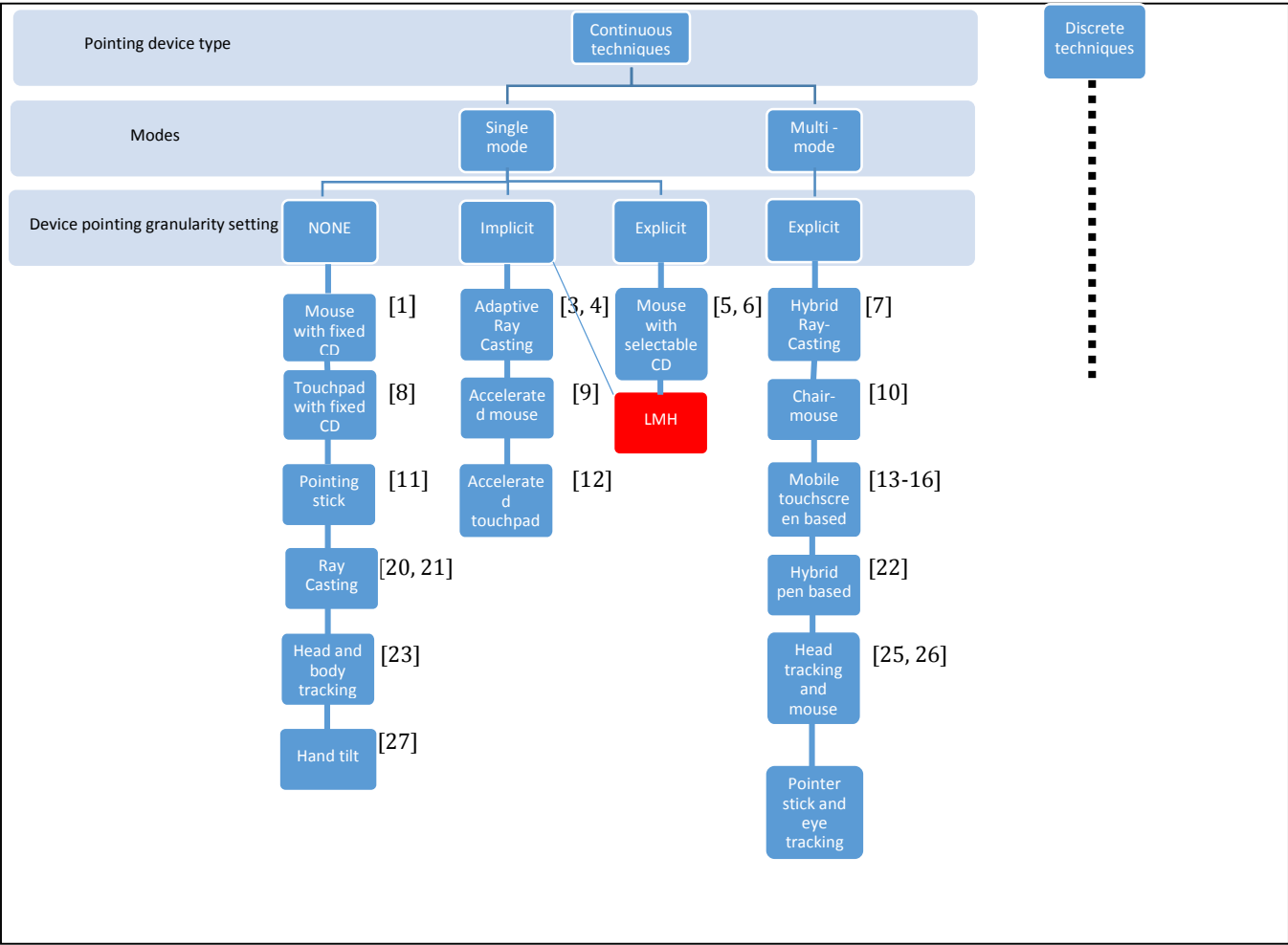
Figure 2: Diagram for the categories of techniques with prominent examples in each category. With LMH we are defining new category of devices that combine both explicit and implicit granularity controls.

2.1 Single mode techniques

Techniques that allow continuous pointing without switching from one type of interaction to another can be dubbed as single mode techniques. Single mode techniques maintain the same mental perception of the interaction technique even if the control display gain ratio is changing. These techniques include ray-casting [20, 21], touchpads, mice, pointing sticks, head and body tracking [23] as well as hand tilting [27].

2.1.1 No device granularity control

Techniques with no granularity control provide pointing experience that has fixed levels of speed and accuracy. With such techniques users have to be physically faster and more accurate in order to change characteristics of the pointing process. Ray-casting techniques allow [20, 21] users to interact with the display from any distance. Users are expected to manipulate the pointing device in a way that laser pointers are used. With such interaction users are able to choose any distance from the display and perform pointing tasks with simple wrist movements. Thus, the advantages of ray casting include natural interaction metaphor and low cognitive load, freedom in choosing distance from the display surface. However, this interaction technique fails to provide high precision pointing [7, 32], especially with displays that feature high pixel density. Indeed, the fatigue associated with the manipulation of the device results in hands involuntarily shaking which in turn makes accurate pointing very difficult.

2.1.2 Implicit device granularity control

Some single mode techniques change the CD ratio depending on the physical input from the user. The objective of implicit granularity control of the input device is to determine the targeting condition through the physical input from the user and then provide suitable CD gain ratio for the inferred targeting condition.

For instance adaptive Ray Casting techniques [3, 4] allow variable CD gain ratio to better match the targeting conditions. With such techniques the CD gain ratio changes depending on the hand movement characteristics and as a result provides faster and more precise continuous pointing experience. While the mental model of the Ray Casting is kept the same, the pointing performance improves.

While pointing sticks are generally considered to provide poor performance, traditional mouse and touchpad provide very comfortable pointing experience with standard sized displays as they provide high accuracy and speed with minimal physical and cognitive load. Modern operating systems provide dynamically adjustable control display gain ratio which provides high accuracy at low speeds and fast cursor movements at high speed [30]. As a result mouse and touchpad have become ubiquitous pointing devices for normal sized displays. Implicit granularity control, while very useful on standard screens, it fails [18] to scale up to meet the demands for broad pointing conditions on LHRDs.

2.1.3 Explicit device granularity control

Single mode interaction techniques with explicit granularity control allow users to maintain the same mental model for the interaction while providing the ability to explicitly change pointing characteristics of the input device.

Extending single interaction mode, by adding explicit controls, into accommodating multi scale targeting environment has the potential to not only provide high speed and accuracy but also eliminate the need to readjust to different pointing modes when interacting with LHRDs.

