RWTH AACHEN UNIVERSITY

Tracking hand tremor on touchscreen

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Registration date: 07.09.2011
Submission date: 21.03.2012

I hereby declare that I have created this work completely on my own and used no other sources or tools than the ones listed, and that I have marked any citations accordingly.

Hiermit versichere ich, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt sowie Zitate kenntlich gemacht habe.

Aachen, March 2012
Alexandru Popa

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Abstract

Accessibility has always been important in making an system or application usable.

Accessibility guidelines are currently aimed at general population disabilities such as visual or auditory impairment and for those persons this guidelines have improved the usability of the systems a lot. For people that suffer from mobility impairment, because of the various types of of disability the existing guidelines are not sufficient.

In this thesis, we investigate what difficulties users that suffer from such a mobility impairment, in this case tremor, have while using touchscreen devices. We create a series of test which users have to perform while their movements are being recorded. We then analyze the data recorded during the tests to see what conclusions we can draw from it.

Based on the analyzed data we propose a series of suggestions in the form of a guideline that would increase the accessibility of touchscreen applications for users that suffer from tremors.

Überblick

Accessibility ist seit jeher bei der Herstellung eines Systems oder einer Anwendung nutzbar wichtig.

Accessibility-Richtlinien sind derzeit bei allgemeinen Bevölkerung Behinderungen wie Seh-oder Hörstörungen und der Personen, diese Richtlinien die Usability der Systeme sehr viel verbessert haben soll. Für Menschen, die von Mobilität Beeinträchtigung leiden, weil von den verschiedenen Arten von Behinderung die bestehenden Richtlinien sind nicht ausreichend.

In dieser Arbeit untersuchen wir, welche Schwierigkeiten Nutzer, die aus einer solchen Mobilität Beeinträchtigung leiden, in diesem Fall Tremor, haben bei der Verwendung mit Touchscreen. Wir schaffen eine Reihe von Tests, die Anwender zu erfüllen haben, während ihre Bewegungen aufgezeichnet werden. Wir analysieren dann die Daten während der Tests aufgezeichnet, um zu sehen, welche Schlüsse können wir daraus ziehen.

Auf der Basis der analysierten Daten schlagen wir eine Reihe von Vorschlägen in Form einer Richtlinie, die die Zugänglichkeit von Touchscreen-Anwendungen für Nutzer, die aus Tremor leiden, erhöhen würde.

Acknowledgements

I would like to thank my thesis advisors Prof. Dr. Jan Borschers and Prof. Dr. Christopher Schilck for their guidance and assistance.
Special thanks to Chatchavan Wacharamanotham and Alexandre Mertens for seeing the potential of the thesis and supporting me throughout this thesis.
To all the users that have participated in the user studies for their feedback, even though they had to travel to the laboratory in order to take part in the user studies.
Also I would like to thank Dr. Peter Kraus for hosting us at the Katholisches Klinikum Bochum St. Josef-Hospital Universtätsklinikum during our user studies there.
Last but not least I would like to thank my family and friends.
Thank you!

Conventions

Throughout this thesis we use the following conventions.

The whole thesis is written in United States English.

Chapter 1

Introduction

With the emergence of touchscreen enabled devices the way users interact with them has also changed. From the classical interaction techniques where the users uses a mouse or keyboard to control the device to the new techniques that allow the users to directly interact with the device. But this transition has also has increased the importance of the human factor in the human-computer interaction. Problems from the human factor using the classical interaction techniques have been either solved or diminished, but with the new interaction techniques they once again have to be tackled. Such problems are the ones encountered by users that suffer from tremors.

1.1 Current challenges for people with tremors

While with abled body users the direct interaction with touchscreens provides no problems, but with users that suffer of tremors this is interaction is greatly affected by involuntary muscle contraction. The oscillating or twitching movement in the fingertips induced by the muscle contractions can cause the user to create fake inputs on the touchscreen, either by touching the screen on a place different from the intended target of the user or by duplicating the input of the user.

Currently the guidelines created to help design applications for touchscreens have been focused only on the way abled body users interact with the applications, but for users that suffer of tremors this guidelines have proven insufficient, creating an unfriendly user experience for them.

The result of my thesis I aim it to be used as a guideline for developers in order for them to create application for touchscreen devices that can be used without frustration by users that suffer from tremors.

1.2 Tremor

1.2.1 What is tremor?

A tremor is define as an involuntary, somewhat rhythmic (4-12Hz), muscle contraction and relaxation involving to-and-fro movements, oscillations or twitching, of one or more body parts.

It can affect the hands, arms, eyes, face, head, vocal cords, trunk, and legs. But it most commonly affects the hands. Which is also the body part that we are interested in for our experiments.

Tremors are associated with disorders in the parts of the brain that control muscles. There are a multitude of conditions that have tremor as an symptom such as multiple sclerosis, traumatic brain injury, stroke, neurodegenerative diseases from which Parkinson's disease is the one most associated with tremors. They can also be caused by lack of sleep, stress, consumption of drugs, alcohol or tobacco.

1.2.2 Types of tremor

Tremor is classified by its the way it manifest its self and by its cause. The most common types of tremor are:

-intention tremor , which is characterized by a slow broad

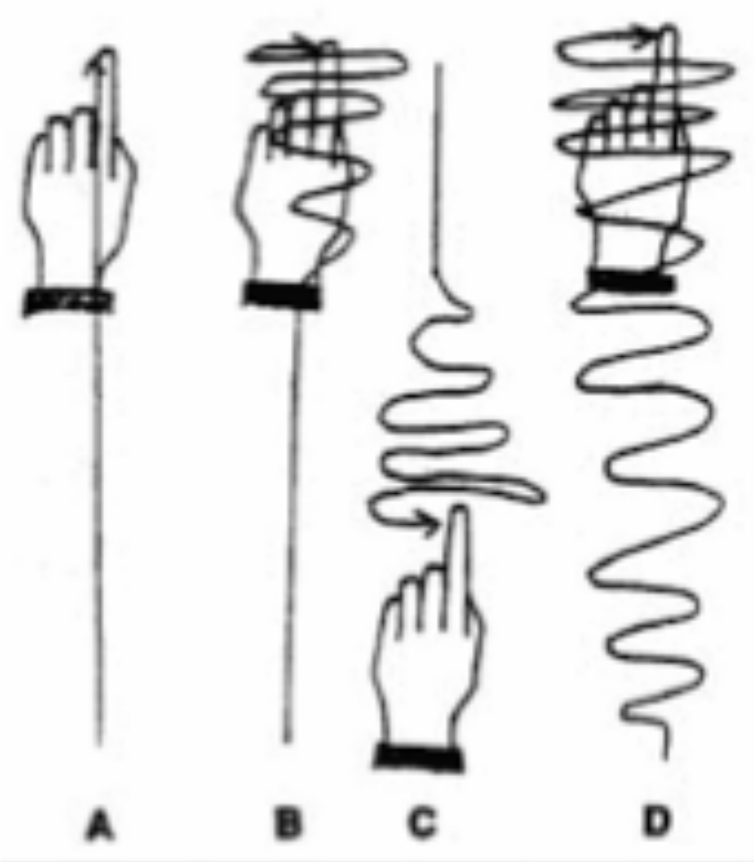

Figure 1.1: A. Normal movement, B. Intention Tremor, C. Parkinsonian Tremor, D. Essential tremor

tremor that appears at towards the end of an intentional action or movement, like picking up a spoon or pressing a button. Intention tremor is commonly associated with multiple sclerosis, an estimate of 75% of the sufferers from multiple sclerosis will suffer from tremor at one point.

