



## MASTERARBEIT

# Comparing Mouse- and Touch-based Map Interaction for Target Search Tasks on Large Screens

Ausgeführt am Department für  
Geodäsie und Geoinformation  
der Technischen Universität Wien

unter der Anleitung von  
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und  
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durch

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30. January 2017

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Unterschrift (Student)



MASTER'S THESIS

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# Acknowledgements

First of all, I would like to thank my supervisor Dipl.-Ing. Florian Ledermann for the continual input, discussion, guidance, encouragement, and support throughout the process of this thesis. Thanks for putting up with my constant skepticism, procrastination, and inarticulateness.

I would like to thank Prof. Georg Gartner for the advice and feedback on the thesis draft. My gratitude also goes to the rest of the members of the cartography research group, for their participation in the pre-tests, suggestions for improving the research design, and their help in finding participants for the user study.

Also, I want to thank all the user study participants for taking part in this study and giving valuable feedback.

Finally, I want to thank all my friends who listened to my complaints about life when I was frustrated and depressed, and my family who supported me all these years.

# Abstract

Large multi-touch devices are gaining more attention in various fields of applications. The device through which the cartographic content is presented plays a role in cartographic interaction. This thesis presents a controlled user study comparing mouse- and touch-based map interaction on a large screen, in the context of target search tasks. Participants' mouse and touch input were logged in the browser. Several measurements were used to evaluate the difference between the mouse and touch interaction—drag length, drag direction, drag and zoom frequency, touch/mouse on-screen locations, and time spent on tasks. The results suggest that when using touch, users pan the map differently from when they are using mouse, with shorter panning distances and different main panning directions. The touch locations concentrate in the lower-middle part of the screen while mouse covers a larger screen area. Drag and zoom frequencies of the two input methods are quite similar, as well as the task completion times. In situ observation of user behavior identified several usage patterns and frequent problems when using touch. User feedback shows a clear preference of mouse input and gives reasons for participants' preference.

**Keywords:** cartographic interaction, multi-touch, large display, user study

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# Abbreviations

<b>HCI</b>	<b>H</b> uman <b>C</b> omputer <b>I</b> nteraction
<b>UI</b>	<b>U</b> ser <b>I</b> nterface
<b>API</b>	<b>A</b> pplication <b>P</b> rogramming <b>I</b> nterface
<b>HTML</b>	<b>H</b> yper <b>T</b> ext <b>M</b> arkup <b>L</b> anguage
<b>CSS</b>	<b>C</b> ascading <b>S</b> tyle <b>S</b> heets
<b>SVG</b>	<b>S</b> calable <b>V</b> ector <b>G</b> raphics
<b>XML</b>	<b>e</b> Xtensible <b>M</b> arkup <b>L</b> anguage
<b>DOM</b>	<b>D</b> ocument <b>O</b> bject <b>M</b> odel
<b>OSM</b>	<b>O</b> pen <b>S</b> treet <b>M</b> ap
<b>POI</b>	<b>P</b> oint <b>O</b> f <b>I</b> nterest



# Chapter 1

## Introduction

### 1.1 Motivation

Since the release of Apple iPhone and Microsoft Surface in 2007, multi-touch technology has enjoyed immense popularity over the years. While the small screen smartphones are easy to carry and hence become an integral part of modern life, large multi-touch devices are also gaining more attention in various fields of application. They have the advantage of large screen estate (unlike mobile devices) while offering intuitive user interaction. These large touch screens are often seen in public or semi-public spaces such as museums, shopping malls, and tourist information centers, as an interactive and engaging way to provide information to visitors.

As cartography is all about the visual representation of geographical information, large touch screens are naturally a suitable choice for cartographic applications. Museums and exhibitions employ multi-touch map applications to tell stories of historical events (e.g., Axis Maps, 2015). City plans and campus maps can be shown on the large multi-touch screen, helping people to find their way (e.g., DOKLAB, 2014). Even broadcasting companies make use of interactive maps on multi-touch large screens. In 2008, US TV networks started using multi-touch screens to present the election results (CNN, 2008). The news anchor could easily present the real-time data to the audience while explaining what is going on. The list of application fields cannot be enumerated. Therefore, map interaction on large multi-touch devices is worth investigating.

## 1.2 Problem Statement

Lots of cartographic studies focus on how differences in visual variables, interface elements, etc. affect user-map interaction. Relatively few work has focused on the impact of different input methods on map interaction. Despite the growing number of map applications on large multi-touch devices, it is not clear how large multi-touch devices affect the way people interact with maps.

## 1.3 Aim of the Thesis

The aim of this thesis is to provide insights into how people interact with maps on large multi-touch screens. By designing and conducting a controlled user study to compare the touch input with mouse, the thesis seeks answers to the following questions: For a large screen size, is multi-touch input more efficient than mouse? Are there different patterns in terms of panning/zooming when using mouse and touch? Do map users prefer using the multi-touch input? The discoveries can be helpful in understanding cartographic interaction, and can be the basis to establish guidelines for designing better cartographic applications on large multi-touch devices.

## 1.4 Thesis Structure

The rest of the thesis organizes as follows:

Chapter 2 discusses related studies in the fields of Human-Computer Interaction and Cartography.

Chapter 3 describes the design of the empirical study in detail, including tasks, participants, materials, procedure and data collection methods.

Chapter 4 presents the results of the empirical study and discusses the findings.

The last chapter summarizes the important findings and makes suggestions for future work.

## Chapter 2

# Literature Review

This chapter first discusses recent research on large multi-touch displays in general, then examines map-related multi-touch applications and comparative studies on touch versus mouse input. Lastly, some relevant concepts and technologies regarding interactive maps are briefly introduced.

### 2.1 Large Multi-touch Displays

The existence of multi-touch surfaces dates back to at least the 1980s (Buxton, 2016), when researchers at University of Toronto (Mehta, 1982) and at Bell Labs (e.g., Kasday, 1984) developed multi-touch systems based on various techniques. Since then there has been a multitude of studies looking into improving multi-touch devices, making them more affordable and easier to use. Later well-known examples include DiamondTouch by Mitsubishi Research Labs (Dietz & Leigh, 2001), which is capable of recognizing multiple users' hands; and the low-cost multi-touch sensing technique presented by Han (2005), who then demonstrated his work in a TED conference in 2006, bringing awareness of multi-touch technology to the general public.

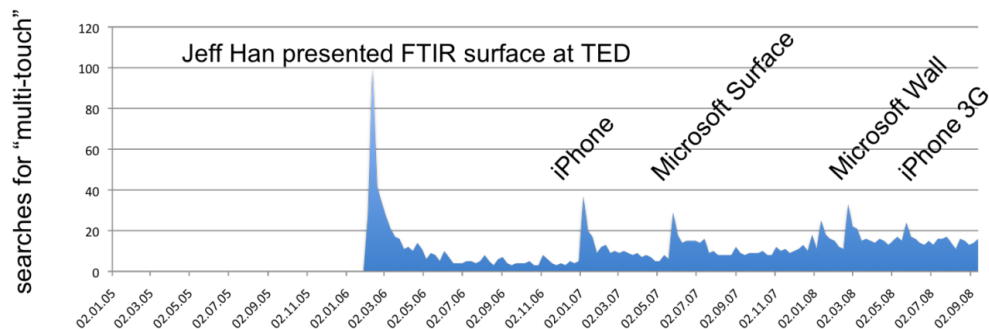


FIGURE 2.1: The popularity of the search terms “multi-touch” by Google Trends, from Schönig et al. (2008)

As the expenses of multi-touch devices have decreased rapidly in the last decade, large multi-touch displays are made accessible to more users. Meanwhile, research about these displays also flourished. Schönig et al. (2008) gave a summary of the important technical aspects of multi-touch surfaces, including the different types of (multi-)touch technologies and the hardware and software required to build a multi-touch surface. In their recent survey, Ardito, Buono, Costabile, and Desolda (2015) examined studies in large public displays to analyze how, why and where large displays are used; among the 206 papers they selected, 57% discuss touch-based systems, and most of them support multi-touch. Bellucci, Malizia, and Aedo (2014) reviewed the state of the art of multi-touch tabletops, while Isenberg and Isenberg (2013) gave an overview of data visualization (map representations included) on interactive surfaces.

In general, studies about large multi-touch displays belong to one of two types: controlled user studies or non-controlled “in the wild” observations. Ryall, Morris, Everitt, Forlines, and Shen (2006) used non-controlled settings to observe user interactions in four different real-world contexts, from casual to more focused usage scenarios. They were able to identify some common usage patterns after two years of observation, such as “aiming and targeting precision problems for large-fingered individuals”, “accidental input is common”, and “the design of the tables edge and its height impacted its use”. Another study investigated long-term usage of a large multi-touch display (Wigdor, Penn, Ryall, Esenther, & Shen, 2007). In the study, the participant used a multi-touch table for everyday office tasks over a 13-month period. Case studies in museums and exhibitions (Hornecker, 2008; Hinrichs & Carpendale, 2011) also belong to the non-controlled setting, where the visitors’ interactions with the system were unstructured and free-form.

Controlled user studies often involve clear separation of independent variables, and their results often include quantitative analysis of task completion time and accuracy. Comparative studies, such as comparing touch with mouse input (see Section 2.3), or vertical with horizontal display, fall into this category. A comparison of vertical and horizontal touch input has been done by Pedersen and Hornbæk (2012), where they measured participants’ speed, accuracy, and fatigue on both orientations in tapping and dragging tasks. They found that tapping was performed 5% faster on the vertical



surface, whereas dragging was performed 5% faster and with fewer errors on the horizontal surface. Most of their participants preferred the horizontal surface because the vertical one is more physically demanding to use.

In this thesis, the author used a controlled user study to investigate the difference between touch and mouse input for map interaction, partly because this kind of study is still rare in cartographic research on multi-touch, as can be seen in the next section.

## 2.2 Large Multi-touch Map Applications

Although numerous studies have been conducted in the HCI domain, studies about large multi-touch displays in the context of map-related interactions are still rare. Not much research has investigated how people can best use the large multi-touch display for maps. Most existing works are case studies which focus on the design and implementation of a visually appealing application with a specific usage scenario, then test them in a non-controlled setting in order to evaluate the prototype, and provide guidelines or insights for designing similar applications.



FIGURE 2.2: A multi-touch map application presented in Rönneberg et al. (2014)

Rönneberg et al. (2014) present a multi-touch, multi-user map application in a natural center (Figure 2.2). The display surface is made up of three separate multi-touch LCD displays with  $1920 \times 1080$  pixels in resolution and  $101.8 \times 57.3$  centimeters in display size. They concentrated on map interface design issues, and based on some user interface (UI) design principles and user feedback, they provided a list of considerations for developing the UI. The authors noted that multi-user map applications in multi-touch environments are still rare, hence these considerations may be helpful for the future development of similar applications.

von Zadow et al. (von Zadow, Daiber, Schöning, & Krüger, 2012) developed a multi-touch, multi-user tabletop application for exploring geographic information for the general public. Their application uses a focus+context visualization technique to allow multiple users to inspect details in different info points on the map simultaneously. All interaction takes place in the so-called “GeoLenses”—the superimposed circles showing detailed information. They installed the application in an exhibition and observed about 150 visitors’ interaction with the system. They made some interesting observations, such as that around one-third of the user used only a single finger, and that older users were as capable of interacting with the application as younger ones although old users focused more on the content. They concluded that the GeoLens approach is viable for data exploration by untrained users in public space, that users were able to learn about the actual content instead of only interested in the technology. However, the authors also pointed out that further use cases and usability studies in a controlled environment would be necessary to verify these findings.