Single mode interaction techniques with explicit granularity control have had little attention in the research community. In 1990 Jellinek et al. introduced[6] modified mouse (manual mouse) that allowed users to change CD ratios on the fly by pressing hardware buttons. In the study [6] they compared manual , accelerated and constant gain mice. The primary objectives were to determine the grounds of the user preference to the accelerated mouse. Unlike our experiment Jellinek's concept of manual mouse had an option of choosing fixed CD gain ratios instead of acceleration curve multipliers. Their metaphor for manual mouse is a manual gearbox where drivers select their own gears. Accelerated mouse was compared to an automatic gearbox which selects gears based on the speed of the vehicle. Although manual selection of CD gains provides support for a multi-scale environment within single interaction technique, Jellinek's implementation suffered from the crude method of switching between the different CD gains

In terms of Jellinek's metaphor the LMH would be a drivetrain with CVT (Continuously Variable Transmission) and a differential with dynamically selectable ratios, as it combines speed based CD gain change (cursor acceleration) with the ability to instantaneously amplify the acceleration multipliers by varying the number of fingers touching the surface of a touchpad. Put differently, metaphorically speaking the CVT would be the acceleration curve while the multiplier that is determined by the number of fingers in contact with the touchpad would be the differential ratio. Thus, with LMH users benefit from both (Figure 3) implicit granularity control (acceleration curve) and explicit one (switching between different curves).
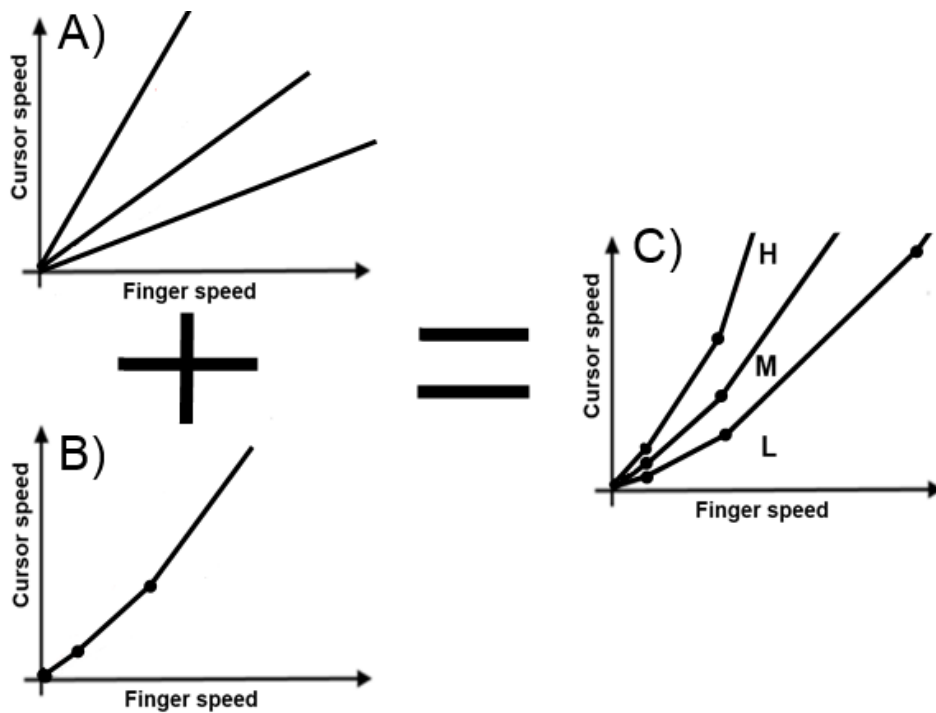
Figure 3: LMH interaction technique C) combines the advantages of explicit A) granularity switching [5, 6] with the benefits of standard accelerated B) mice and touchpads

With LMH we are demonstrating modern approach to the problem of incorporating explicit controls into single mode device.

While most of the interaction techniques for LHRDs focus on multi-mode interactions the issues associated with the process of switching between modes and the issues of two modes interfering with each other are likely to remain. With LMH we are addressing this issue by incorporating multi-scale nature of the interaction technique into just single mode of interaction. Thus, we eliminate the cognitive barriers that would normally occur during the transitions between different modes of interaction.

2.2 Multi-mode techniques

Multi-mode techniques of continuous cursor pointing introduce the notion of manual switching between the modes of interaction in order to better handle particular targeting conditions. Such techniques allow users to perform fast and accurate cursor positioning with the help different modes of interaction.

Eyegazing and head tracking techniques allow users combine the tracking technique for the coarse positioning with traditional mouse/touchpad for the precise target acquisition [25, 26]. Ray-casting is improved when precise positioning is added. Specifically , Vogel et al. introduce [7] interaction technique that allows switching between direct pointing for coarse positioning and relative cursor manipulation for precision. Forlines et al. introduced technique [22] that allows switching between direct pointing with pen for precision, and

coarse positioning with high gain relative pointing. Endert et al. captured [10] natural body movements with the help of chair to enable coarse positioning and combine it with precise positioning using traditional mouse.

Malik et al. introduced [14] a multi-finger gestural input with multitouch touchpad for interaction with large displays. The input technique enables coarse and fine positioning by mapping the left half of the touchpad to the entire screen, and right half to a small rectangular area previously positioned using the left half (analogous to overview + detail). Effectively this approach allows dynamic manual control of the scale of interaction. Users can switch between the two parts of the touch surface in order to alternate between absolute and relative positioning.

Casiez et al. introduced RubberEdge [13] which is primarily focused on reducing clutch rate by combining position and rate controls. The technique combines touchpad and elastic rate control ring around the edges of the touchpad. The elastic part is designed to translate the physical pressure into directional cursor movements with the speed proportional to the pressure applied. This approach provides an ability to manually select between relative and rate based positioning inputs. Comparisons with a standard cursor accelerated touchpad showed effectiveness of the technique.

ARC-Pad [15] is another technique that is aimed at improving touchpad performance with large displays. It uses a small resistive touchscreen that combines absolute and relative positioning. Users tap the touchscreen to perform coarse-grained absolute positioning, then for near target refinements they drag their finger for relative positioning. The next version

of this technique [16] uses capacitive screen and allows users to switch from absolute to relative mode by switching to two fingers. Similar to RubberEdge [13], this technique showed improvements over regular touchpads.

M.Nancel et al. conducted a study [28] that compared pointing with dual-mode techniques against a single mode technique on a large, high resolution screen. Three dual-pointing techniques were used: a variation of Vogel et al.'s free hand pointing where users switch modes by holding a button, laser pointer with gyro mouse with a button that switches modes in a likewise fashion and laser pointer with touchpad where modes switch whenever users touch the surface of the touchpad. For the single mode pointing technique they used a Gyroscopic Mouse with cursor acceleration. The results of the study show that the dual-mode techniques outperform the Gyroscopic Mouse in both consistency and speed. However, with the dual-mode techniques some users tended to stay in the coarse pointing mode which resulted in bad pointing performance. According to the subjective feedback, some of the participants found it cognitively taxing to perform the explicit mode switching with the three techniques. The process of switching modes with the three techniques was not instantaneous; the length of time required for switching modes exhibited correlation with the distance between targets and their size. According to the author, some users tended to stay in one mode with the intention to perform faster pointing.