-dystonic tremor, it is a tremor that affects people of all ages and involves involuntary muscle contractions causing twisting and repetitive motion and can be painful.

-essential tremor, is the most common disorder among the people suffering from tremors, it is characterized by tremor that occur during the action. It affects the hands mostly but other body parts can be also affected. About 4% of people around the age of 40 are affected by essential tremor, the percentage increases as people get older, at the age of 60 about 14% of people are suffering.

-Parkinsonian tremor is caused by the Parkinson's disease and it is a resting type of tremor, it appears after an action has been performed and will stop as soon as another action starts. Parkinson's disease affects 1-2% of the population over the age of 60.

1.2.3 Affected groups of persons

Tremors can appear at any age but is most common in older person. Depending on the type of tremor a person is suffering from the age the tremor starts manifesting itself is different, for example, for Parkinsonian tremor the onset age is around 60 years old while for people that suffer from essential tremor the onset appear most commonly after 40 years of age. Men and women are affected equally be tremor.

1.3 Touch screens

A touchscreen is a electronic display that detects the location of one or multiple contacts with it's surface within its display area. The contact with the surface can be realized by finger or hand, but also with other objects such as styluses.

In the last years devices that use touchscreens have become wide spread. If until the middle of the 00's the number of devices that used touchscreens was quite small, many of the devices being limited to the industrial area, and only a hand full of devices that used touchscreens were destined to the consumer market, with the decline in prices and the rise in popularity of device such as smartphones, tablets, touchscreen tabletops, smart refrigerators, portable gaming devices, the number of devices that uses this technology also increased. That means that more and more peoples have access to this technology, and at the same time the number of issues that appear from their use has also increased.

The technology use to create touchscreens is variate, and it depends a lot on the size of the device since some of the setups required to detect the touch on the surface can be quite big.

1.3.1 Types of technology used to build touchscreens

:

Resistive touchscreens is made out of a several layers. The layers have different jobs in detecting the touch and his position on the surface of the screen. Two layers that are separated by a small space provide the information that a contact occurred. So when a contact occurs the two layers touch and a connection is made. The benefit of this technology is that it is cheap to manufacture such screens and also it is resistant to water, so it is used a lot in environments where liquid spills can occur, such a hospitals or restaurants. Unfortunately because of the way the touch sensor is build resistive touchscreens suffer from issues with the contrast and also they are not as sensitive to users inputs because, in order to register the input a bit of pressure must be applied to the surface, for this reason operating them with a stylus is easier then using a finger.

Capacitive touchscreens are built by coating the glass of the screen with a layer of transparent conductor. Because the human body is a electrical conductor when we touch the surface of the screen the electrostatic field of the screen changes. This change is measurable as a change in capacitance. In order to determine the location of the touch happened different techniques can be used. Although, compared with resistive touchscreens, capacitive touchscreens are more responsive and you don't need to apply pressure on the surface in order to register the touch, capacitive touchscreens can only be used with a conductive body. This means that using touchscreens while wearing gloves is impossible without using a capacitive stylus or having conductive thread woven in the fingertip of the glove.

Infrared touchscreens are built using pairs of arrays of infrared LEDs and photodetectors around the ages of screen. When the surface of the screen is touched the beam from the LEDs is being disrupted, since the light from the LEDs creates a matrix of beams across the surface of the screen, the sensors can easily detect where a touch occurred. The advantage of this technology is that it allows the detection of any type of touch on it's surface.

Optical imaging, relies on placing sensors around the edges of the screen, most common at the corners. On the opposite side of the sensors there are place infrared lights. When a touch occurs, it appears as a shadow on the cameras which can locate its position. This technique also allows to determine the size of the object that touched the screen using visual hull technique. It is a new technique but it is growing in popularity due to the scalability and affordability of the system.

Surface acoustic wave is a technology that relies on ultrasonic waves that travel over the touchscreen surface. When the screen is touched part of the wave is absorbed by the item that touched the screen, thus changing the ultrasonic waves. The sensors record the change in the wave and determine the position of the touch. This type of screens are sensitive to the environment and dust or any other pollutants on the surface of the screen can interfere with its functionality.

Dispersive signal technology it is a new technique that was introduce in 2002. It is based on the piezoelectricity property of glass when it is touched, this information is interpreted using algorithms and it provides the actual location of the touch. It is claimed that this technology is not affected by the environment since it relies on mechanical vibrations to detect the touch, thus any object can be used with this type of screen, but since it relies on mechanical vibrations it also makes it impossible to detect an touch on its surface after the initial event if the object is motionless.

Acoustic pulse recognition was introduced in 2006, it relies on the fact that each location on the glass creates a unique sound when it is touched. This sound is picked up by four transducers, after being digitized it is then compared with a list of prerecorded sounds for each position on the glass. It is a cheap technology because it uses a table lookup instead of expensive signal processing hardware that tries to calculate the position of the touch. This technology provides a good optical clarity for the screen since it uses just a normal piece of glass, and it is also good for large displays. But similarly to the dispersive signal technology the acoustic pulse recognition system cannot detect a motionless object on its surface after the initial touch.

1.4 Why is accessibility important

As current generations are getting older and the older persons are starting to use technology more and more, the number of users that suffer from tremor increases. This means that the user experience that they feel now will start to degrade. In 2010, an estimated 17.6% of the population of the European Union will be over the age of 65. Currently 5% of the persons over 65 and between 0.4% and 4% of the people in Germany are suffering from tremor.

Simple tasks like pushing a button, dragging items across the screen, pinching and stretching gestures, or rotating are becoming harder to accomplish or the result of such actions is not the intended one because of the tremor's influence on the hand while trying to accomplish the task. Tremor also affects the ease of movement of the users arm in certain directions, making it harder to use certain parts of the devices screen.