Nagel et al. (2014) used both “in the wild” and lab settings to evaluate an application they developed for exploring public transit data on a multi-touch tabletop (Figure 2.4). In their user study, they tested 27 participants from three different user groups—local citizen, domain expert, and neither local nor expert—and evaluated the different levels of insights made by the participants, ranging from basic visual properties to complex tempo-spatial patterns. The researchers asked participants to come up with insights while using the application, and recorded the audio as well as observed user behavior. The results suggest that non-experts were able to have a general understanding, citizens were able to gain a deeper sense of their city, and experts could use their prior



FIGURE 2.3: Multi-touch application by von Zadow et al. (2012)

knowledge to gather higher levels of insights. They argued that well-designed interactive tabletop applications visualizing urban data can inform both citizens and experts and help them deepen their understanding of the city.



FIGURE 2.4: Visualization of Public Transit application by Nagel et al. (2014)

Artinger et al. (2011) investigated several alternative multi-touch gestures for panning, zooming, rotating and selecting the map and map objects in an emergency management scenario. They conducted an exploratory user study with 6 participants to evaluate the easiness of learning, using and remembering those gestures. Based on their observation and user feedback, they made some recommendations for the design of future gestural interfaces.

White (2009) implemented a large format multitouch interface for the purpose of map navigation. He created some custom gestures for some of the most common map



FIGURE 2.5: Feedback and help functionality in Artinger et al. (2011)

navigation tasks: zooming, panning and accessing menus, and identifies some problems such as lack of hover state and obstructed views created by the user's hands. However, his thesis mainly focused on the hardware construction, which is understandable given the high cost of large multi-touch devices at that time.

## 2.3 Touch vs. Mouse Input

Comparison between mouse and touch input has been the focus of many studies in the human-computer interaction (HCI) field. According to Forlines, Wigdor, Shen, and Balakrishnan (2007), one of the most often argued benefits is that direct-touch is more “natural” than indirect input such as a mouse or pen; but since “naturalness” is difficult to measure, the underlining argument is that the direct-touch input improves efficiency and accuracy. It is based on measuring efficiency and accuracy that many empirical studies are carried out. The dependent variables are usually time and accuracy (or errors). Participants' preferences are usually also collected.

One of the most-cited works comparing direct-touch with mouse input is done by Forlines et al. (2007). They conducted two experiments: one unimanual (using one mouse or one finger) and the other bimanual (two mice or two fingers). For the first experiment, they compared single-finger direct touch input with single-mouse input for selection and dragging operations on a tabletop. The participants were asked to perform a 2D target selection and docking task (Figure 2.6). The independent variables were: input method, target size, and target distance; the dependent variables

measured were selection/docking time and selection/docking errors. Their second experiment compared two-mouse input with two-finger input for a symmetric bimanual task (Figure 2.7). They concluded from the results that in unimanual situations a mouse is better than a finger, while in bimanual situations touch is better than two mice. However, they pointed out that speed and accuracy may not be the only consideration when choosing an input method—factors such as fatigue and spatial memory might also influence a designer’s decision.

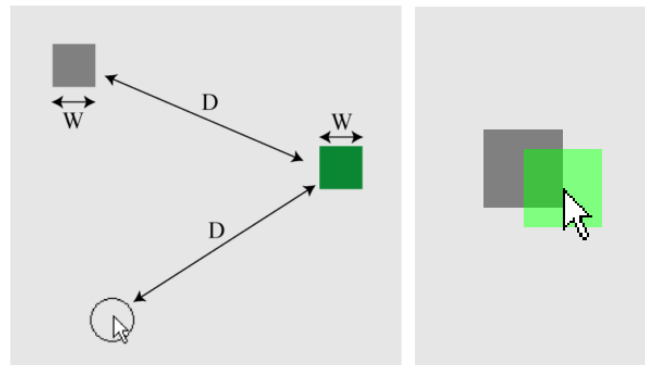


FIGURE 2.6: Task in the unimanual experiment in Forlines et al. (2007). (left) Round home location, the target on the right, and the dock on the left. (right) After selecting the target, participants dragged it to the dock.

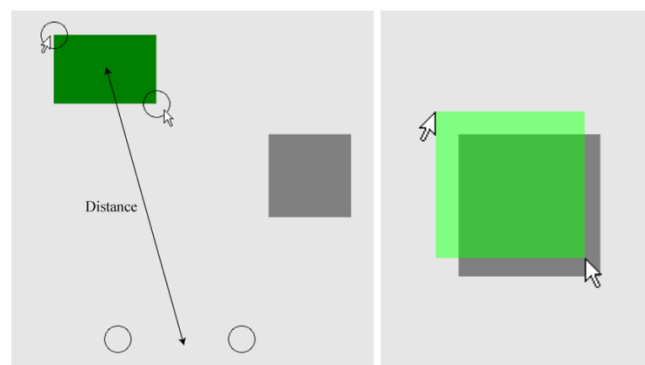


FIGURE 2.7: Task in the bimanual experiment in Forlines et al. (2007). (left) Participants selected targets by selecting opposite corners. (right) Participants then dragged and resized the target so that it matched the dock.

In another empirical study, Kin, Agrawala, and DeRose (2009) compared four input methods—one mouse, one finger, two fingers with one from each hand, and multiple fingers—in multi-target selection tasks. By measuring selection time, they found that

one finger direct-touch provides a large performance improvement over one mouse condition, and multi-touch further provides a small improvement over single-touch. They also measured miss rates but found no significant difference across the four conditions.

Hansen and Hourcade (2010) compared multi-touch tabletop (81cm by 61cm) and multi-mouse single-display groupware (two mice, 15-inch vertical display) for a collaborative visual task, and concluded that, despite users' preference for the multi-touch tabletop, the multi-mouse setup is actually more efficient (both in terms of completion time and number of operation). They use this to argue that users, as well as researchers, are often biased by "exciting" technologies (in this case, the multi-touch tabletop), therefore results of this kind of comparative studies should be interpreted with caution. The limitation of this study is that the two setups differ not only in input modality (touch vs. mouse), but also in display size and orientation, so it is unclear which factor made a difference (or to what degree).

It should be noted that the above-mentioned studies, as well as many other empirical studies in HCI research, mainly focus on simple "selection" and "dragging" tasks. Therefore, the conclusions cannot be applied directly to cartographic applications. There are, however, a few studies that focus on map-based tasks.

In a study perhaps most relevant to this thesis, Beheshti, Van Devender, and Horn (2012) compared multi-touch tabletop with the desktop on map navigation performance in a single-user situation (Figure 2.8). To determine whether participants who use the tabletop have a better performance in navigation tasks (in this case finding their way in a virtual world from a specific start point to a specific end point), the researchers measured the map interaction time and navigation time, and the result suggests no significant difference between the two conditions. Additionally, they observed how users drag, zoom and rotate the map on the multi-touch tabletop, and identified some interesting gestures which seem to be only typical in map navigation tasks. The problem with their experiment design is that, there are too many independent variables—modality, orientation, and screen size, to name a few. Therefore the influence of each factor cannot be decided.

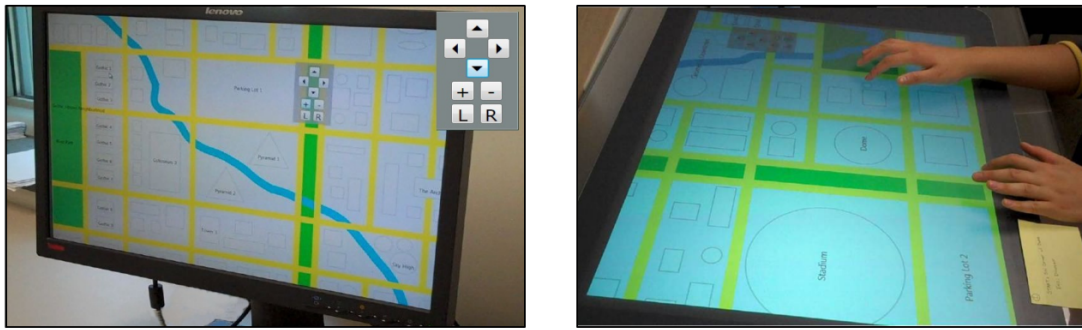


FIGURE 2.8: Desktop and tabletop conditions in Beheshti et al. (2012)

Wu, Lin, and You (2011) compared the performance of mouse and single-touch input for different navigation modes of a web map. As stimuli, they used an artificial campus map with a limited area displayed on a 17-inch touch screen slanted at 40 degrees. They asked each participant to find designated targets (red points) which appear at ten randomly-selected locations on the map. To finish the tasks, participants need to pan and zoom the map. The results show that the task completion time varied with the input device: mouse performed better in all three navigation modes they investigated, confirming the findings in (Forlines et al., 2007). The authors reasoned that the poorer performance of touch is due to hand/finger occlusion and unfamiliarity of the device. However, their study has serious limitations. First, they used single-touch instead of multi-touch. Moreover, the participants were not interacting with the map itself—they were only pressing the buttons which provide the zoom and pan functionality.

## 2.4 Interactive Cartography

Using the definition proposed by Roth (2013), cartographic interaction is the dialogue between a human and a map, mediated through a computing device (Figure 2.9). Therefore, in the research area of interactive cartography, users, map interfaces (including the maps), and the devices through which the users interact with the maps, should be equally important to investigate.

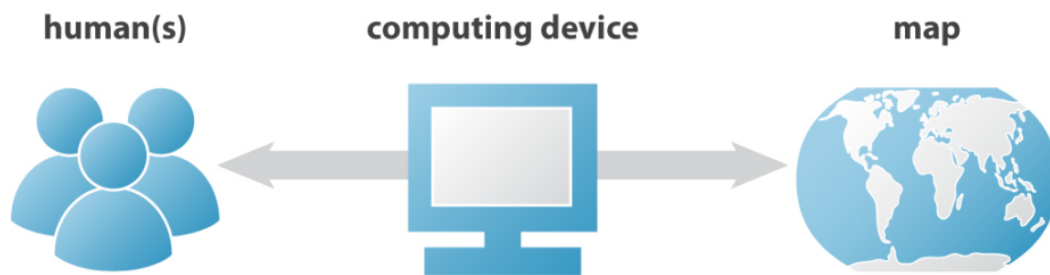


FIGURE 2.9: Components of cartographic interaction, adapted from Roth (2013)

In the literature, a lot of studies have focused on the “map interface” component, for example different map interface designs (Çöltekin, Heil, Garlandini, & Fabrikant, 2009; Poplin, 2015), various interactive techniques (Andrienko & Andrienko, 1999; Harrower & Sheesley, 2005). This thesis is focusing on the “device” component, by comparing mouse and touch input.

Harrower and Sheesley (2005) identified three basic questions for all interactive mapping systems: (1) what type of interactivity is needed, (2) how much interactivity is needed (degree of control), and (3) how should this interactivity be implemented. In this thesis, the goal is to compare two different input modalities, not to design a specific map interface for any particular application scenario. Therefore, a general-purpose map with the most common interactivities—pan and zoom—and very simple interface is used in this study.

### 2.4.1 Panning and Zooming

**The “Google Maps Effect”** Google Maps was introduced in 2005 and has revolutionized online mapping (Peterson, 2008). Since then, slippery maps (i.e., maps that users can pan around and usually also zoom in/out) have become a new cartographic standard (Muehlenhaus, 2013). Millions of map users pan and zoom every day (Harrower & Sheesley, 2005), thus it is necessary to include this functionality when designing research concerning interactive maps.