While multi-mode techniques do improve the pointing performance on LHRDs, the process of transitioning between modes imposes cognitive load on users. Additionally,

differences between modes sometimes discourage [16] users from switching, and this has negative effect on the performance. With LMH we are attempting to incorporate the ability to explicitly and instantaneously switch continuous pointing granularity levels into single interaction metaphor.

Chapter 3

Design

Our main goal is to explore how users utilize the ability to dynamically alter acceleration curve properties by simply varying the number of contacting fingers touching the surface of a touchpad. We would like to see if this access mechanic has the capacity to minimize the physical and cognitive barriers introduced by manual switching. Also, with this experiment we are going to see if the ability to dynamically and instantly select different acceleration curve multipliers is going to be leveraged towards conquering the multi-scale nature of the large, high resolution displays.

Various multi-finger gestures have gained popularity in modern operating systems and for some (Mac OS X) are already standard. These gestures are typically used for tasks such as scrolling, application switching, dragging/selection, zooming and etc. [33]. Low cognitive load of the multi-finger interactions [34] is the basis for the design inspiration of LMH. With this particular design approach we are trying to minimize the potential cognitive barriers introduced by the manual switching of acceleration multipliers. By associating higher speeds with more fingers on the touchpad, LMH offers users a way to externalize and associate particular targeting conditions with the number of fingers they have in contact with the surface. By overriding two and three finger swiping gestures for the cursor manipulations, we exploit the low cognitive load of multi-finger interaction in order to allow

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users to adapt pointer speeds to the diverse targeting conditions that arise with large, high resolution displays.

LMH allows users to choose any one of three cursor speed multipliers at any given time. Users can add and release fingers during a finger movement to change speeds. When multiple fingers are used, LMH uses average speed of the finger movements.

We established three different cursor speed multipliers: L for low speed, M for medium speed, and H for high speed. These three multipliers are scaling factors applied to the acceleration curve. In the study, we used L=0.7, M=3.4, and H=7.2. These three values were identified through a focus group that has experience with large, high-resolution displays. Acceleration multipliers are applied to the acceleration curve (Figure 4) that was optimized for the touchpad and large, high resolution screen.

3.1 Implementation

LMH is implemented with the help of TUIO [35] open framework which is commonly used for tangible multitouch user interfaces. We used TUIO API in order to implement the client software that is responsible for the cursor manipulations on the LHRD PC. The client on the LHRD PC receives input from the MackBook Pro 13 over a WiFi network. In order to capture multitouch events on the laptop's touchpad we employed Tongesng [36] TUIO event wrapper which also allows sending of the TUIO events over WiFi to the TUIO client.

For the acceleration curve we used a modification of the Windows XP curve [30] (Figure 4).The acceleration curve is applied to the vertical and horizontal components of the physical speed of fingers. The following pseudo-code demonstrates how the LMH, L, M and H work:

```
moveCursorLMH () {

  fingersInContact = tuio.getNumberOfFingers ();

  xSpeed = tuio.getAverageXSpeed ();

  ySpeed = tuio.getAverageYSpeed ();

  motionSpeed = sqrt (xSpeed^2+ySpeed^2);

  accelerationCurveMultiplier = accelerationCurve (motionSpeed);

  moveCursor (getMultiplier (fingersInContact)*
accelerationCurveMultiplier *xSpeed, getMultiplier (fingersInContact)*
accelerationCurve*ySpeed);

  }
--------------------------------------------------------
moveCursorL () {

  fingersInContact = 1;

  xSpeed = tuio.getAverageXSpeed ();

  ySpeed = tuio.getAverageYSpeed ();

  motionSpeed = sqrt (xSpeed^2+ySpeed^2);

  accelerationCurveMultiplier = accelerationCurve (motionSpeed);

  moveCursor (0.7* accelerationCurveMultiplier *xSpeed, 0.7*
accelerationCurve*ySpeed);

  }
--------------------------------------------------------

moveCursorM () {

  fingersInContact = 1;

  xSpeed = tuio.getAverageXSpeed ();
```

```
   ySpeed = tuio.getAverageYSpeed ();

   motionSpeed = sqrt (xSpeed^2+ySpeed^2);

   accelerationCurveMultiplier = accelerationCurve (motionSpeed);

   moveCursor (3.4* accelerationCurveMultiplier *xSpeed, 3.4*
accelerationCurve*ySpeed);

   }


--------------------------------------------------------
moveCursorH () {

   fingersInContact = 1;

   xSpeed = tuio.getAverageXSpeed ();

   ySpeed = tuio.getAverageYSpeed ();

   motionSpeed = sqrt (xSpeed^2+ySpeed^2);

   accelerationCurveMultiplier = accelerationCurve (motionSpeed);

   moveCursor (7.2* accelerationCurveMultiplier *xSpeed, 7.2*
accelerationCurve*ySpeed);

   }
```

Since the acceleration curve is the function of motor movement it is computed every time fingers are moved (Figure 4). Similarly, the multiplier (L, M or H) is chosen depending on the number of fingers touching. However, for L, M and H modes we simply use fixed multipliers (0.7, 3.4 or 7.2).

For LMH each finger is detected as an independent controller that adds its vertical and horizontal speed components to the average(Figure 5) of horizontal (Equation 1) and vertical (Equation 2) speeds. The acceleration curve is determined based on the magnitude

of the finger motion speed (Equation 3). The average speeds are computed as arithmetic

means:

$$xSpeed = \frac{1}{n}\sum_{i=1}^{n} xSpeed_i \qquad (1)$$

$$ySpeed = \frac{1}{n}\sum_{i=1}^{n} ySpeed_i \qquad (2)$$

$$motionSpeed = \sqrt{xSpeed^2 + ySpeed^2} \qquad (3)$$
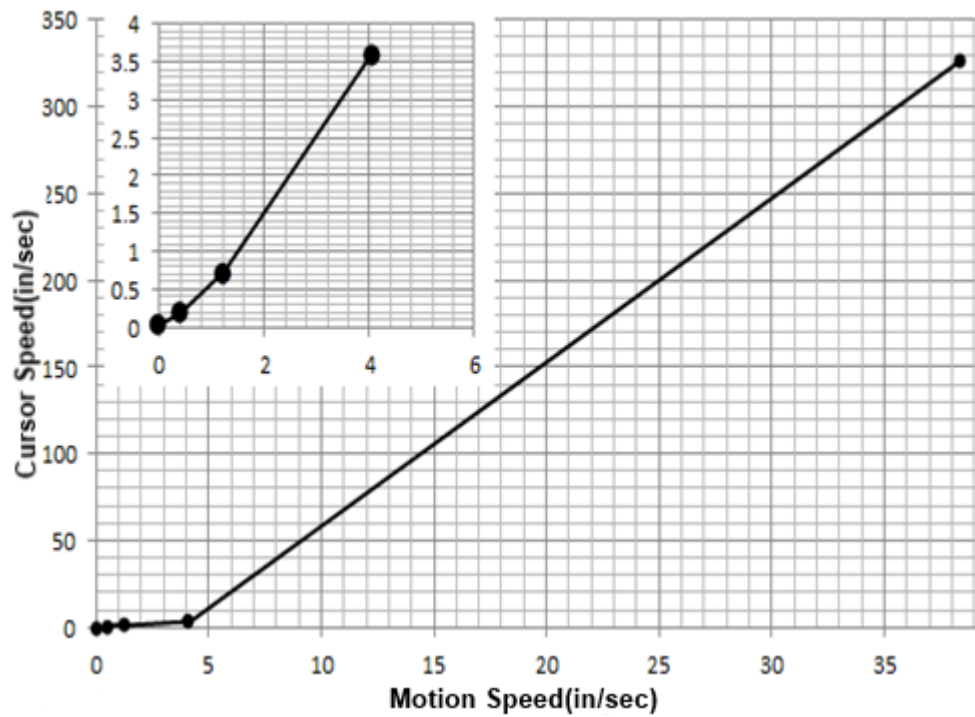
Figure 4: The acceleration curve used throughout this experiment. The figure depicts the curve with the multiplier that has the value of 1.0.
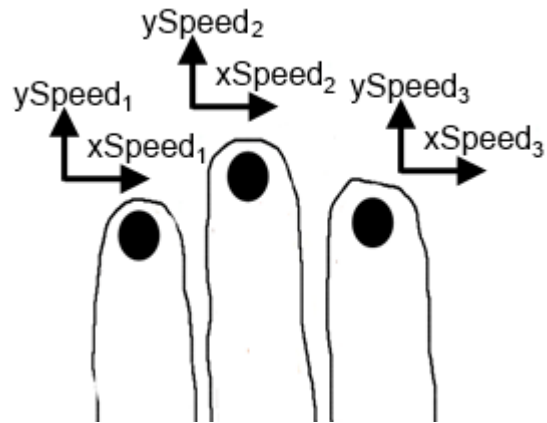
Figure 5: Total speed is the average of all fingers that are in contact with the surface. The total speed is computed by averaging both vertical and horizontal components contributed by each finger.

Thus the cursor speed is determined as follows:

$$cursorSpeed_x = multiplier * accelerationCurve * xSpeed$$

$$cursorSpeed_y = multiplier * accelerationCurve * ySpeed$$

$$cursorSpeed = \sqrt{cursorSpeed_x{}^2 + cursorSpeed_y{}^2}$$

Chapter 4

Experiment

To study and understand the usage of LMH, we compared LMH with the regular single finger technique at each of the three fixed multipliers (L, M and H). The goal of the experiment is to understand how LMH is used and whether the ability of manually switching input characteristics fits the multi-scale nature of large, high resolution screens. Additionally, we are interested in observing how the combination of implicit and explicit pointing granularity controls in LMH is going to be leveraged. Also, we would like to learn how the multiple fingers are used when acquiring targets, whether the process of switching fingers is going to represent a cognitive barrier to the users.

4.1 Techniques

In this study we compared four techniques: multi-finger LMH that allows three different multipliers (L=0.7, M=3.4, H=7.2), and three single finger techniques with L, M, and H multipliers. Each participant was asked to perform trials with all four techniques.

Figure 6: The screen used in the user study. Red, yellow and green lines demonstrate the concept of LMH technique in terms of distances covered with each multiplier. H is used for large distances (red lines), M is used for medium distances (yellow lines) and L is for short distances.

Figure 7: Users performed target acquisitions using MacBook Pro 13 laptop's touchpad. Users performed clicking using the space bar of the laptop.

4.2 Hardware

For this experiment we used the multitouch touchpad of a 2010 MacBook Pro 13. The touchpad was used to control the cursor on a large display (Figure 6). One of the reasons we opted for MacBook Pro's touchpad is the familiarity of users with the ergonomics that this touchpad offers. The large display has a total resolution of 10240x3200, constructed using eight (2x4) 30-inch monitors with 100DPI. The clicking was performed (Figure 7) with the spacebar button of the laptop instead of tapping. By doing so we kept tracking performance and cursor trajectories isolated from the potential issues that could arise from tapping/clicking the touchpad itself.

4.3 Participants

Eight undergraduate students participated in the experiment (three male, five female) between 19 and 23 years old. Participants were asked to perform the task as quickly and accurately as possible.

4.4 Tasks

Two dimensional reciprocal target acquisition task(Figure 8) with round targets was used, similar to the one by Casiez et al. [13]. We used three target sizes and three distances.

Each participant performed 216 trials (4 Techniques x 3 Sizes x 3 Distances x 3 Blocks x 2 Repetitions). Cases with missed clicks were marked as cases with error, and number of errors was recorded. The task presentation order of L, M, H and LMH was counterbalanced based across 8 users. The following is the distances between targets and their sizes:

Target size		Distance	
px	mm	px	mm
12	3.05	512	130.05
24	6.1	2048	520.19
48	12.19	8192	2080.77
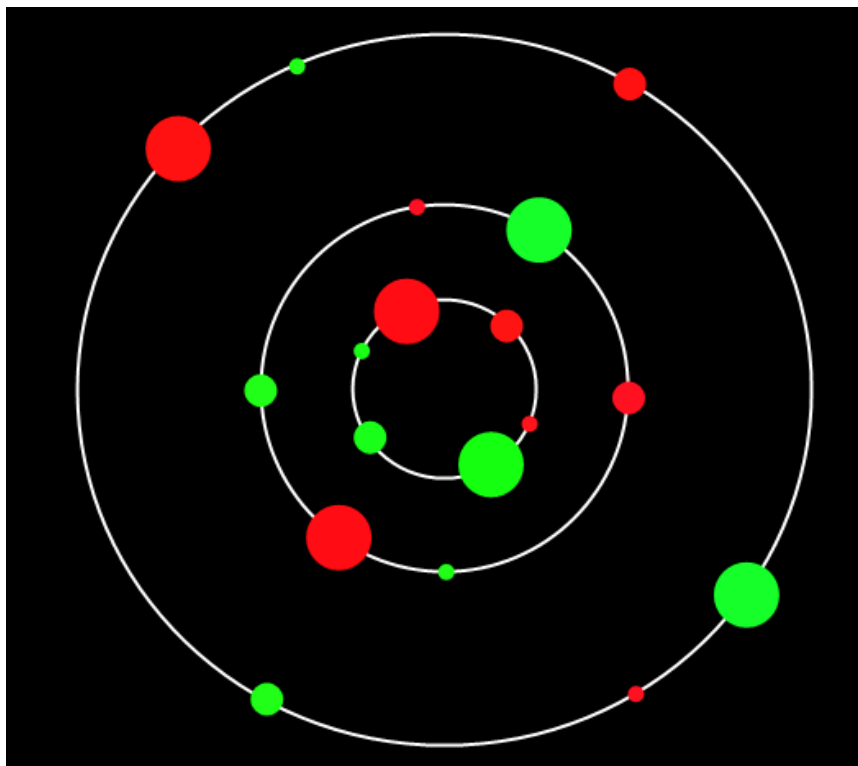
Figure 8: (Not drawn to scale) Reciprocal target acquisition task: users have to start by clicking green target that appears in random size and in a random location on any of the rings. Once the green target is clicked red target appears reciprocally to the green target. The measurements begin after green target is clicked and end after the red target is acquired.