In order to keep the user experience at a satisfactory level new guidelines must be introduced, guidelines designed for users that suffer from tremors.

Chapter 2

Related work

Since the goal of this thesis is to introduce guidelines for designing applications for touchscreen devices that ease their use be users with tremors, this chapter will present current and related research that has been realized for this purpose. Since research in this area is quite limited because of the relatively new adoption of touchscreens in everyday devices. But providing accessibility to users that suffer from tremor has been a concern also when they use devices that use mouse and keyboard as an input Hwang et al. [2001]. The chapter will present research that was based on traditional input devices and also on touchscreens.

2.1 Improving accessibility for impaired users in traditional interfaces

For people that suffer from tremors the using keyboards and mouses to interact with the computer is often difficult or even impossible. For this reason new ways of interacting with the interface and ways to enhance the current interaction techniques have been proposed Hwang et al. [2001] Findlater et al. [2010].

Adding new interaction channels trough multimodal input systems has was one of the proposed interaction modes Hwang et al. [2001]. Using a combination of head and hand gestures to interact with the system, and an simple alphabet: for the hand 4 directional movements were defined LEFT, RIGHT, UP, DOWN, and for the head 2 gestures UP-DOWN-UP for YES and LEFT-RIGHT-LEFT for NO. The devices used for the input were an analog joystick for the hand gestures and a Polhemus system, similar to Vicon system, for the head gestures. During the tests the user had to make either a Single, Duplicated and Different gestures. If for Single gestures the peak input rate was over 0.7 bits/s in both the case of hand or head input. When required to combine the 2 gestures in the Duplicate and Different test the peak input rate was 0.65 bits/s respectively 0.56 bits/s. The smaller input rates for the Different and Duplicated input modes is explained by the increased cognitive difficulty of input modes. When presenting users with new input modes we should not increase the cognitive loads on the user, otherwise they will perform slower then with traditional ones.

Enhancing the current interactions techniques has been the looked at in several studies Hwang et al. [2001] Findlater et al. [2010]. One of the techniques proposed is adding feedback to the mouse interactions. Force feedback in the case of users that suffer from tremor has the ability to restrain the users input Hwang et al. [2001]. The force feedback was used to create a gravity well around the target or to provide a dampening effect on the movement of the mouse. Both of the force feedback types provided improvements in the time necessary to perform the task. The gravity well proved a solution for when users would try to hold the cursor over the target, but because of the tremor the cursor would move from the target area by the time users would click the button to select it. While damping has proved to be an efficient method for that suffer from spasm because the dampening effect would increase linearly with velocity, acceleration or velocity and acceleration combined. Force feedback should be used on systems in a manner that would be supportive of the current input.

Small area targets are one of the problems encountered by users that suffer from motor impairment such as tremors. The problem appears during the last stages of the target selection, when the cursor has to be accurately positioned over the target. But the effect of the tremor over the pointing device makes this task difficult. Out of the proposed solutions Visual-Motor-Magnifier and Click-and-Cross have proven to be the best Findlater et al. [2010]. The Visual-Motor-Magnifier works by magnifying the area around the cursor, when them mouse button is clicked. The magnification provides an increase in the visual space of the action and also in the motor space. The Visual-Motor-Magnifier technique decreased the error rate by 70% compared to a normal user pointer. Click-and-Cross method works by detecting the possible activities under a area around the pointer when a button is pressed. Then the possible activities are spread in an arc around the circle. In order to select an activity the cursor must cross the corresponding arch, a selection method similar to the one in swiping. Wacharamanotham et al. [2011] This method decreases the error rate by 82% compared with the normal pointer.

2.2 Tremor causes in able bodied users

One study focused on the connection between the tremor manifested by users and the users state Dobrea and Teodorescu [2004]. Based on the results of they study the researchers confirmed that there is a connection between the two. The subjects of the study were all abled bodied and were subjected to two test sessions, one in the morning when they were rested and the other in the afternoon when they showed signs of fatigue. The system they used recognize the difference between the rested state and the fatigue state based on the tremor they were showing, and also between muscle fatigue and psychological one. The rate for successful state recognition when the users were rested was 85.71%, for the case when the subjects were fatigued the success rate was of 31.58%. The smaller success rate for the fatigued state is due to the fact that except for Parkinsonian tremor, for other types of tremors the way the tremor is generated is not well understood. The study managed to determine that the causes of tremors in are also related to a persons fatigue and psychological states.

2.3 Hand gestures and hand shapes in multi touch surface environments

The Index finger is the most common hand gesture used for interacting with the touch screen devices Epps et al. [2006] . It is used in about 70% of the cases where actions such as single selection, selecting links or buttons, drawing, moving the slider, selection of text, magnifying, moving items on screen, opening floating menus need to be performed. On the second place with 20% of the total actions is the spread hand, it was used in tasks such as multiple selection, zooming actions, rotation, scrolling. The other 10% actions was realized with hand gestures where the hand was flat on the surface, a grab/release gesture was performed, keeping the hand vertical to the screen, putting a fist sideways on the screen or keeping the fingers together. This results were for able bodied users. Unfortunately, for users that suffer from tremors the disabilities that they suffer from might not allow them to perform the gestures.

An alternative to traditional gestures a new language of gestures was proposed Yuan et al. [2005] . The main characteristics of the new gestures was that they should be easily performed by users with disabilities and they should have distinct 2D projections in order for them to be recognized by the system. The gestures were performed using two hand shapes, partial palm and pinky side, also the gestures were chosen so they can be performed in a single movement, trying to create as little fatigue as possible. The results of the test showed an rate of 94.5% for overall gesture recognition, showing that using alternative gestures for interaction with multi touch surfaces is option to be considered. We can see the proposed alphabet in Figure 2.1

In the paper Design Pattern TRABING Mertens et al. [2010], Mertens et al. propose the introduction of a new method of single touch selection. The user touches the screen and then he slides his finger over the intended target, positioned along the edges of the screen. To confirm the selection the user has two choices, either he lifts his finger from the screen or he moves it beyond screen area. Canceling is done by moving the finger back.