## 2.4.2 Web Mapping

Internet mapping, or web mapping, started early after the emergence of the World Wide Web (Haklay, Singleton, & Parker, 2008), since then the design and use of web maps has changed dramatically. Client-side web mapping has been transitioning away from standalone, proprietary technologies (such as Adobe Flash) and towards open technologies that built on the HTML, CSS, SVG, and XML web standards (the Open Web Platform) and the JavaScript programming language (Roth, Donohue, Sack, Wallace, & Buckingham, 2015). With the help of mapping APIs (application programming interface), even relatively novice map users can include a functioning map in their websites or apps, with just a few lines of code. The technologies and concepts used in building the testing web page for this study are introduced briefly here.

**HTML** HyperText Markup Language (HTML) is the standard markup language for creating web pages and web applications (W3C, n.d.). Web browsers receive HTML documents from a web server or from local storage and render them into multimedia web pages. HTML describes the structure of a web page.

**CSS** Cascading Style Sheets (CSS) describes how HTML elements are to be displayed on screen, paper, or in other media, including the color, font, layout, and variations in display for different devices and screen sizes (W3C, n.d.).

**JavaScript** Alongside HTML and CSS, JavaScript is one of the three core technologies of World Wide Web content production. It adds client-side behavior to the web page. The majority of websites employ it, and all modern Web browsers support it without the need for plug-ins. Scripts are embedded in or included from HTML pages and interact with the Document Object Model (DOM) of the page.

**Map Tiles** Slippy maps are made up of many small, square images called tiles. These tiles are typically  $256 \times 256$  pixels and placed side by side to form a large seamless image of the mapped area. The very first tile covers the entire globe, and is called

zoom level 0 (denoted by “z0”). The next zoom level z1 divide z0 into four equal squares, and the next divide z1 into four equal squares. . . and so on. At zoom level Z the number of tiles equals  $2^z \times 2^z$ . As the zoom level gets higher, the map scale gets larger, meaning that the map has a higher level of detail.

With the help of mapping libraries such as Leaflet<sup>1</sup>, map tiles can be downloaded from the map server on request, and positioned correctly on a web page. Figure 2.11 shows the composition of a typical tile-based web map.

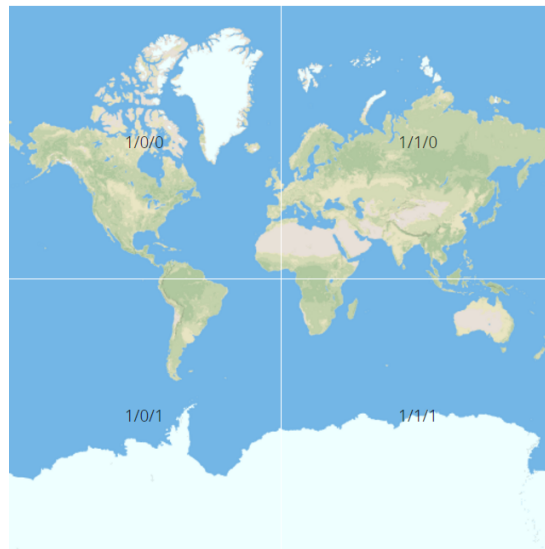


FIGURE 2.10: Map tiles at z1. Image from Mapbox<sup>2</sup>

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<sup>1</sup><http://leafletjs.com/>

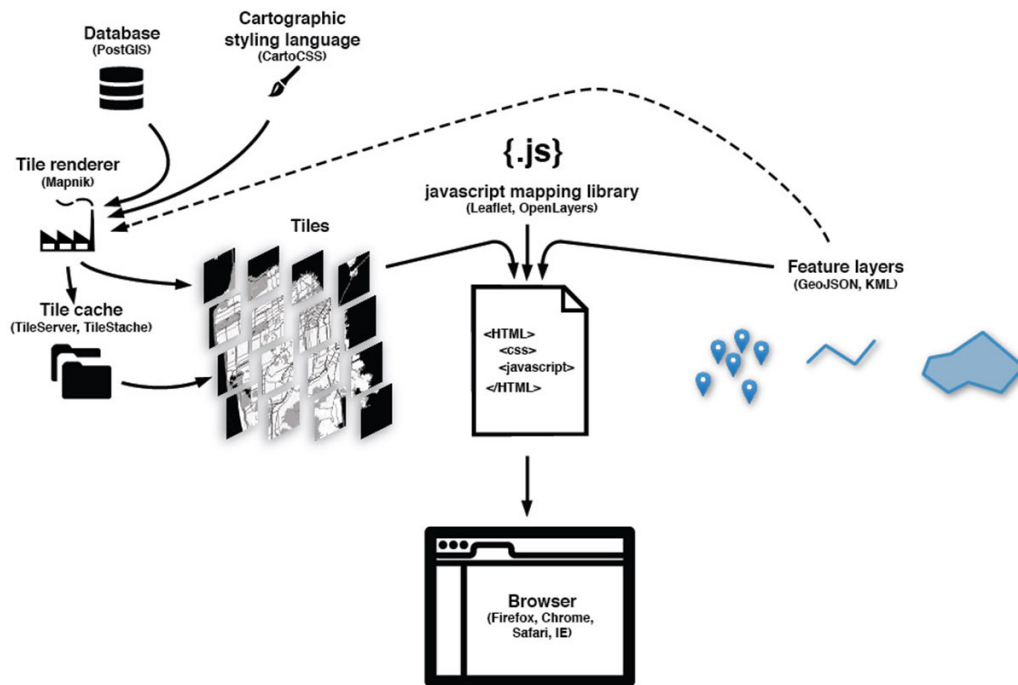


FIGURE 2.11: Composition of a typical web map, from Woodruff and Foster (2014)

## Chapter Summary

To summarize, there are few studies that tackle the problem of finding out how users use interactive maps on large multi-touch devices. As Roth (2013) pointed out in his review, research is still needed to determine to what degree can the input device, in this case, the large multi-touch device, impact cartographic interaction. It is the task of this thesis to make an investigation. Web mapping technologies are used to build the testing map for the user study. Next chapter will give a detailed description of the design of the user study.



# Chapter 3

## Methodology

### 3.1 Introduction

A controlled user study was conducted to compare how people interact with maps displayed on a large screen using two different input methods—mouse and touch. In a lab setting, participants were asked to perform target search tasks, using panning and zooming operations. During the study, mouse and touch events were logged, user interaction with the map was observed, and user feedback was collected. The overall workflow of the user study is shown below.

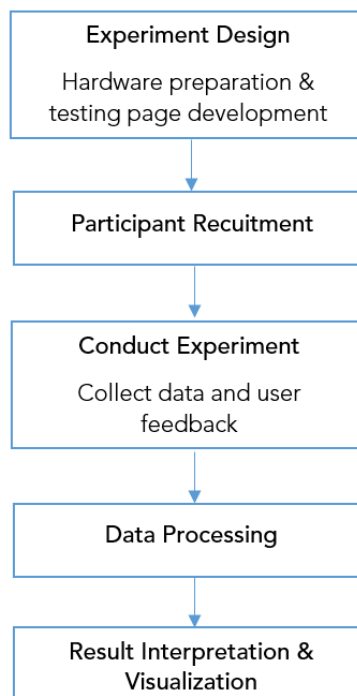


FIGURE 3.1: User study workflow

## 3.2 Task

The participants were asked to find a series of targets (e.g. museum, hotel, ...) on maps of small towns. Every participant needed to use both (touch and mouse) input methods (i.e. a within-subjects or repeated-measures design). To counterbalance the order of the two conditions, participants were randomly assigned into two groups: half of the participants (Group M) performed the tasks first with the mouse, then with touch; the other half (Group T) first used touch then mouse. The same 10 tasks were given for all participants (5 for each input method), and the order of the tasks always remained the same.

Real-world towns instead of fictitious ones were used, to improve ecological validity. Ten different towns were chosen for ten tasks, so the tasks were independent of each other. The criteria for choosing the towns were: 1) it should be unfamiliar to the users; 2) it should be located in an English-speaking country, to ensure all target names are English, since the whole study is conducted in English; 3) users would spend a reasonable amount of time searching for a target in the absence of a search function, meaning that the town is neither too small (too few POIs) nor too big (too many POIs). The criteria for choosing the targets were: 1) it has a unique label (not, for example, a supermarket chain); 2) it requires at least zooming the map once from the map's default view. In order to examine users' behavior under the condition where they face a very difficult task, we included two targets that were not shown on the map, hence impossible to find.

The difficulties of the tasks vary, meaning that users may take from several seconds to several minutes to find a target, according to the preliminary tests conducted within the research group. Because a user's ability to find a target on a map depends on many factors, for instance, their map-using experience, their prior knowledge about urban planning, etc., it is arguably impossible for the researcher to select a set of targets so that all tasks have the same level of difficulty to all the users, in contrast to the highly simplified tasks used in HCI studies. However, our main goal here is not to test which input method performs "better" than the other by measuring how fast the user

finds the target, but to investigate how the user interacts with the map differently in different input conditions. Although some kind of evaluation of task difficulty might be useful, it is beyond the scope of this thesis. Nevertheless, we tried to balance the task difficulties by choosing targets with varying distances to the original map center and at different zoom levels.

### 3.3 Participants

20 participants (14 male, 6 female) voluntarily took part in the study, with ages ranging from 19 to 38 (mean=26.7, SD=5.88). Most of them were university undergraduates or graduate students from various disciplines. All participants but one were right-handed; the one who was left-handed usually used the mouse with his right hand. All participants could understand English very well (the whole study is conducted in English). Before the user study, the participants were told that the goal of the study was to investigate how people use interactive maps, and that it was not a test of their abilities of any kind, and they should use the map as they would normally do. After the experiment, each participant was given a map of Vienna as a small gift.

18 out of 20 participants used web maps frequently (e.g. Google Maps, OpenStreetMap, etc.), while the other 2 used occasionally. They were quite familiar with both mouse and touch devices; only one participant said she rarely used a mouse but used the track-pad instead. Most of them did not have experience with large multi-touch screens, others said they had used such device a few times in museums or at tourist information points.

### 3.4 Materials

The display device used in this study is iiyama ProLite TF4237MSC-B1AG, a 42-inch capacitive multi-touch screen with  $1920 \times 1080$  resolution and  $522 \times 927.9$  mm display area. The touchscreen is placed near-vertically (slanted at 15 degrees) on a desk. Although horizontally installed displays (i.e. tabletops) are more prevalent in the literature (see Chapter 2), we used this setup in order to ensure that the only

changing factor (independent variable) is the input modality. In the mouse input condition, the same touchscreen is used as a display-only monitor. The lower edge of the screen is 70cm above the floor. Participants were sitting on an office swivel chair when using the device. The height of the chair is adjustable and ranges between 40 and 50 centimeters. Figure 3.2 shows the setup of this study. The experiments were conducted in a controlled laboratory setting, with minimum distraction.