We measured target selection time, number of clutches, as well as distance travelled by one, two and three fingers. The clutch is defined as instance of lifting all fingers from a

touchpad. We recorded number of clutching instances during the target selection. We recorded the distance travelled by the cursor and the number of fingers used at all times, which allows us to see individual contributions of all finger combinations. We also recorded a path taken by the cursor. The recordings were done within the custom reciprocal target acquisition task program that we wrote ourselves. The data was captured by monitoring both cursor and TUIO events within the program.

Participants were given enough time to familiarize with the setup. The average duration of the experiment was 75 minutes.

Chapter 5

Results

5.1 Selection time

Repeated measure analysis of variance demonstrated (Figure 9) significant main effect on selection time for the Technique ($F_{3,21}$=18.72 P<0.0001), distance between targets ($F_{2,14}$=422.43, P<0.0001) and their width, ($F_{2,14}$=190.08, P<0.0001). The interaction Technique x Distance revealed significant main effect on selection time ($F_{6,42}$=57.17, P<0.0001). We detected significant differences through pairwise comparisons of LMH with M (P<0.001), LMH with H (P<0.0001) and M with H (P<0.0001). Pairwise comparison, showed us that LMH and L yield significant difference on selection time for short distances (P<0.017). This is not expected since LMH with one   finger is identical to L. LMH performs 13% worse than L for the short distance; this is explained by the fact that for some short distance trials users kept using more than one finger. For the medium distance (2048 px) pairwise comparison of M, L, and LMH revealed no significant differences. Pairwise comparisons of H against M, L and LMH show significant differences (all three with p<0.0001). For the large distance (8192 px) we observed significant differences for the following pairs: H & LMH (P<0.0001), M & LMH (P<0.0001) and L & LMH (P<0.0001). There is also a significant difference between H & L (P<0.0001), M & L (P<0.0001). For the M & H pair the difference was insignificant.
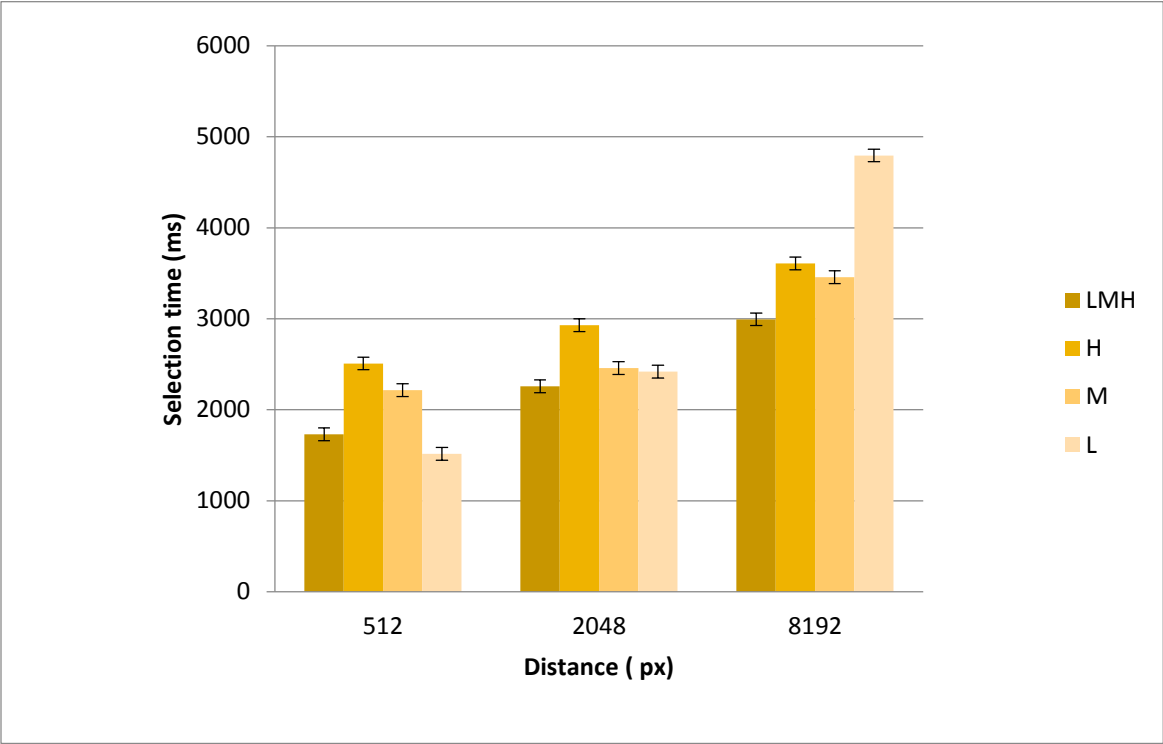
Figure 9: Mean selection time for each technique and distance. Overall LMH is the most balanced (error bars 1 SE).