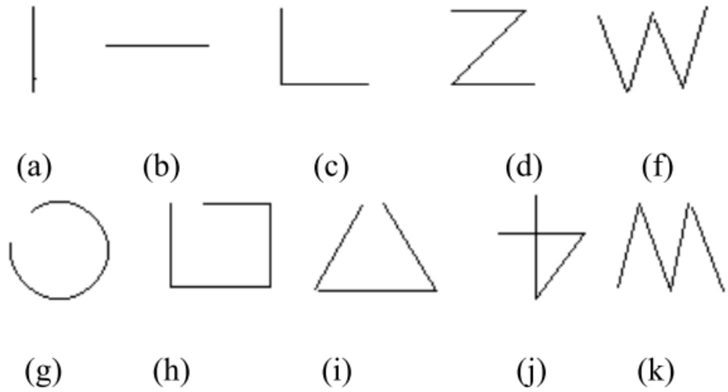

Figure 2.1: Gesture alphabet proposed

This new method was evaluated in the paper Evaluating Swabbing: a Touchscreen Input Method for Elderly Users with Tremor. The evaluation was focused on three areas: (1)Is there a difference in tremor when interacting with the screen between tapping and swabbing? (2)What is more accurate as a selection method:tapping or swabbing?(3)User satisfaction with swabbing. For the first focus area the results showed that sliding the finger decreases the tremor oscillation. Regarding the second point, swabbing has proven to be better when the target area is under 41mm wide but for targets that exceed 54mm wide tapping is also a viable choice. Users were overall more satisfied with swabbing over tapping as an input method even though swabbing is slower then tapping.

2.4 Accuracy in multi touch interfaces for users with tremor

The input accuracy of the multitouch surface was compared with input devices such as the mouse, optical trackball and a joystick for users that suffer from Parkinsonian tremor and essential tremor. The task the users had to perform was the 2D Fitts' law test in the WinFitts software

Douglas et al. [1999] . The mouse performed the best of all the devices in terms of speed, accuracy and throughput, with the MTS performing second best for the users with tremor in terms of speed, but it had the highest rate of error in terms of accuracy. This is caused by the high sensitivity of the MTS where the slightest touch will be registered as an action, compared with the mouse where the users face a slight resistance when pressing a button. The tests also showed MTS are better at suppressing the tremor from users with Parkinsonian tremor, because of the nature of the tremor to manifest after the action was completed and the hand is at rest, then for users with essential tremor

Chapter 3

Own work

In order to gather data to use in our analysis we had to perform user studies.

The idea behind the studies was to make the users perform actions that would be performed by and user that uses a touchscreen surface normally. Then by analyzing the data that was generated by the studies we are able to draw conclusions about the way users that suffer from tremors interact with touchscreen surfaces.

The studies that the users had to perform were tapping, dragging, rotating, pinching, stretching and typing tasks that are similar to actions that users must accomplish while using touchscreens everyday.

In the tapping test the users had to tap once, twice or three times in a time interval, and at different position on the screen.

For the dragging test the users had to drag their finger or fingers, depending on the test, on the screen from a given start position to a given end position. The users could chose weather to keep the fingers united or separated.

The rotating test was designed to measure how accurately an user can rotate a picture at a given angle, for example 45 or 90 degrees, clock wise and counter clock wise.

Pinching and stretching tests were designed to check the accuracy with which users can change de size of an object by either pinching or stretching and object to a given size.

In the typing test we test the accuracy and the speed with which users can type given character strings.

3.1 Users

We had 22 users that participated in our tests. They all suffered from tremors of different intensity. Some of the users did not exhibit any symptoms because they were on medication while others exhibited strong tremor.

Using the Fahn, Tolosa, Marin Tremor Rating Scale for tremor rating the number of users split by the tremor intensity is displayed in the figure below Tremor rating scale[1]

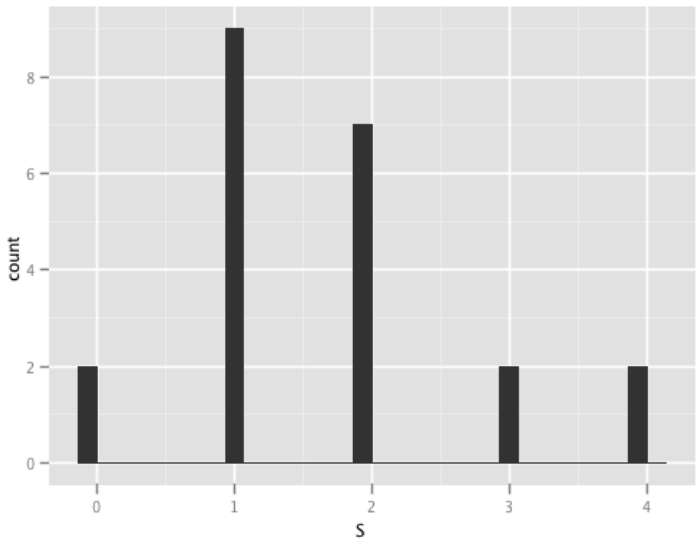

Figure 3.1: Number of users distributed by the intensity of the tremor they exhibit

[1] http://www.essentialtremor.org/SiteResources/data/files/fahn_tolosa_marin.pdf

Experiment Hardware

The main hardware used in the experiment is the VICON tracking system, iPad and a experiment control laptop.

The Vicon system consists of 7-8 infrared Vicon Bonita cameras, reflective markers, 2 routers and a laptop that has the Vicon Tracker software installed on it. Using this system we track the markers that we attach to the users hand. The cameras record the position of the markers between 20 an 100 times per second. The markers used in the experiments are 4mm in diameter.

On the iPad there was installed the test software where the tasks were presented to the users and which recorded the users interaction with the touch screen.iPad Technical data[2]

On the the experiment control laptop a software is installed that controls de software on the iPad, and it also saves the data generated by the Vicon system.

Technical data

- Frame rate:240Hz
- Resolution: 0.3 megapixel 640 x 480
- Camera output: grayscale
- System latency 2ms
- Accuracy: sub millimeter, depends on the distance and the size of the marker
- Operating range: 12m
- Focusing Range 0.3m - inf

[2] http://support.apple.com/kb/SP580

3.2 Experiment setup

The hardware setup of the experiment was designed to maximize the number of cameras that a marker could be tracked by, since a marker to be recorded needs to be in the detection range of at least 3 cameras, that is the minimum value that can be set in the Vicon Tracker software. Vicon

The cameras were placed in a half circle that had it its circle the table where the iPad would be positioned. During the calibration of the system it was important to position the cameras in such a way that they couldn't be seen by the other cameras, so they would not create false readings.In the impossibility of such a setup masks could be created to hide the other cameras in the software.

The setup of the cameras looked like in the photo below.

Figure 3.2: Vicon camera setup used for recording

After the setup of the cameras we would place the iPad on the table and then put 3 markers on it in order to record its position. The location of the markers depends if the person is left handed or right handed, since they should be visible all the time and at the same time not interfere with the actions of the user.