FIGURE 3.2: Lab setup

The testing web map page is built based on Leaflet (version 1.0.1), an open-source JavaScript library for interactive maps. Initially, Google Maps JavaScript API<sup>1</sup> was chosen but it had problems for logging touch events, therefore we opted for Leaflet, which is probably the most widely-used and well-documented open-source mapping library. The map tiles are provided by Mapbox<sup>2</sup>. Although the OpenStreetMap<sup>3</sup> standard style is more commonly used, the OSM tile servers are often so busy that sometimes the map tiles need a long time to be loaded in the browser, which would

<sup>1</sup><https://developers.google.com/maps/>

<sup>2</sup><https://www.mapbox.com/maps/>

<sup>3</sup><https://www.openstreetmap.org/>



severely hinder the map's usage. The Mapbox tile server did not have this problem throughout our testing phase and hence became the choice of this study. The map style used here is the "Mapbox Streets" style, which is a comprehensive, general-purpose basemap with high-contrast colors and a broad range of POIs. The style can also be easily customized in the Mapbox Studio to fit more specific purposes. Here the default style is used.

The zoom levels of the map were limited within 12 to 19. The lower limit is to prevent users from zooming out too much and going too far away from the original map center; the upper limit is to ensure that the number of POIs shown on the map is not too large, otherwise the user would be overwhelmed by all the icons and labels, and spend too much time on one task. Zoom in/out buttons and a "reset" button were on the upper-right corner of the map area, in case the user needs them during the tasks. The top part of the screen showed the information of current task. The testing page was displayed in Google Chrome (version 51.0.2704) and in full-screen mode, to maximize the map area as well as preventing the participants from being distracted by irrelevant display elements. Figure 3.3 shows the screen content for task no.1.

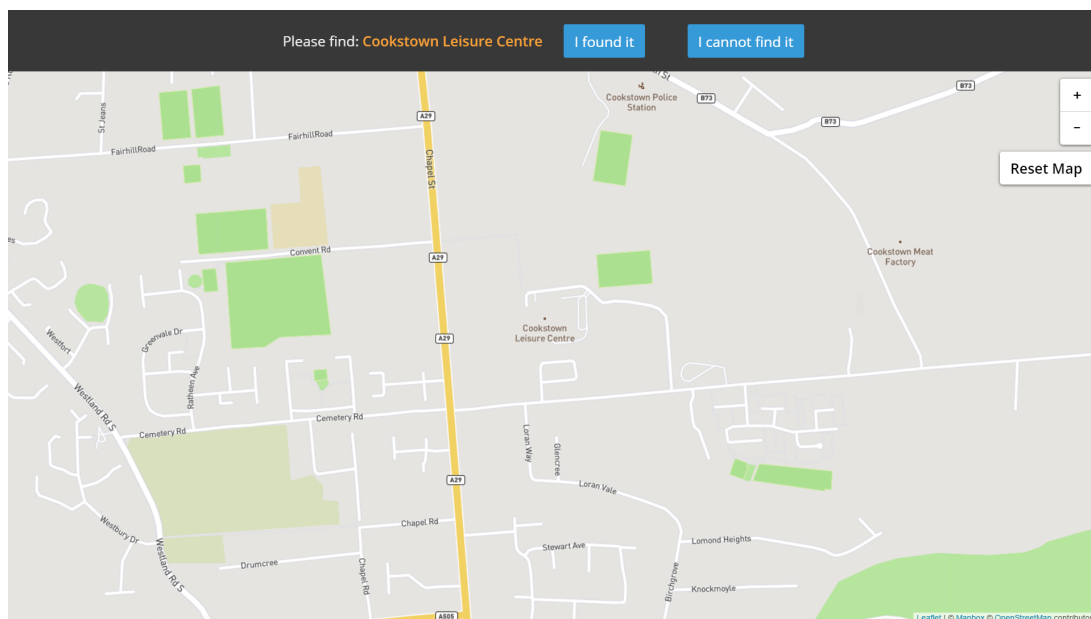


FIGURE 3.3: Full screenshot of task 1

User interactions with the map are recorded by using JavaScript to capture the events (i.e. user inputs) fired in the browser, for example, we can know when a user pressed

and released the mouse button, or when the user's finger touched and lifted from the screen. A complete list of events logged is discussed in the "data collection" section. In addition to the event log, all the sessions were video recorded to provide help analyzing user behavior.

### 3.5 Procedure

The detailed procedure of one user study session is as follows:

- 1) The participant was first directed to the waiting room (the foyer of the research group), where they were welcomed and given instructions by the research conductor. (See Appendix 1 for the instruction script.)
- 2) After the introduction, the participant was guided to the lab and sat in front of the screen. The participant could adjust the seat until they feel comfortable. What the participant saw initially was a welcome screen with brief instructions (Figure 3.4). To start the trials, the participant needed to press a "start" button, and the first task would appear.

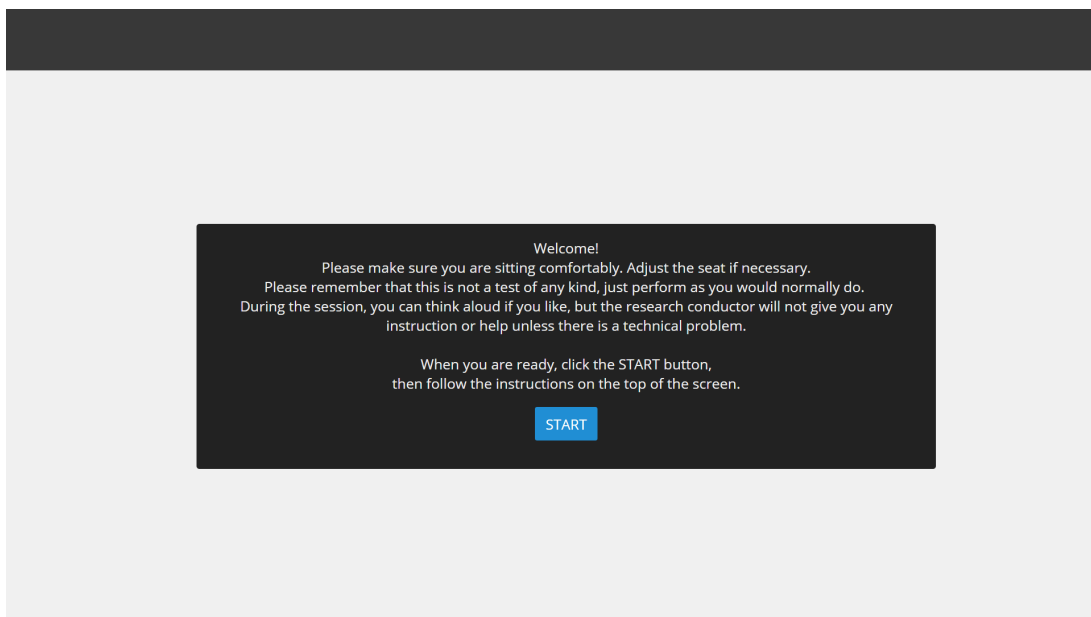


FIGURE 3.4: Welcome screen

At the beginning of each task, the map was set to the default zoom level and starting position, with a modal dialog showing the name of the target the participant needed to find. After clicking “OK”, the dialog would disappear, but the name of the target would be displayed on the top of the screen to remind the participant. If the participant successfully located the target they could choose “I found it” on the top of the screen, and then select the corresponding target on the map. To verify that the participant indeed found the target, we set a bounding box for every target, and if their selection was within the bounding box, the system would mark the result as “success”, otherwise it would be marked as “miss”. If they could not find the target after some time (there was no time limit, they could take as much time as they wanted), they could give up by choosing “I cant find it” and proceed to the next task. After 5 tasks, the participant would switch the input method from mouse to touch, or vice versa, and complete the remaining 5 tasks.

During the experiment, the researcher remained in the room with the participant, to observe and take notes of their interaction with the map as well as to answer questions if necessary. The researcher did not provide any help or hint regarding how to find the targets. The only occasions where the researcher would interrupt the participants would be when they forget to change input method, or other unforeseeable incidents happen.

3) After the experiment, participants were asked to fill out a post-experiment questionnaire (see Appendix 2), including their background information and their preference of the two input methods, with both Likert scale evaluation and open questions.

4) The research conductor thanked the participant and offered to answer any remaining questions from the participant. Then the research conductor explained to the participant that there are two “impossible tasks” in which the targets were not on the map, so they should not feel bad about not being able to find those.

One session (10 tasks + questionnaire) lasted approximately 30 minutes. All the data collected during the experiment is anonymous.

## 3.6 Data Collection

### 3.6.1 Raw Data

The raw data collected are mouse and touch events captured by the browser and the Leaflet API, arranged in a tabular format and saved as .csv files. Table 3.1 shows all the captured event types. Each row of the csv file is an event with attributes such as event type, time-stamp, X/Y screen coordinates, current zoom level, and number of touches (if it is a touch event). In addition, specific button clicks were also logged, which include the task start button, zoom-in/out buttons, “reset map” button, and “found it” and “can’t find it” buttons. Figure 3.5 shows an example of the raw csv file (first several rows).

Browser event	Map event	Other
click, dblclick, mousedown, mouseup, mousemove, touchstart, touchend, touchmove	dragstart, dragend, zoomstart, zoomend	session_start, button_click, task_completed, task_intro_ok, task_foundit, task_result_success, task_result_miss, task_giveup, button_zoomIn, button_zoomOut, button_resetMap

TABLE 3.1: Captured event types

task	type	time_task	time_rel	time_abs	x	y	touch_n	zoom
	session_start			1.48E+12				
1	window_touchstart	33821	33821	1.48E+12	973.3334	659.3334	1	
1	window_touchend	33899	33899	1.48E+12	973.3334	659.3334	1	
1	window_mousedown	33911	33911	1.48E+12	972	658		
1	button_click	33911	33911	1.48E+12				
1	task_completed	33912	33912	1.48E+12				
2	map_zoomstart	25	33937	1.48E+12				
2	map_zoomend	25	33937	1.48E+12				15
2	window_touchstart	5261	39173	1.48E+12	1146	431.3333	1	
2	window_touchend	5366	39278	1.48E+12	1146	432	1	

FIGURE 3.5: Original csv file obtained from browser

### 3.6.2 Measurements

From the raw data gathered in the browser, useful measurements can be derived. Python scripts are used to process the raw data. More specifically, the open-source Python packages pandas<sup>4</sup> (version 0.19.0) and Numpy<sup>5</sup> (version 1.11.2) are used because they are well suited for analyzing tabular data and are widely employed in the scientific community.

Some measurements can be directly filtered from the raw data, for example the X and Y screen coordinates of touch and mouse locations, and zoom levels. Others need further calculation, such as drag length, drag direction, drag and zoom frequency, and task completion time. The rest of this section gives a detailed description of how these measurements are obtained.

#### Task completion time

The task completion time is calculated from the moment the user click or tap “OK” on the task introduction box (corresponding event type “task\_intro\_ok”), to the moment they click or tap “found it” (corresponding event type “task\_foundit”) or “cannot find it” (corresponding event type “task\_giveup”) on the top task bar.

#### Touch and mouse locations

Most events have the attributes of X and Y screen coordinates. However, events in the column “map event” in Table 3.1 do not have X and Y information. Therefore, for mouse zooms, the coordinates of the preceding “mousemove” event are given to “zoomstart” and “zoomend” (we assume they are at the same position); for pinch-to-zoom, the value of the center point between the two touch positions before the zooming starts is assigned to “zoomstart”. For a “dragstart” or “dragend” event, the coordinates of the previous event are assigned to it.