5.2 Errors

The error rate is high (Figure 10) which is not surprising given the fact that we were conducting the experiment on a large, high-pixel density display with small targets. Interaction techniques had no significant ($F_{3,21}=1.97$, $P<0.117$) main effect on the error rate, this can be attributed to the fact that we used combination of large display with 100dpi density and small target sizes. Several participants noted that targeting the 12 pixel circle was hard because they had hard time seeing it on the screen. We still observed significant

differences between the error rates of LMH & H (P<0.037), and L & H (P<0.037). The advantage of LMH and L over H is obvious since both of them are optimized for precision positioning.
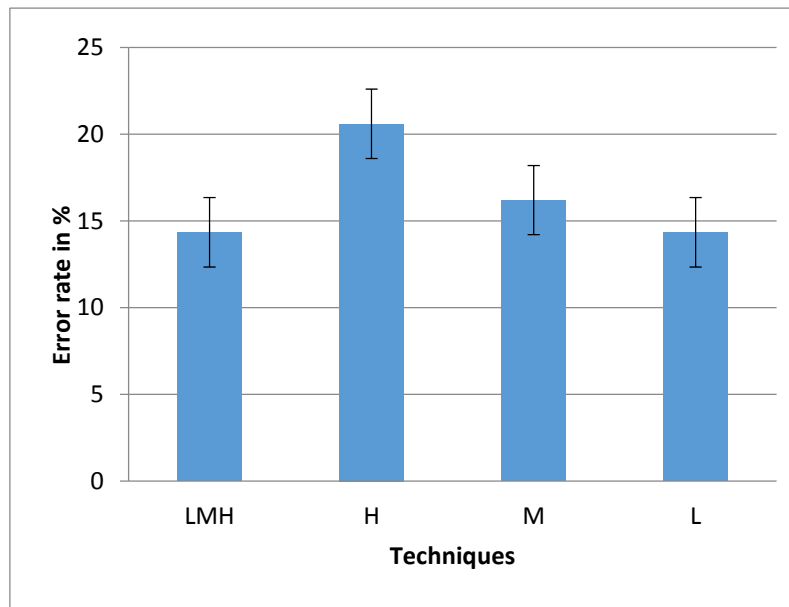
Figure 10 : Mean error rate for each technique (error bars 1 SE)

5.3 Clutching analysis

We believe that excessive number of clutches (instances of no fingers touching the touchpad) negatively affects user performance, thus we are interested in the number of clutches for different techniques. The average number of clutches (Figure 11) for the experiment was 2.16. Significant main effects of technique ($F_{3,21}$=69.97, P<0.0001), distance between targets ($F_{2,14}$=125.34,P<0.0001) and interaction Distance x Technique ($F_{6,42}$=94.01, P<0.0001) were observed. For the large distance H had the least number of clutches (1.92) followed by LMH (2.86), M (3.21) and L (8.74).The higher clutch rate L is predictable given

the low acceleration curve multiplier. It must be noted that H has 33% less clutches than LMH despite the fact that "top gear" of the latter exhibits identical multiplier for the
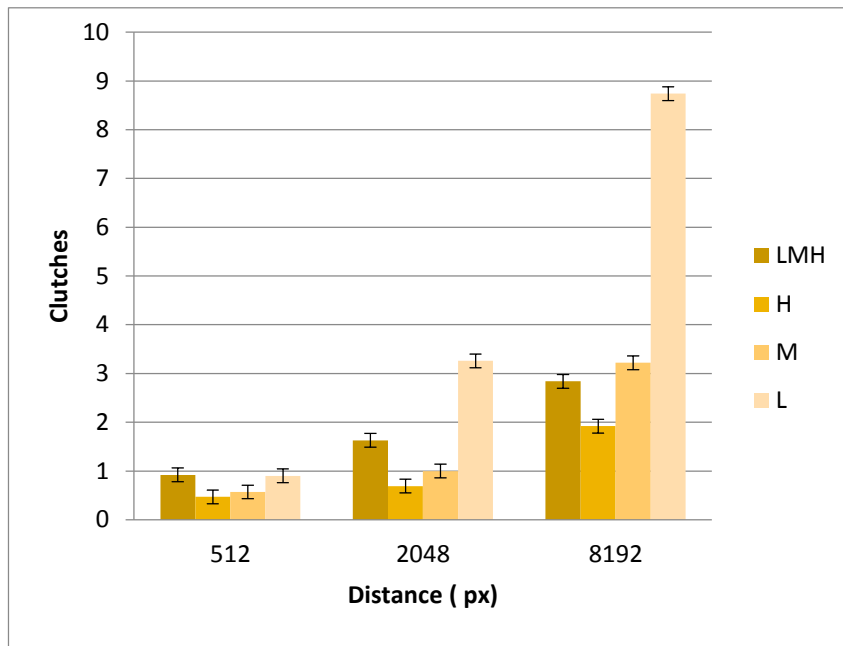
Figure 11: Clutch rates of each technique per each distance (error bars 1 SE)

acceleration curve. The extra clutching on behalf of LMH is rooted within its multi-scale nature which assumes switching to lower gears as the cursor approaches a target. Given the limited training time in the experiment it is clear that participants could not use LMH to its full potential and as a result they would prematurely switch to the lower gears and produce extra clutches. This is discussed in more detail later in the paper.

5.4 Target acquisition patterns

The most efficient use of LMH assumes switching of "gears" depending on the targeting conditions. For quick long distance targeting high speeds should be used to reach the near target area, once the cursor is close to the target lower speeds should be used for an accurate target acquisition. In order to analyze the patterns of LMH use we recorded X and Y coordinates of the cursor as it moves between targets (Figure 12), and the number of fingers touching the surface of the touchpad at all times. With this type of data we are able to visualize the patterns of LMH use.

2048 pixel distance. For the medium distance targeting (Figure 12a, b, c) all users used combination of one and two fingers. They would start out with two fingers (medium speed) and once near the target switch to one finger (low speed). Some users had issues with switching to one finger prematurely (Figure 12a), which had a negative effect on time performance as the one finger speed is low (L). We also observed cursor overshooting in some cases.

8192 pixel distance. Large distance targeting (Figure 12d, e, f and g) exhibited consistent use of three fingers: on average three fingers were used to cover 84% of the total trip towards the target. One and two fingers, on the other hand contributed only 9% and 7% consequently. However, one of the participants deliberately used only one and two fingers (Figure 12d), ignoring three finger mode. Cursor overshooting was observed for some of the