So if the user was right handed the markers would be positioned on the top right corner, top left corner and bottom left corner of the iPad. If the user was left handed the markers would be positioned on the top right corner, top left corner and on the bottom right corner for the iPad.

When this preparation was over we would record then the position of the iPad using the control software.

Then we would ask the user the to approach the table and we would place markers on the hand where the tremor was present. The markers were placed on the thumb, index and on the hand joint.

When the user is fitted with all the markers then he places the hand on the table for 10 seconds in order for us to record the position of each marker on the table. Then the experiment is ready to start.

We also used a video camera to capture the view over the iPad.

3.3 Output

The output of the experiment consist of two files for each task except the typing test where an additional file is generated. The files that result from the experiment contain the readings from the Vicon system, the readings from the users interaction with the iPad and for the typing experiment the file contains which string of characters the user had to type and what keys he pressed.

The format of the files is as following:

Vicon file name : the number of the User-Test Number and conditions. Vicon file contents:

- first row - user number - test number - condition

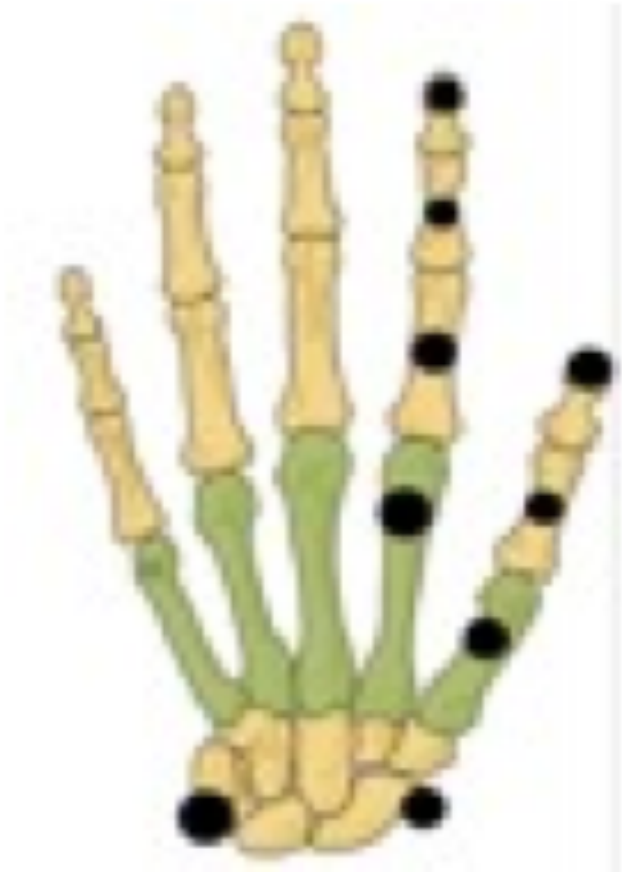

Figure 3.3: Position of reflective markers on users hand

- file contents: each line starts with a Unix time stamp followed by a array of markers and marker position, like m,x,y,z where m is the marker number, x the position on the X axis, y the position on the Y axis and z the position on the Z axis. this is repeated for each marker registered by the vicon system;
- last row - is again the user name - test number - con-

dition

iPad file name: the number of the user-Test Number and conditions iPad file contents: contains the list of touches with the position of the touches, the timestamp of when the touch occurred and the radius of the touch event

Type test file : contains two sections, the first part of the file contains the input from the user and the second part of the file contains the string that the user had to enter on the keyboard.

3.4 Test variables

Directions relative to the starting point for tap testing where the user must press the screen: N, NE, E, SE, S, SW, W and NW; Corresponding to 0, 45, 90, 135, 180, 225, 270, 315 degrees from the center of the screen clock-wise.

Directions relative to the starting point for tap testing where the user must swipe on the screen: N, E, S, W Corresponding to 0, 90, 180, 270, degrees from the center of the screen clock-wise.

The order of the direction in which the user must tap or swipe has been decided using latin square.

We define a trial as the movement starting from the starting position and ending at the target position. The start of a trial is triggered by a trigger sound.

3.5 Experiment procedure

Before starting with the tasks on the touchscreen the user is asked several questions to determine his handedness and based on those results we decide which hand the user will use during the tests. The questionnaire adapted from Oldfield, R.C. The assessment and analysis of handedness: the

Edinburgh inventory. Oldfield Questionnaire[3] . The questions to determine the users handedness are based on the everyday actions that users perform.

The user also has to perform an Purdue Pegboard test in order to measure their dexterityPegboard[4]

Markers are placed on the selected hand, the user can move his hands until he feels comfortable with the markers on his hand. Then the user must hold the hand still for 10 seconds while the system records the positions.

3.5.1 Task 1

Tapping task The user has to press certain marked places on the screen. At the start of the test the user has to place his index finger on the marked place on the screen and then when he hears a trigger sound he must press on the target place on the screen and then go back with his finger to the start position. He must repeat this action five times, each time he will hear a sound when he has to press on the marked spot. There are a total of 8 positions where he must touch the screen for a total a 40 trials.

3.5.2 Task 2

Tapping N-times. The user must tap on the screen 2 times and 3 times, The direction of movement the user must move his hand from the starting position is up. The test consists of 10 trials. Each trial is triggered by a trigger sound.

3.5.3 Task 3

Sliding: direction This test is used to determine in which of the 8 directions: N, S, E, W, NE, NW, SE and SW; starting

[3] http://web.psy.ku.dk/Anders_Gade/Readings/Oldfield1971.pdf
[4] http://www.lafayettelifesciences.com/product_detail.asp?ItemID=159

from the starting posiotion the user can perform easier sliding gestures. For each direction the user must perform the sliding action for 5 times for a total of 40 trial for this task.

3.5.4 Task 4

Sliding: distance In this task the user must perform the sliding gestures for two different lengths, 150Px and infinity, the sliding gesture is continued past the edge of the screen. The user must perform this actions in four directions N,S,E and W. For the 150Px trial the starting position is the center of the screen, for the infinite trials the starting position is the in the opposite starting of the target area relative to the center of the screen. For each direction and each distance the user must perform the task 5 times for a total of 40 trials.

3.5.5 Task 5

Sliding: two finger. For this task we attach a new marker to the nail position of the users middle finger. The user must slide in four directions N, S, E, W using two fingers, in each direction the user must perform 5 trials for a total of 20 trials

3.5.6 Task 6

Pinching and Stretching In the first part of this task the user must reduce the size of a given circle to match the size of a sample circle using the pinching gesture. The trial ends when the user is satisfied with the size of the circle he started from. Three trials are performed for this part of the task. The user must use his thumb and index finger to perform the pinching gesture.