---

<sup>4</sup><http://pandas.pydata.org/>

<sup>5</sup><http://www.numpy.org/>

## Drag length

Drag means the user moves (or pans) the map for a distance. In the event log this is identified by a “dragstart” event, followed by a series of “mousemove” or “touchmove” events and ends with “dragend”. For each drag (i.e. dragstart-dragend pair), the drag length is calculated by summing up all the increments of neighboring dragmove points within this drag, that is:

$$\sum_i \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}$$

where  $i$  denotes the set of points within this drag. Figure 3.6 shows the relevant code snippet. Figure 3.7 shows a snippet of the processed drag length file.

```
# calculate distance between 2 consecutive dragmove points
def dist(x):
    return math.hypot(x.diff_x, x.diff_y)

drag_df['diff_x'] = drag_df['x'].diff(1)
drag_df['diff_y'] = drag_df['y'].diff(1)
drag_df['dist'] = drag_df.apply(dist, axis=1)
len_sum = 0
for i, row in drag_df.iterrows():
    if row['in_drag'] == True:
        len_sum += row['dist']
        drag_df.loc[i, 'length'] = len_sum
    if row['in_drag'] == False:
        len_sum = 0
```

FIGURE 3.6: Code snippet for calculating drag length

task	type	ID	modality	touch_n	in_drag	diff_x	diff_y	dist	length
3	map_dragstart	M06	M		FALSE				
3	dragmove	M06	M		TRUE	-6	0	6	6
3	dragmove	M06	M		TRUE	-2	2	2.828427	8.828427
3	dragmove	M06	M		TRUE	0	0	0	8.828427
3	dragmove	M06	M		TRUE	-2	0	2	10.82843
3	dragmove	M06	M		TRUE	0	0	0	10.82843
3	dragmove	M06	M		TRUE	-2	0	2	12.82843

FIGURE 3.7: First several lines of the processed drag length file

In the end, all drag length can be acquired by extracting all the “dragend” events and the “length” column shows the length of each drag.

## Drag direction

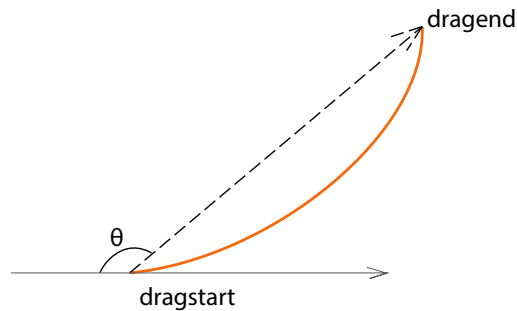


FIGURE 3.8: Drag direction  $\theta$

Drag direction is approximated by the angle between the line which connects dragstart and dragend points, and the negative X-axis (pointing left). Figure 3.8 gives an example. Note that for screen coordinates, the positive Y-axis points down, thus we have

$$\theta = \pi - \arctan \frac{-\Delta y}{\Delta x}$$

This simplified model only takes into account the start and end points of a drag, therefore cannot represent complicated drag paths, such as V-shaped or circular paths, but we assume that the majority of drags are quite simple and thus can be represented by this model.

```
def direction(x):
    angle = math.atan2(-x.diff_y, x.diff_x) # y-axis is inversed in screen
    rotated = 360 - (180 + math.degrees(angle))
    return rotated

drag['diff_x'] = drag['x'].diff(1)
drag['diff_y'] = drag['y'].diff(1)
drag['direction'] = drag.apply(direction, axis=1)
```

FIGURE 3.9: Code snippet for calculating drag direction

## Drag and zoom frequency

The frequency denotes the number of drags/zooms per minute. The drag frequency is derived by counting the number of “dragend” events, and divide it by task completion time. Similarly, the zoom frequency is derived by counting “zoomend” events and divide the number by task completion time.

### 3.6.2.1 Zooming operation

In addition, different ways of zooming—pinch-to-zoom, zoom by mouse wheel, double click/tap, and zoom buttons—are recorded.

### 3.6.3 Observation and User Feedback

Quantitative measures alone cannot reflect how exactly did users interact with the map. In addition to the event log, direct observations of how users interact with the map system were made. During the lab session, the research conductor observed user interactions with the device and noted down interesting usage patterns as well as frequent problems. In addition, video recordings also help to analyze the user interaction, in case that the research conductor missed any important user behaviors.

Subjective feedback was collected in the post-test questionnaire. Participants were asked to rate how easy it is for them to use mouse and touch respectively, from “very difficult” to “very easy”, and give reasons for their preference of mouse or touch.

## 3.7 List of Hypotheses

Based on findings in the existing literature and the author’s experience, the following hypotheses are made:

- (1) The task completion time in mouse- and touch-based interactions would be similar. However, the “give-up-time” would be shorter in the touch condition due to fatigue.
- (2) Mouse and touch locations on the screen will show different patterns. More specifically, the touch locations would be more concentrated in the center of the screen than mouse locations, because reaching for a position near the far corner of the screen using the arm requires more physical work than doing it with the mouse.
- (3) The drag (pan) length in the touch condition would be shorter than in the mouse condition.



(4) The drag (pan) directions in the mouse and touch conditions would have different patterns.

(5) Mouse and touch input will have different drag/zoom frequencies: a). users drag(pan) the map more frequently when using touch; b). users zoom the map more frequently when using touch.

## **Chapter Summary**

This chapter gave a detailed description of the research design of this thesis, including the participants, hardware and software used in the experiment, the tasks, procedure, and data collection methods. Next chapter will present and discuss the results of the user study.



## Chapter 4

# Results and Discussion

The user study sessions were conducted between October and December of 2016. Twenty participants each performed 10 target search tasks (5 for each input method) using the same large screen. Usage data was collected and processed as described in the previous chapter. The results are presented and discussed here.

### 4.1 Quantitative Results

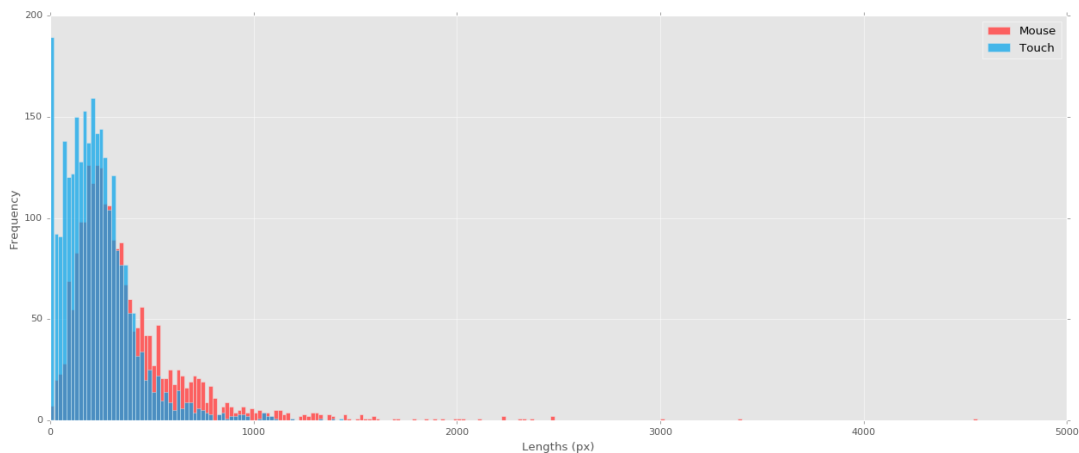


FIGURE 4.1: Histogram of drag length before filtering; bin width = 20px

#### 4.1.1 Drag Length

The histogram of all the drag lengths is shown in Figure 4.1. Note that there is a large number of touch drags that are shorter than 20 pixels, which is impossible since 20px on this particular device is less than the width of a finger (according to the device manufacturer, 1 pixel on the device corresponds to 0.483mm physical length, meaning

20px is less than a centimeter). The author argues that “drags” less than 20px ( $20 \times 0.483 = 9.66\text{mm} \approx$  the width of a finger) should not be counted as “drag” but rather logging errors, and should be filtered out. Figure 4.2 shows the filtered version of the histogram. Also note that the histogram only shows drag lengths of up to 1600px, due to page width limitation.

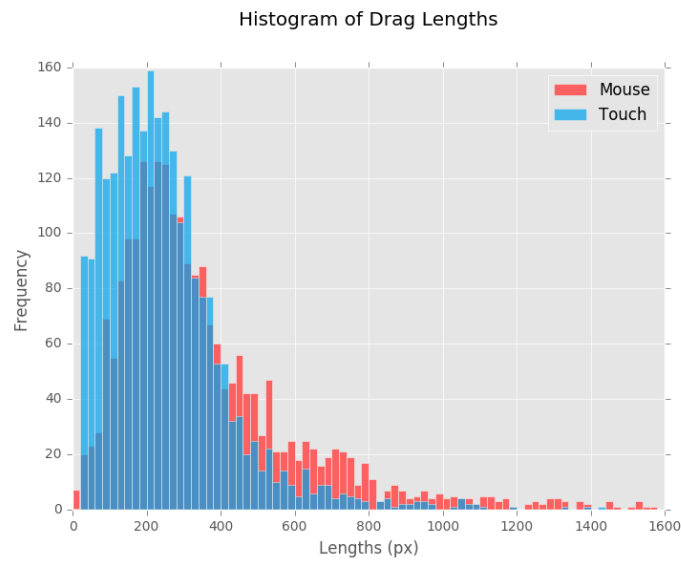


FIGURE 4.2: Histogram of drag length after filtering; bin width = 20px

At first glance we can see that the drag lengths of touch and mouse input overlap a lot, and both have the most frequent length of around 200px. However, more touch drags are shorter than 200px while more mouse drags are longer than 400px.

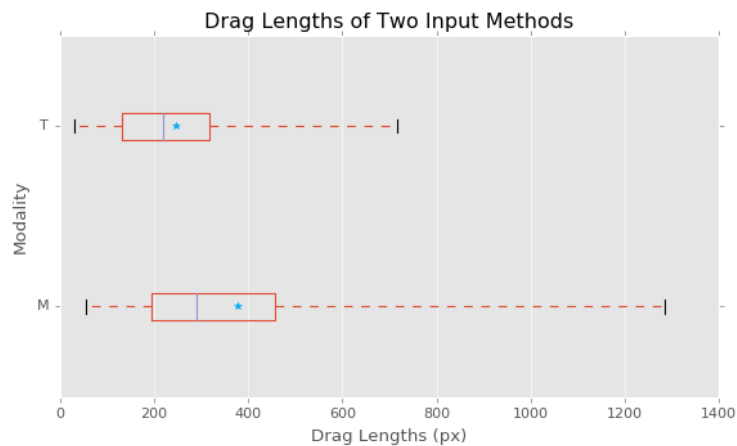


FIGURE 4.3: Box plot of drag length

Another way to show the drag length distribution is through the box plot (Figure 4.3). The whiskers in the box plot represent the 2nd and 98th percentile; means are represented by blue stars; medians are purple lines. All the data points that are outside the 2nd and 98th percentile are considered to be outliers and are not shown on the plot.

The result suggests that when using touch, the drag lengths tend to be shorter than using mouse. In other words, the users tend to pan the map for a shorter distance in the touch condition.

The overall trend could be caused by individual participants who like to use short drag lengths. Therefore, to further examine the relation between mouse and touch drag length, the mean touch drag length was plotted against the mean mouse drag length for each participant. It can be seen that all the dots are below the  $x=y$  line, meaning that for all participants, their mean touch drag length is shorter than their mouse drag length, which is consistent with the overall pattern.