participants; it was most prominent during the practice. We believe overshooting is attributed to the fact that users need some time to learn how to switch from three fingers to one finger as the cursor gets close to the target. For the entire experimental data three general patterns emerged: 1) "spot on pattern" with straight trajectory with minimal use of slow speeds and with no overshooting (Figure 12e), 2) "gradual pattern" with straight trajectory (Figure 12f) , prolonged use of slower speeds and no overshooting, 3) "zig-zag" pattern with a bent trajectory, overshooting and prolonged use of slower speeds (Figure 12g).
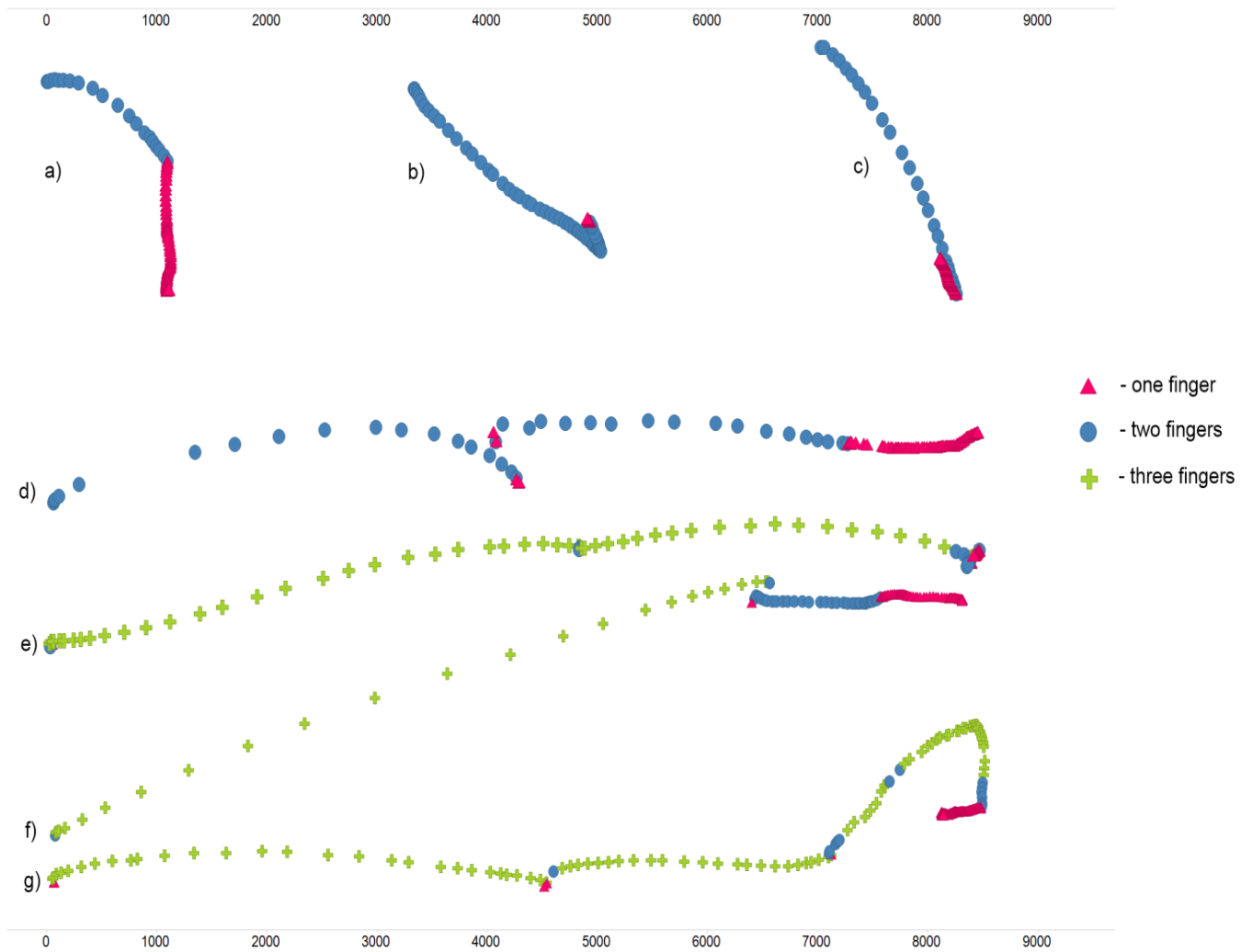
Figure 12: Cursor patterns captured at a constant rate. The gaps between objects are proportional to the speed of the cursor.

5.5 Usage of different techniques and feedback

The usage patterns of all four different techniques were consistent among all the users.

LMH. For the targets separated by 8192 pixels all but one participant used three fingers for rapid cursor movements to the nearby area of the target. As our analysis of the usage patterns reveals (Figure 12) the refinement of the cursor position was achieved with the shift to the lowest speed L. Same analysis reveals that for medium distances (2048 px) all participants used two fingers for the fast movements and one finger for the final position refinement. For the short distance (512 px), participants used single finger in most of the cases, however in the 18% of cases, 5 out of 8 participants used more than one finger, which explains the difference in performance between L and LMH for the short distance. The post experimental discussion revealed that only one participant knowingly used two fingers for the short distance targeting. The participant believed that with two fingers it would have been faster to acquire targets.

Single Finger. For H and M speed settings all users verbally expressed frustration, especially for H. Small target acquisition turned out to be challenging due to the higher CD ratios despite the cursor acceleration. Participants noted that they had to commit significant levels of effort for the precise target acquisition. With L all participants noted that they had no difficulties acquiring targets but high number of clutches for long distance cursor movements resulted in fatigue. As a result all participants expressed a preference for the LMH over H, M and L.
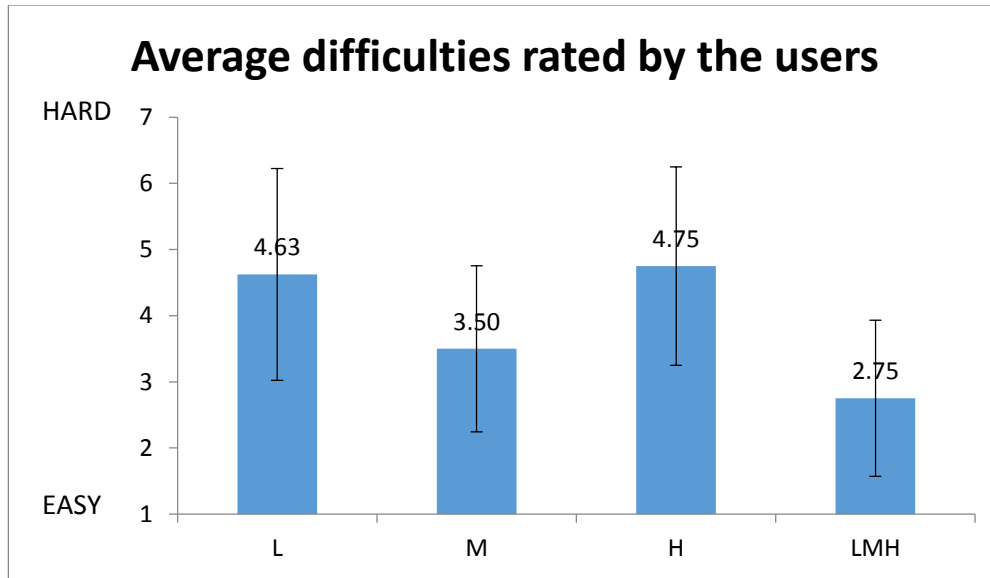
Average difficulties rated by the users

Figure 13: Averages of the user rated difficulty for L, M, H and LMH on a scale from 1 to 7 where higher numbers mean more difficult (questions 3-6, Appendix A1)

Feedback. All participants preferred LMH technique due to its adaptive nature. They appreciated the ability to slow down near the targets by lifting extra fingers. They emphasized that "speed" switching required no noticeable effort and was performed "without thinking about it". Participants were asked to describe their target acquisition strategies and all of them mentioned switching to the "slow speed" when approaching a target. Several participants described LMH as "fun" and "engaging". As for the one finger techniques participants preferred M over H, since it is easier to precise target positioning due to lower acceleration multiplier, although they still describe it as somewhat uncomfortable. However, the worst technique according to participants was L, because of the high number of clutches required for long distance target acquisition. Although, for the short distance (512 pixels) they preferred L due to its low CD gain ratios, which makes it easy to select small targets. Seven out of eight participants said that they would use LMH if

they had a display that is as large as the one used during the experiment. Five participants said that they found LMH intuitive after the first dozen clicks; the other three also described it as intuitive, although during the first several minutes with LMH they had an opposite opinion.