For the stretching part of the task the user must increase the size of a given circle to match the size of sample circle. The user must use his thumb and index in order to perform the stretching gesture. One trial ends when the users is satisfied with the size of the circle he had to resize. Three trials are performed during this part of the task. In total this task has 6 trials.

3.5.7 Task 7

Sliding: screen angles In this task the surface of the screen is tilted, at two angles. the user must perform the sliding gesture in four directions: N, S, E and W starting from opposite position relative to the center of the screen. The two angles of the screen are 30 and 45 degrees. For each direction he must perform 5 trials, in total 40 trials must be performed for this task.

3.5.8 Task 8

Typing. In this task the user must enter, with the help of a keyboard, a string of numbers displayed on the screen. The time limit for this task is of two minutes. The user must try to insert as many strings as he can in this time limit. The user cannot correct the number he inserted. A new string of numbers will appear on the screen to be inputed when the number of characters in the given string matches the number of characters that was inputed.

After the tasks are done we asked feed back from the users regarding the tasks they performed. Which direction of movement they felt it was easier for them to move their hands in? If they thought that tilting the screen at an angle they feel it was easier for them to slide the fingers on?

Chapter 4

Evaluation

The data that was gathered during the tests was analyzed to see what conclusions we gather from it. We wanted to check:

- How what is the influence of tremor on the different stages of movement?
- What is the movement direction effect on accuracy and movement speed?
- How accurately can users slide their fingers without visual feedback?
- What is the effect of tremor in sliding? Does the angle of the screen affect the tremor?
- Does the layout of the keyboard affect the users when typing?

4.1 Tremor effect on different stages of movement

In order to check the effect of tremor on the users movement, the movement performed by the user was divided in to 2 parts, the homing movement and the tap movement.The homing movement is defined to be 95% of the time the user was moving his hand and the tapping movement is defined as to be 95% of the time the users finger is in contact with the surface. The homing movement begins when the users finger is lifted from the screen. The tapping movement begins when the users finger touches the surface of the screen. Using the average frequency on the X, Y, Z axes the user for when the finger in the homing part and also the average frequency on X, Y, Z axes when the user finger touches the screen we can see that during the contact with the screen the users we can see that the is a significant effect on the tremor. The X axis is the axis that starts from the bottom right corner of the iPad screen as it faces the user and goes to the bottom left corner of the screen. The Y axis is the axis that starts form the bottom right corner of the iPad screen as it faces the user and goes to the top right corner of the screen. The Z axis is the axis that starts from the bottom right corner of the iPad screen and it moves upwards away from the screen surface. If a movement was performed towards the E and W direction then we projected the movement on the YZ plane, ignoring the X plane because the tremor movement would mix with the normal hand movement on the X axis. Similarly for the N and S directions we projected the movement on the XZ plane since the movement on the Y axis is mixed with the normal hand movement. For the diagonal directions NE, SE, SW and NW, because of the direction of the movement, in order to determine the tremor frequency for the X axis we projected the movement on the XZ plane and for the Y axis on the YZ plane. During the fingers contact with the screen the tremor decreases on all axis. In the Figure bellow we can see the difference in tremor by axis between the the two stages of movement.

4.2 Direction of movement effect on accuracy and movement speed

In creating the user guidelines we had to determine if the direction in which a movement is performed affects the accuracy and the time it takes for the movement to be performed.

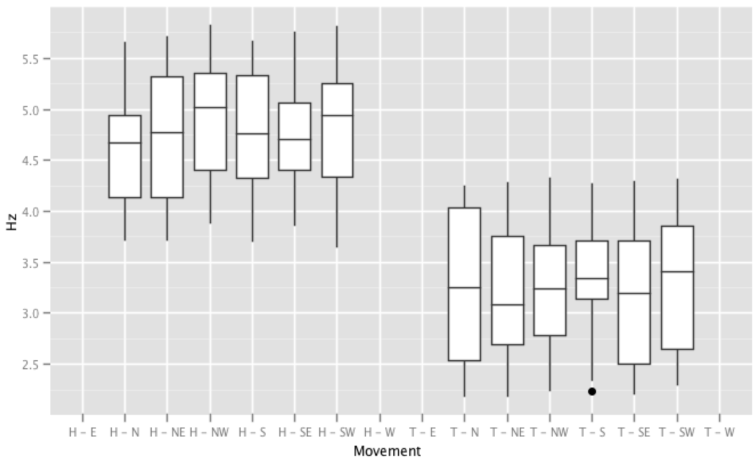

Figure 4.1: Frequency on the X axis sorted by movement part and direction

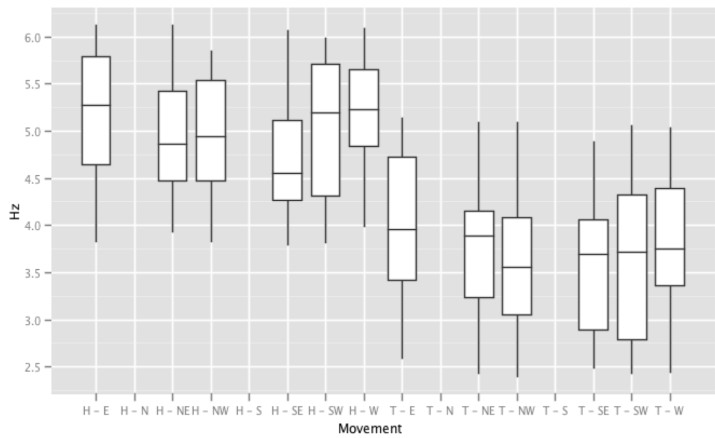

Figure 4.2: Frequency on the Y axis sorted by movement part and direction

For this analysis I used the data from the Tapping trials in order to get the time required to perform the movement from lifting the finger from the starting position to when the finger touches the screen next. Based on the iPad data.