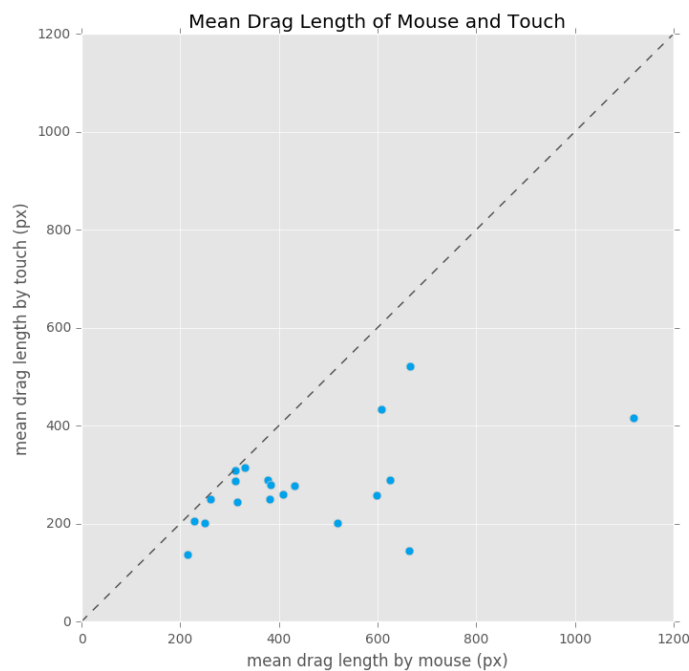


FIGURE 4.4: Mean drag length of each participant

### 4.1.2 Drag Direction

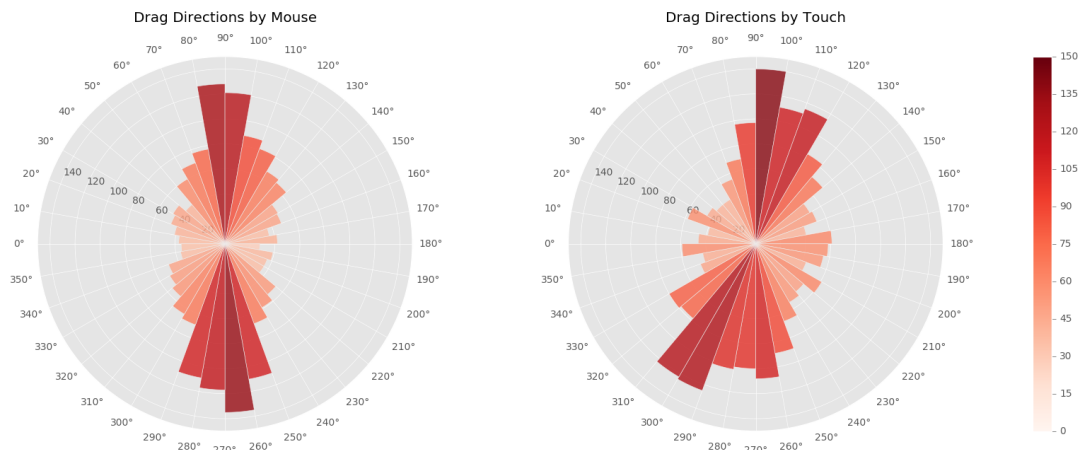


FIGURE 4.5: Drag direction of mouse(left) and touch(right)

Based on the calculation described in section 3.5, the drag directions are grouped into 10-degree intervals, i.e. 36 direction groups, and are plotted as polar bar charts (Figure 4.5).

From the charts, it can be seen that there are different patterns for mouse and touch drag directions, which confirms the author’s hypothesis. In the mouse condition, users are most likely to drag the map vertically or near-vertically, and least likely to drag the map horizontally. The axis of symmetry is (nearly) the vertical and horizontal line. In the touch condition, users are most likely to drag the map somewhat diagonally, i.e. in the near-“north-east” and “south-west” directions, with about 10 to 40 degrees’ deviation from the vertical direction. The axis of symmetry is approximately the 30 – 210 degree line. Moreover, comparing to the mouse condition, users are more likely to drag the map horizontally.

The reasons for the different patterns can be summarized as follows:

- Minimizing movement: when using touch, the user’s right hand is usually at a position shown in Figure 4.6. At this position, to keep the finger’s contact with the screen, it is more natural to move the hand (or fingers) in the “north-east” and “south-west” directions, because the user only needs to slightly rotate the hand. To drag the map

in the “north-west” or “south-east” direction, the user needs to move the whole arm, or they need to curl the finger. The former would require more physical effort. The latter would change the contact angle of the finger with the screen, which often causes problems such as loss of contact, and most users seemed to be aware of this and tried to avoid it, especially if the user has long fingernails.



FIGURE 4.6: Hand position when using touch

- Regarding the domination of near-vertical directions over near-horizontal ones, one explanation would be that the users prefer to search the map systematically using a “up-down” and “left-right” strategy. Since the screen is wider on the horizontal dimension, the user would more frequently drag the map vertically in order to reveal more map area.

However, from this plot we do not know the corresponding drag length of each direction, i.e. the question “what is the relation between drag length and drag direction?” More research into this question may provide further insight into the dragging pattern.

### 4.1.3 Drag Frequency

The overall frequency (count per minute) of mouse and touch drags are shown in Figure 4.7. There is no significant difference between the two input conditions, thus the hypothesis is rejected. Figure 4.8 gives a more detailed look into each participant’s drag frequency (M06, M07, ... T13 are participant IDs). Here a distinct individual difference can be seen: some participants dragged the map twice as frequently in the touch condition as in the mouse condition, while others have similar drag frequencies.

Therefore it cannot be concluded that user drags more frequently using one of the input methods than the other.

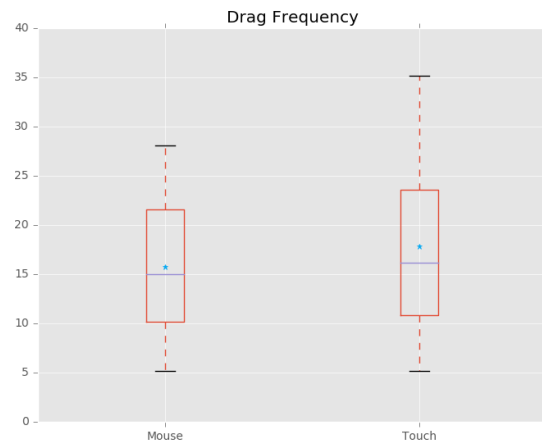


FIGURE 4.7: Box plot of drag frequency

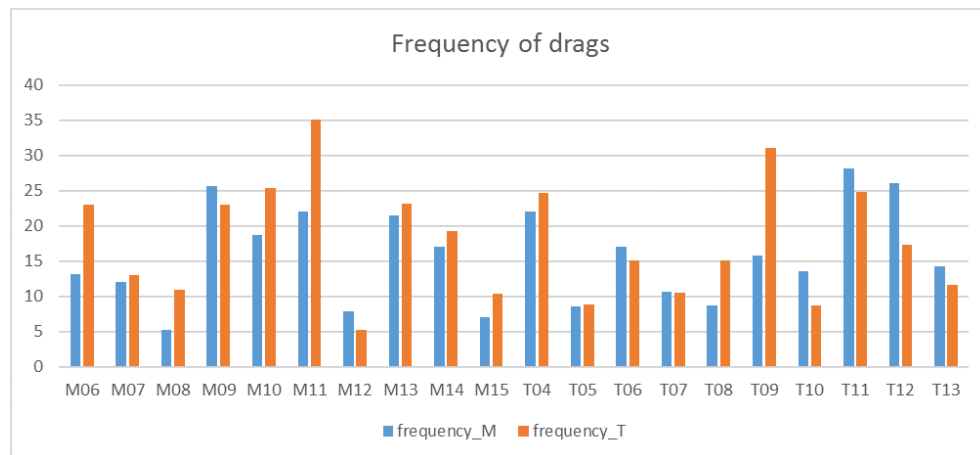


FIGURE 4.8: Drag frequency of each participant

#### 4.1.4 Zoom Frequency

The overall frequency of mouse and touch zooms are shown in Figure 4.9. The result shows no significant difference between the two input conditions, thus the original hypothesis is again rejected. However, touch-based zooming has a much higher variation.



This might be caused by the accidental zooming (discussed in section 4.2), which happened more frequently to some participants than the others. Figure 4.10 gives a more detailed look into each participant’s zoom frequency.

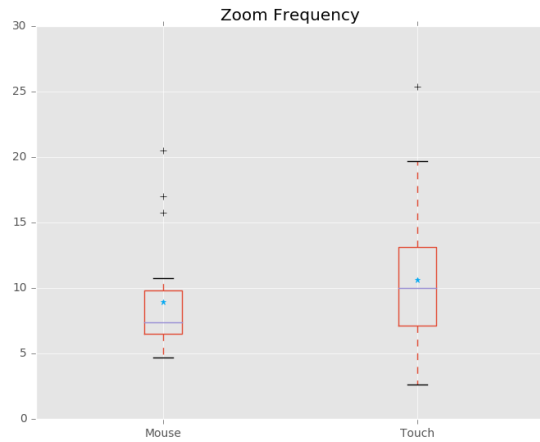


FIGURE 4.9: Box plot of zoom frequency

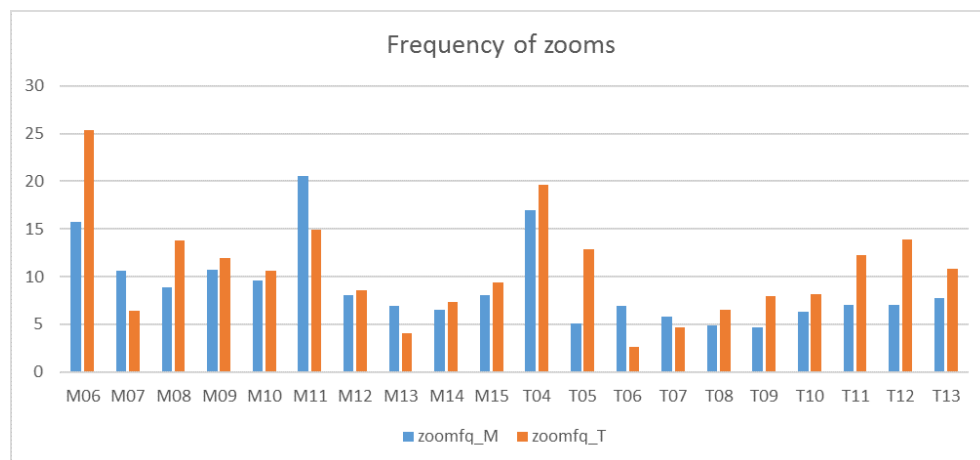


FIGURE 4.10: Zoom frequency of each participant

The lack of significant difference in drag/zoom frequencies indicates that touch input does not necessarily lead to a more frequent interaction between the user and the map.

#### 4.1.5 Mouse and Touch Location

Figure 4.11 and 4.12 show the “heatmap” of mouse and touch points of all the participants. The hypothesis that touch and mouse locations on the screen have different

patterns, and that touch would be more concentrated on the center of the screen is confirmed. We can see that the touch input covers a smaller area on the screen and mainly concentrates in the lower-middle part. A large portion of the screen is left untouched.