Users were also asked to fill out our index of difficulty questionnaire. With that questionnaire (Appendix A1) users could choose index of difficulty as a number from 1 to 7 where higher number stands for higher level of difficulty. While the results from the questionnaire resonate with the results from the informal interviews that we conducted, the numerical results are not statistically significant (Figure 13). It is interesting to note that according to the participants both L and H are noticeably worse than M and LMH. This shows implicitly that users find it difficult to use techniques that are either inaccurate (H) or require way too much clutching (L).

Our main contribution is the result of the study, which shows that users do manually switch acceleration curve multipliers. The study showed that users utilized larger multipliers for fast and coarse positioning, while performing near target acquisitions using the lowest multiplier. The study also demonstrated the advantages of the ability to change device pointing granularity setting while keeping the same mental model of interaction: participants found it intuitive and effortless to switch the settings. Numerical results showed that by dynamically changing acceleration curve multipliers users were able to combine the strengths of low speeds for precision and of high speeds for coarse positioning. The combination of explicit granularity control with the implicit one yields better overall results. Additionally, the target acquisition patterns show that users utilized the LMH in a way that

it was originally meant to be used as: two and three finger swiping for coarse pointing and single finger for precise positioning.

Based on user feedback the switching mechanism for multipliers using multiple fingers on the capacitive touchpad was perceived as natural and easy to use. All users noted that they were switching fingers on the fly without interrupting the physical finger movement. The study also shows that the usage patterns confirm our initial assumption of LMH being capable of supporting and handling the multi-scale nature of large, high resolution screens.

Chapter 6

Conclusion and future work

With LMH and the results of the study we contribute:

1. The new class for interaction techniques; combination of explicit and implicit granularity controls within the same mental mode of interaction.

2. The technique in the new class: touchpad based interaction technique that allows changing multipliers for the acceleration curve by changing number of fingers.

3. Results of the study on 8 human subjects show that combination of implicit and explicit granularity control in the form of LMH improves performance when compared to just implicit control (L, M or H). Results show that participants did use the ability to explicitly switch granularity settings depending on the targeting conditions. The post study interview show that participants found it easy to use.

This thesis shows that large, high resolution screens encourage manual switching of multipliers. It is interesting to see how LMH would perform on a large screen with even higher pixel density. Another aspect that might reveal the full potential of the LMH is a long term study in which the effects of novelty will not be present. We anticipate that such long term study is going to more prominent performance improvements and new insights into how users utilize multi-scale interaction technique with large, high-resolution screens.

In the future we intend to further investigate the concept of dynamically switching input parameters within a single mode of interaction. The core concept of LMH, which is a combining

explicit and implicit pointing granularity controls, can be applied to other kinds of devices. For instance, number of fingers touching the surface of a mouse could act as a trigger that changes acceleration multiplier similar to LMH. In addition to varying number of touching fingers, one could employ other input mechanisms such as distance [37] from the screen. As the part of the investigation of new techniques of this type we would also like to conduct studies that would compare them with techniques from different domains such as dual-mode techniques.

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APPENDIX A
A1. Questionnaire

Questionnaire

1) Did you find it intuitive/natural to use multiple fingers for increasing the speed of the cursor ?

2) Do you think you would use LMH for everyday use on a large display?

3) One a scale from 1 to 7 how would you rate the difficulty of using L (low speed single finger) ? EASY 1—2—3—4—5—6—7 HARD

4) One a scale from 1 to 7 how would you rate the difficulty of using M (medium speed single finger) ? EASY 1—2—3—4—5—6—7 HARD

5) One a scale from 1 to 7 how would you rate the difficulty of using H (high speed single finger) ? EASY 1—2—3—4—5—6—7 HARD

6) One a scale from 1 to 7 how would you rate the difficulty of using LMH ? EASY 1—2—3—4—5—6—7 HARD

A2. Consent form

Evaluation of a multi-finger input system

Investigators: Dr. Chris North, Andrey Esakia, Alex Endert

I. Purpose of this Research

The purpose of this study is to compare two different input methods using touch sensitive touchpads. The goal is to compare the performance of the two methods in terms of accuracy and speed. In order to measure the performance, participants will be repeatedly clicking on the targets displayed on the screen. Speed and accuracy data will be detected for each click. This data will help with the design of future input methods based on touch sensitive touchpads.

II. Procedures

At the start of the study we will ask you to perform several mouse clicks in the evaluations tool. After familiarizing with the evaluation tool, you will work basic click tasks throughout the study session. After finishing the tasks, you will be asked to comment on the two different types of the input method used. The computer will record time between clicks.

III. Risks

There are no known risks in this study. In case of exhaustion you are encouraged to take a break.
The task does not require continuous activity.

IV. Benefits

The long-term benefit of this study is that the information gained from the study will give us insights into how multitouch touchpads are used. This will guide us in the design of an improved multi-finger input system.

V. Extent of Anonymity and Confidentiality

Given the minimalistic nature of the study there is no need for any private information such as name, video/photo materials. The only data obtained in this study is the measurements of speed and error. Hence, confidentiality and anonymity is guaranteed.

VI. Freedom to Withdraw

You are free to withdraw from a study at any time without penalty. There may be circumstances under which the investigator may determine that you should not continue as a subject. You will be thanked for you time.

VII. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities: to let the experimenter know if I am feeling overly frustrated and need to take a break; to let the experimenter know that I need to leave the study.

VIII. Subject's Permission

I have read the Consent Form and conditions of this project. I have had all of my questions answered. I hereby acknowledge the above and give my voluntary consent:

IX.Approval of research

This research has been approved, as required, by the Institutional Review Board (IRB-12-216) for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Computer Science.

_____ Date:_____
Subject Signature

Should I have any pertinent questions about this research or its conduct, and research subjects' right, and whom to contact in the event of a research-related injury to the subject, I may contact:

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