For the accuracy value I am considering, only the first touch event and only the touches that were performed in the target area which is defined as in the following figure. I chose

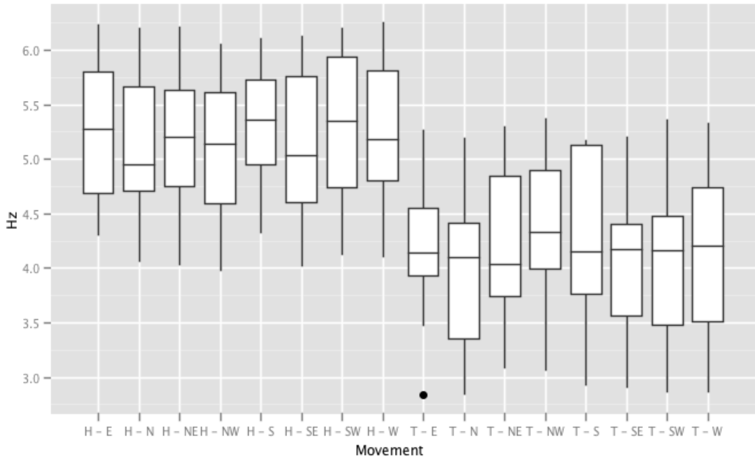

Figure 4.3: Frequency on the Z axis sorted by movement part and direction

the square as the shape of the target because that is a common shape for buttons. Based on the plot of the time re-

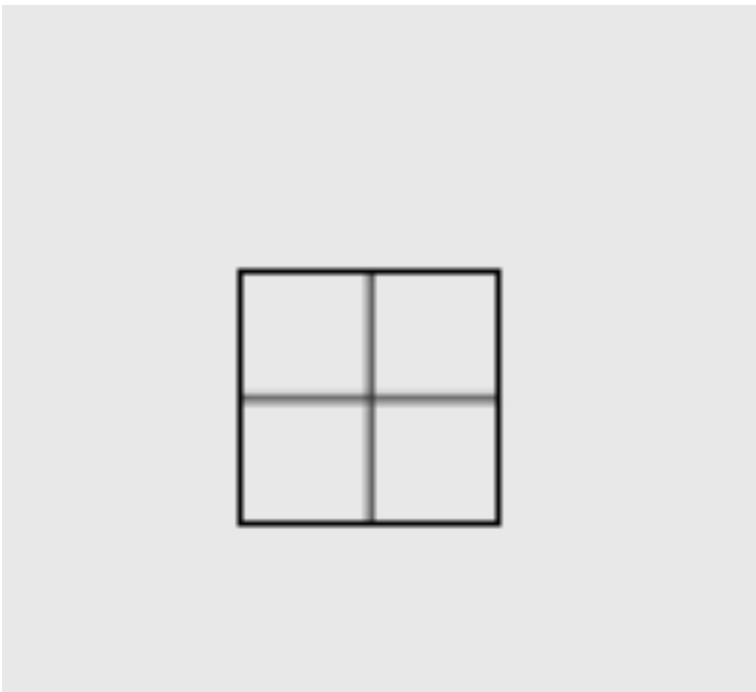

Figure 4.4: Target area considered is inside the black square

quired to perform the actions we can clearly see that the actions where the users had to move the hands away from the body are slower then those that are performed towards the users body. Movement direction does not have a significant influence on the accuracy of the users when they performed the tapping task. In the picture below we can see the statis-

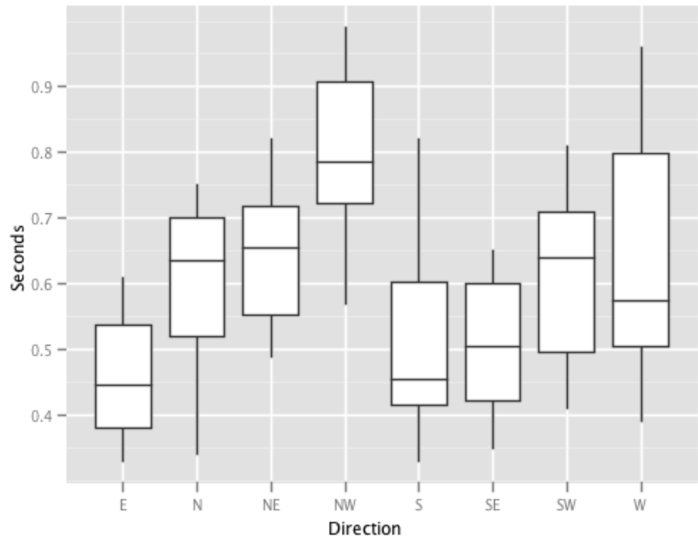

Figure 4.5: Average homing time sorted by trial

tical difference in the time it takes to perform the homing movement between directions of movement. We can see

	E	N	NE	NW	S	SE	SW
N	0.00050	-	-	-	-	-	-
NE	2.3e-06	0.18038	-	-	-	-	-
NW	1.4e-15	4.1e-07	0.00012	-	-	-	-
S	0.23045	0.02003	0.00030	1.7e-12	-	-	-
SE	0.24917	0.01770	0.00025	1.3e-12	0.96241	-	-
SW	3.2e-05	0.47266	0.53257	1.0e-05	0.00251	0.00216	-
W	1.4e-05	0.35258	0.68014	2.4e-05	0.00126	0.00108	0.83206

Figure 4.6: Statistical significance in the movement between directions

there is a significant statistical difference between the time users needed to make movements towards the body compared with the time needed for users to make movements away from the body.

4.3 How accurately can the users slide the fingers without visual feedback

In order to determine the accuracy with which users can perform sliding actions with out visual feedback we took the data gathered in the sliding test and analyzed it. We calculated the Euclidian distance between the target point and the closes point which the user touched.

You can see the result split by the direction in which the user was performing the sliding movement. The distance is measured in pixels We can see that the directions where

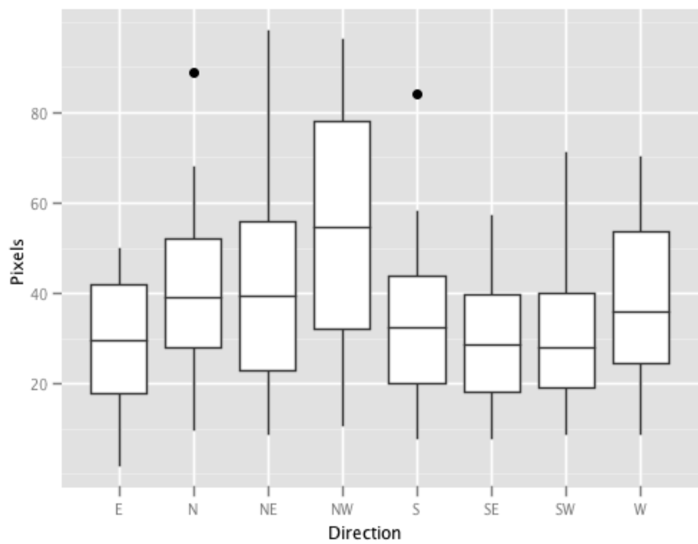

Figure 4.7: Distance to target split by the direction the movement takes place

the movement is performed towards or close to the users body show a lower average distance from the users closes touch to the center of the target.