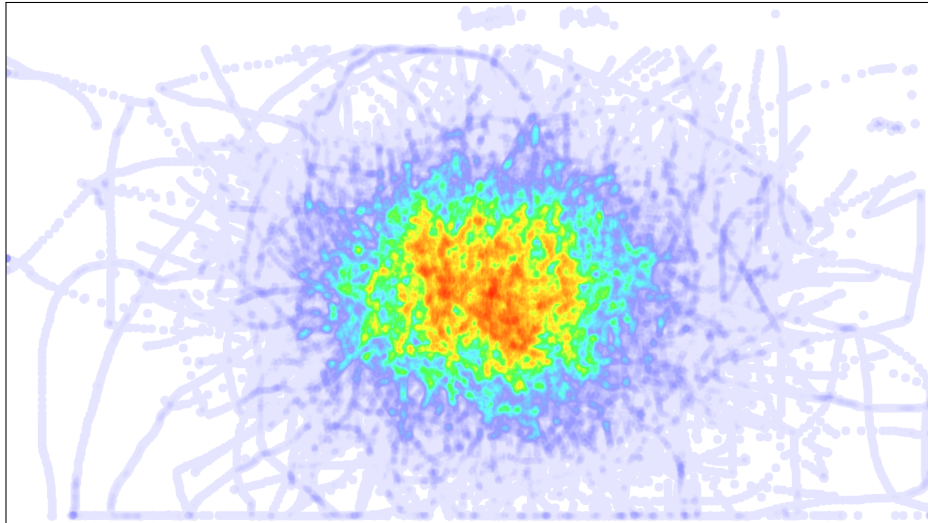


FIGURE 4.11: Mouse locations

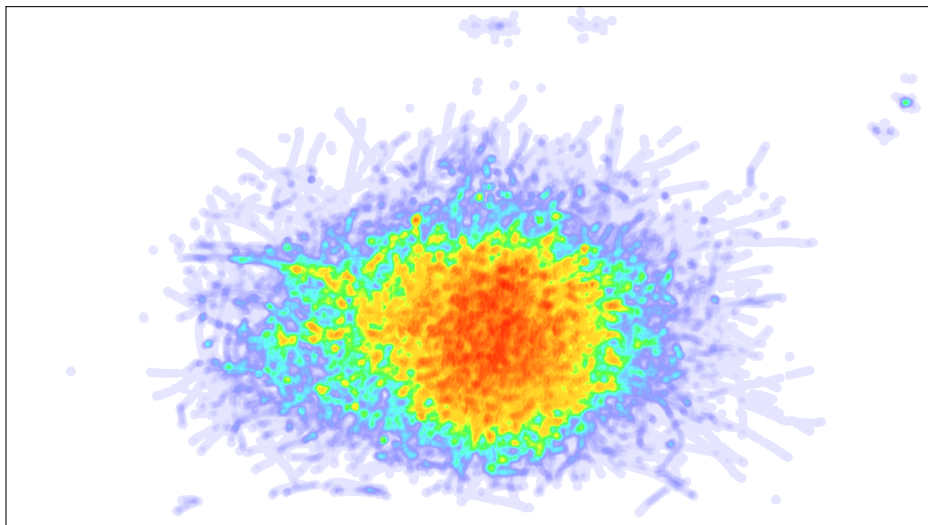


FIGURE 4.12: Touch locations

### 4.1.6 Task Completion Time

Since there were two “impossible tasks” (task no.5 and no.10), the time of these two are evaluated separately from the other eight tasks. Also, sometimes the participant could not find the target even if it is not task no.5 or no.10, these data points (14 in total) were omitted from the analysis because they cannot be considered as “completed”. Figure 4.13 shows the mean completion time of the two input methods. Figure 4.14 shows the mean completion time of each task. From the plot we cannot conclude that input modality has any effect on the speed of which a user completes the tasks. The long error bars indicate big individual differences.

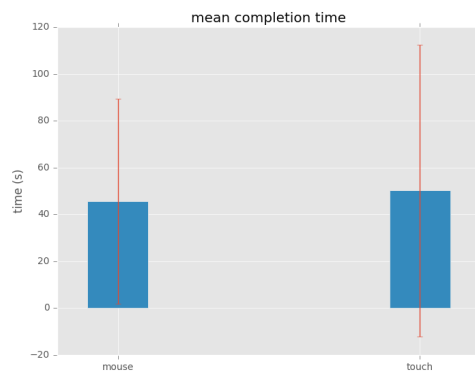


FIGURE 4.13: Mean completion time for mouse and touch



FIGURE 4.14: Mean time for eight tasks

For the “impossible tasks”, we examined how long they spent on these tasks before giving up. The result is shown in Figure 4.15. Again there is no significant difference between the two conditions.

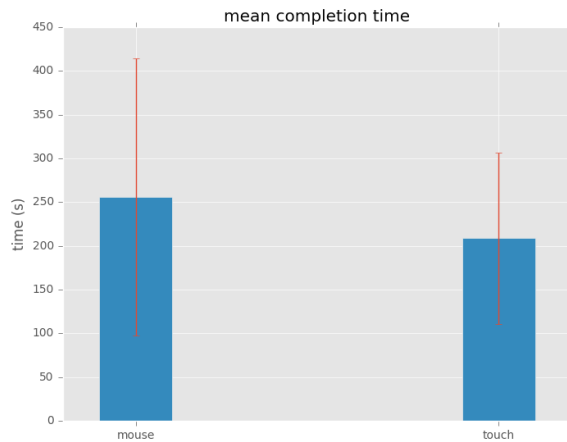


FIGURE 4.15: Mean time for impossible tasks

## 4.2 Observations of Participant Behavior

Both in situ observation and video recordings were used to identify noteworthy participant behavior. This section summarizes the observed usage patterns and problems occurred during the interaction.

### Panning patterns

Most participants used one finger (index or middle finger) to pan. A few used two fingers (index+middle) or even two hands (one finger of each hand).

### Zooming patterns

Most participants used pinch to zoom in and out, as they would do on their mobile phones, using thumb + index finger or thumb + middle finger. Some used index + middle fingers. Some used two hands (one finger of each hand, mostly index fingers

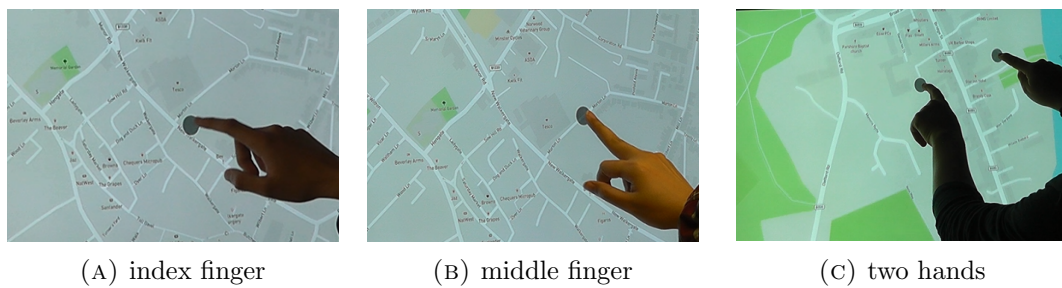


FIGURE 4.16: Panning patterns

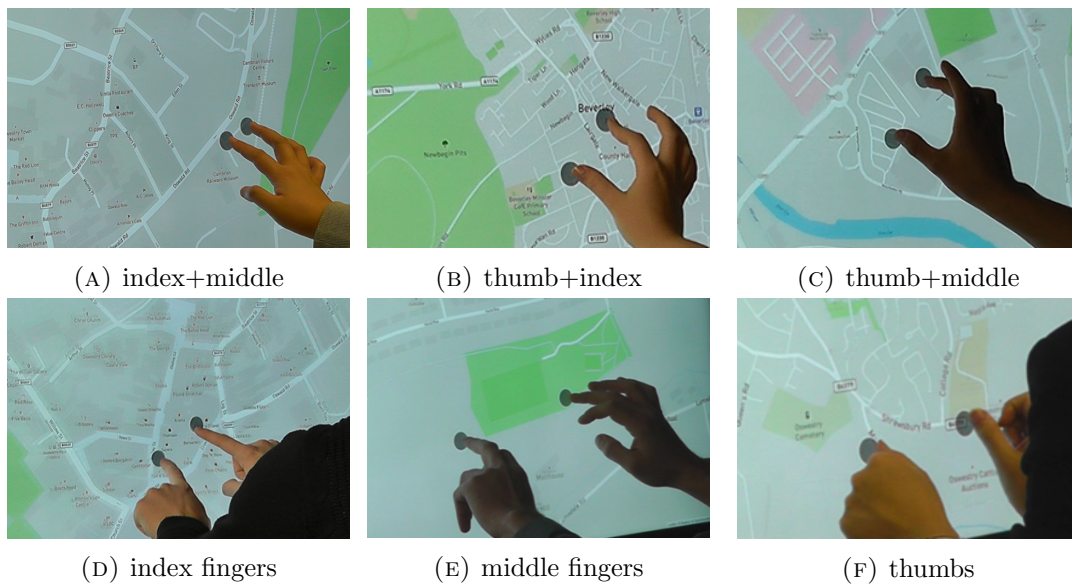


FIGURE 4.17: Zooming patterns

but one participant used two thumbs and another participant used two middle fingers) to zoom in, but used one hand to zoom out. When asked about this, one participant explained that he felt it is easier to control the zoom level with two hands since the screen is so big and the spread of two fingers of the same hand is too limited comparing to the screen size. Some participants chose to use the zoom buttons on the top-right of the map interface, possibly to avoid accidental zooming.

In the mouse condition, no one used double click to zoom, one participant used the zoom buttons. In the touch condition, some participants used double tap to zoom, and two participants used zoom buttons.

## Problems regarding using the device

**Zooming** Sometimes the pinch-to-zoom gesture led to unexpected outcomes. When the user wanted to zoom in but did not stretch their fingers wide enough, the map would bounce back to the lower zoom level. Or they wanted to zoom in/out one level but the map jumps several levels instead.

The zoom levels of the map are only integers, for instance it changes from 15 to 16 without any intermediate states. However, many users seemed to expect the map to zoom continuously with their fingers pinching and stretching and stay precisely at their desired scale. This leads to the map "bouncing" back to its zoom level before the pinch gesture.

**Panning** Sometimes when the user wanted to pan the map, it zoomed instead, or it did not move at all.

These false responses seem to be more likely to occur when the screen is not clean, i.e. when previously used by others. However, even if the screen was cleaned by the researcher before the lab session, problems still existed. Another cause can be that the users' fingers were not dry and clean.

## Strategies when encountering problems

When the participants encountered problems, for example when they wanted to pan the map but it did not respond or zoomed instead, or they tried to zoom but the map did not respond or zoomed in the wrong direction, they used different strategies. Some participants just kept repeating the gesture until the map zooms or pans as they intended; some added the other hand to help to zoom, while others chose to use the zoom buttons and/or double tap to zoom in instead.

Some participants (7 out of 20) noticed the "Reset Map" button and used it when they were disoriented, for example when they pan the map too far away from the original center, or the map zoomed in too many levels accidentally.

## Change of hands

Some participants switched to their left hand after spending some time touching the screen with their usual right hand. The change of hands can be very brief, i.e. only several seconds, but can also last for a few minutes. A few participants used both hands alternately. This is supposedly due to fatigue after lifting one arm for too long (one session normally lasts more than 10 minutes), and the user feedback shows it is indeed the reason (see next section).

## 4.3 User Feedback

### 4.3.1 User Preference

User feedback was collected using post-test questionnaires. Figure 4.18 shows the participants' opinions of mouse and touch, respectively. The overall result suggests a clear preference towards mouse input. 17 participants rated mouse input as “easy” or “very easy” to use, while only 10 participants rated so for touch input. 6 participants thought that the touch input is “slightly difficult” and 1 participant even rated the touch as “very difficult” to use.

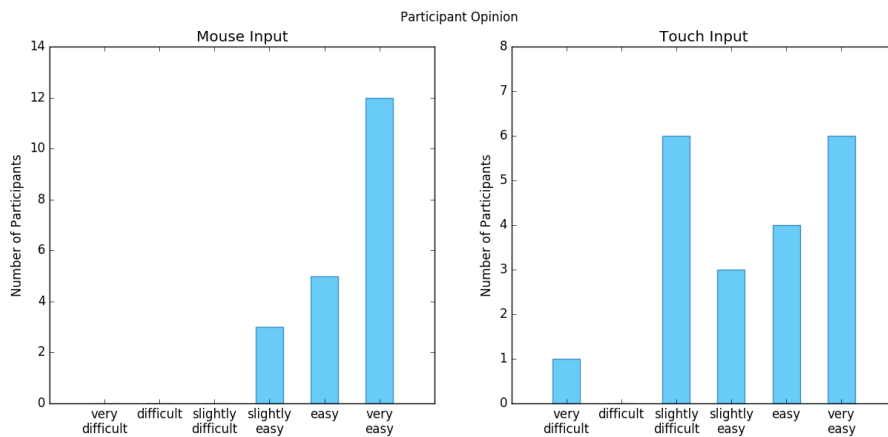


FIGURE 4.18: Participants' opinion of mouse and touch

### **Reasons for preferring mouse**

15 out of 20 participants (75%) preferred mouse over touch. Their reasons for preferring mouse can be summarized as follows:

**Familiarity** The participants were more familiar, or had more experience with the mouse, therefore they felt more confident while using it.

**Physical comfort** Those participants felt more “comfortable” using the mouse, because it requires less movement of hands and arms. The touch input, on the contrary, makes them feel tired easily after a short while, especially for a device this big.

**Easiness/precision of control** As can be confirmed by in situ observation, most participants reported problems when using touch to zoom and pan, saying that the touch input did not always work as they intended. For example, sometimes they wanted to pan the map by sliding the finger, but the map zoomed instead, or they tried pinch-to-zoom but the map failed to do so. These behaviors made them feel “frustrated” and “insecure” when using the touch input, while mouse input did not have such problems and always worked precisely as the users intended.

**Better overview** A few participants expressed that they could get a better overview of the whole area when using mouse, because they could sit further away from the screen and not only focus on the area around their hand. They felt that this can make their search of the targets easier.

### **Reasons for preferring touch**

The other 5 participants (25%) preferred the touch input. Their reasons include:



**Easiness of control** Exactly opposite to what others have said, they felt that the touch input is easier to zoom in/out and drag the map around. Although they also had problems when using touch, they were not particularly frustrated by that.

**More intuitive** Some participants felt it is more intuitive and natural to use the hand as the pointing device, because they could directly move the map instead of using a mouse as a mediator.

**Better immersion** One participant felt that she was more “involved” with the map when using touch, possibly because the user was sitting closer to the large screen, hence she felt that she was “surrounded” by the map.

#### 4.3.2 Other complaints

Some participants mentioned that for a screen this big (42 inches), the information shown is too sparse. This concerns the design of the map, and is out of the scope of this thesis. However, it suggests that a separate study about large screen size and its influence on map design would be of value.

Some also said that a physical setup like this is somewhat “strange” because it is too large and too close to the user, making them uncomfortable. Admittedly, the setup (vertical installation and sitting position) used in this thesis is unusual in the real world, it is only used here to limit the number of independent variables in the experiment. More research is needed to investigate different setups, for example when users are standing instead of sitting, and when the device is horizontally installed.

### 4.4 Discussion

From the results concerning dragging (panning), we can see that longer panning distance comes more natural in mouse-based map interaction, while users tend to have shorter panning distances in touch-based interaction. The different panning distances

may be caused by the fact that users were sitting more closely to the screen when using touch, thus looked at the map more in detail. However, it should be noted that although participants used shorter panning distance in the touch condition, they did not use the panning operation significantly more frequently. The longer panning distance in mouse-based interaction may also be related to the mouse speed (a higher mouse speed means the mouse pointer moves faster and requires less effort to get across the screen). A small movement of the mouse can result in a long panning distance, while the ratio for touch is 1:1 (in terms of distance on screen, not considering map scale). For inexperienced mouse users, the variation in mouse speed may take time to get used to, while touch-based interaction seems to offer more direct control (the map moves directly with the fingers sliding across the surface).

Users mainly pan the map in the north-south direction when they are scanning for targets under the mouse condition, while under the touch condition, there are more diagonal panning directions. This difference in panning direction patterns is supposedly due to the hand position (as discussed in 4.1.2), but does this affect the map user's actual map reading process? To answer this question, combining eye movement data might be a necessary next step.

The difference in mouse and touch locations shows that the area covered by touch is more limited, although they both concentrate in the center of the screen. This indicates that map users are unlikely to extend their arms to reach towards the edge of the screen. Of course this result can be caused by the physical setup, where users were sitting in front of the vertical display.

The completion time shows that the task performances under the two conditions are not significantly different. This means neither input method is "superior" than the other, at least in target search tasks. However, when choosing the computing device for cartographic products, "efficiency" should not be the only criterion, other factors such as fatigue and spatial memory also worth taking into account (Forlines et al., 2007).

The results from user behavior observation suggest that when designing a cartographic product on large multi-touch screen, UI elements such as "reset to default view" and

zoom in/out buttons should be displayed on the screen as a fallback when the gestures fail to work properly. Moreover, false responses are frustrating and should be avoided. For touch-based interaction, the discrete zoom levels often confuse the users, thus continuous zooming is required.



## Chapter 5

# Conclusion and Outlook

### 5.1 Summary

The study presented in this thesis compared the use of the relatively new multi-touch input with traditional mouse input, in the context of map interaction on a large screen. A controlled user study was conducted to collect users' mouse and touch behavior in target search tasks. Several measurements were used to evaluate the difference (or similarity) between the two input methods—drag length, drag direction, drag and zoom frequency, touch/mouse on-screen locations, and time spent on tasks.

The results suggest that there are indeed differences between the two input methods: when using touch, users pan the map differently from when they are using the mouse, with shorter panning distances and different main panning directions. The touch locations are also different from mouse locations, concentrating in the lower-middle part of the screen. Contrary to the hypotheses, the drag and zoom frequencies of the two input methods are quite similar. The task completion times also show no significant difference. This indicates that the multi-touch input does not make the users interact with the map more frequently, nor does it prove to be more efficient in the target searching tasks.

User feedback shows a clear preference of mouse input. Their reasons for preferring the mouse include familiarity, physical comfort, easiness and precision of control, and a better overview of the map. Too many false responses and fatigue are the main complaints towards the touch input. In addition, direct observations identified a list of panning and zooming patterns, and frequent problems occurred during the touch interaction.

## 5.2 Future Work

Due to time constraints, only 20 participants were recruited in this study. This could be the reason for the lack of statistically significant results, thus more participants should be recruited in future studies.

To make a cartographic application available to as many people as possible, it is also necessary to consider different user groups. The participants in this study were all between 19 and 38 years old and all quite familiar with touch technology and web maps. It would be interesting to include people from different age groups, educational backgrounds, and with varying degrees of expertise concerning the device or maps. For example, we could include older users who are not familiar with new technologies, or a group of young children who have never used web maps, etc.

More research can be done to further investigate dragging (panning) patterns. As described in 3.6.2, the calculation of the drag direction is highly simplified, thus a more accurate representation of drag directions should be created. Also, the relation between drag length and direction needs to be further explored.

One challenge during the experiment design was choosing the proper tasks. A more rigorous process of task selection should be established for future studies. What are the criteria for evaluating task difficulties? Moreover, it would be worthwhile to test if and how different input devices affect user's performance on various types of cartographic tasks. Kiefer, Giannopoulos, and Raubal (2013) used the characteristics of eye movements to identify tasks such as free exploration, target search, route planning, etc. Similarly, we can study how users perform these tasks differently in touch- and mouse-based interaction, and whether certain input modality is better suited for certain types of task.

Different physical setups, for example sitting versus standing, different angles of the device installation (horizontal or vertical or oblique), and varying head-to-screen distances, are also worth more research. Admittedly the setup used in this thesis is not very common in real-world situations, where the users are usually standing when interacting with the map. Those different setups may yield different usage patterns.

However, if it turns out that there are common patterns in all these different setups, they would be the basis to develop guidelines for multi-touch cartographic applications in general.

A single-user setting was used in this study. It would be worthwhile to explore the potential of the large multi-touch screen for multi-user collaborative cartographic applications, because such a large screen is unlikely to be owned by a single user but more often used by a group of people.

A few users pointed out that when they are using touch, their views tend to focus on the map area around their hands. Eye tracking can be used to verify this statement, perhaps similar to the eye-hand coordination research by Çöltekin, Demsar, Brychtová, and Vandrol (2014). In this study, only screen coordinates were logged and analyzed. To further understand the map using process under different input conditions, the actual geographic coordinates should also be recorded.

This thesis used a general purpose slippy map as the stimuli. More specific applications can be developed, for example, an interactive thematic map, or a map for navigation in a museum or university campus.

To conclude, this thesis is an initial investigation into the comparison of mouse- and touch-based map interaction on large screens. Based on the study presented here, more research can be designed to further explore cartographic interaction on large multi-touch devices.





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# Appendix 1. Pre-test Instructions

Hello! Thank you for coming to the study. Please have a seat. This study is about how people use interactive maps. There will be a lab session where you need to finish some tasks using the device we provide you, then you need to fill in a questionnaire about some background information and your experience during the lab session. To help us better analyze the data afterwards, the lab session will be video recorded, but your face will not be in the video, and all the data we collect during the study is anonymous.

Do you have any questions so far?

You will use 2 input methods: mouse and touch. There will be instructions on the screen to inform you when you need to change the method. There is no time limit for the tasks, and its not a test of your ability of any kind, so dont feel like you need to rush, just perform as you would normally do, and read the instructions on the screen carefully. During the session I wont give you any instructions or help, unless there is a technical problem.

OK. If you don't have any questions, please follow me to the lab.





# Appendix 2. Questionnaire

Participant ID. \_\_\_\_\_

*This questionnaire is to help the research conductors to analyze the test results. All data collected here is anonymous and will only be used in this study. The participant ID is a number which is used to associate the questionnaire with the lab session, your identity will not be revealed.*

- Your gender:  Female             Male
- Your age: \_\_\_\_\_
- Your height: \_\_\_\_\_ cm (Give an estimation if you are not sure.)
- Are you left- or right-handed?  Left-handed             Right-handed
- Do you have normal or corrected-to-normal (contacts, glasses) eyesight?
- How often do you use web maps?  
 Never                                     Occasionally                                     Frequently
- If you have used web maps, what kind of web maps did you use?  
 Google Maps                                     OpenStreetMap                                     Bing Maps  
 Other, namely: \_\_\_\_\_
- How often do you use mouse?  
 Never                                     Occasionally                                     Frequently
- How often do you use touch screen devices?(mobile phones, tablets, etc.)  
 Never                                     Occasionally                                     Frequently
- Before this study, did you have any experience with large multi-touch devices like this?  
 No             Yes