4.4 Distance effect on tremor

We wanted to know what is the distance effect on the tremor a user exhibits while sliding his finger on the screen. For this analysis the data compared came from the distance sliding test where the user had to slide his finger over the screen for short distance, 150 pixels, and for an infinite distance, the users finger would go past the edge of the screen when the sliding gesture was performed.

We can see that the frequency for the small distance movements is lower then for the infinite movement. Smaller distances are better for user to do sliding gestures. In Figures 4.8, 4.9 and 4.10

If a movement was performed towards the E and W direction then we projected the movement on the YZ plane, ignoring the X plane because the tremor movement would mix with the normal hand movement on the X axis. Similarly for the N and S directions we projected the movement on the XZ plane since the movement on the Y axis is mixed with the normal hand movement. For the diagonal directions NE, SE, SW and NW, because of the direction of the movement, in order to determine the tremor frequency for the X axis we projected the movement on the XZ plane and for the Y axis on the YZ plane.

4.5 Does the angle of the screen affect the tremor

Using the iPad stand we tested if the screen angle affect the tremor frequency in users. The tested angles were for 30 and 45 degrees, the users had to perform sliding gestures on the surface of the screen in four directions. The movement that the users had to make for all directions except towards the E and W directions where the tremor movement on the X axis was mixed with the normal movement, have been analyzed on all three axes.

We can see from the plotted results that the angle of the

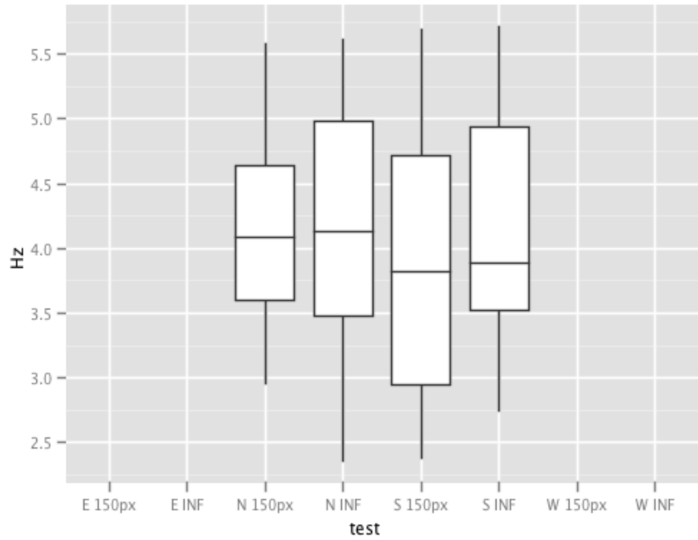

Figure 4.8: Frequency on the X axis sorted by the sliding distance

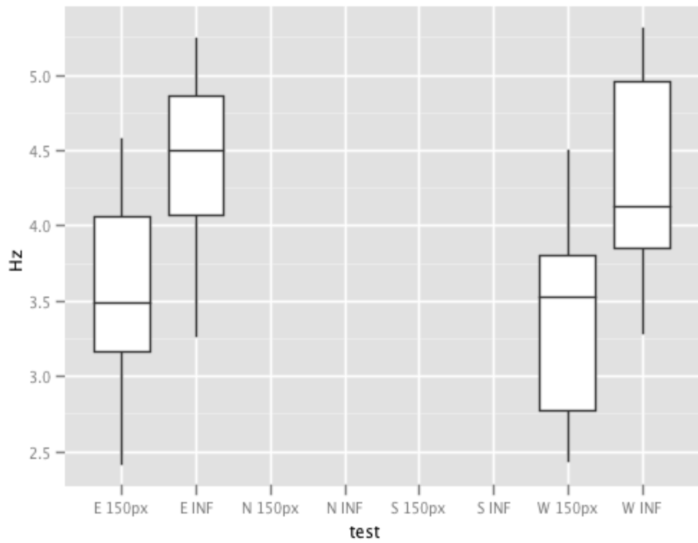

Figure 4.9: Frequency on the Y axis sorted by the sliding distance

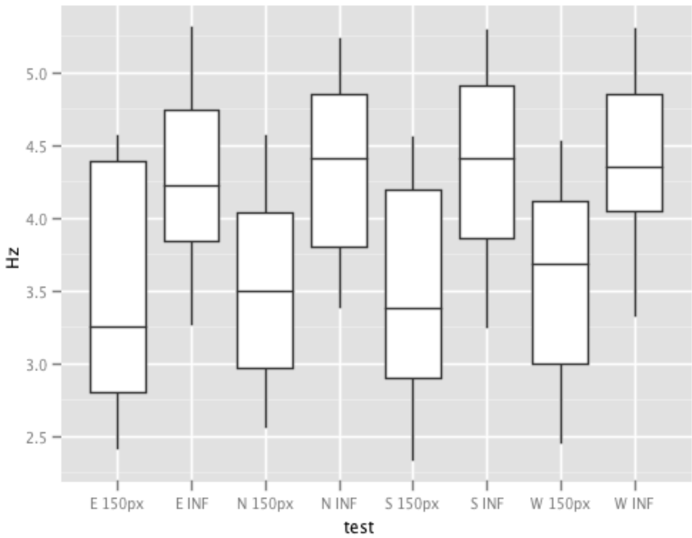

Figure 4.10: Frequency on the Z axis sorted by the sliding distance

screen does not appear to have any significant influence on the tremors of the users.

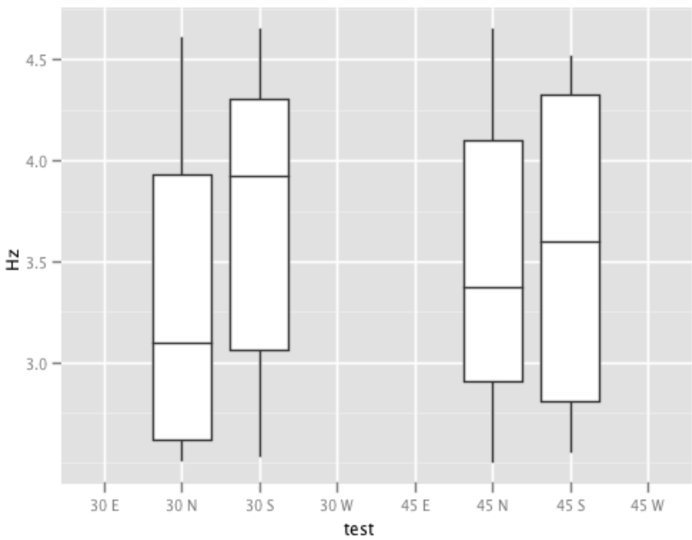

Figure 4.11: Frequency on the X axis when the screen is tilted at 30 and 45 degrees

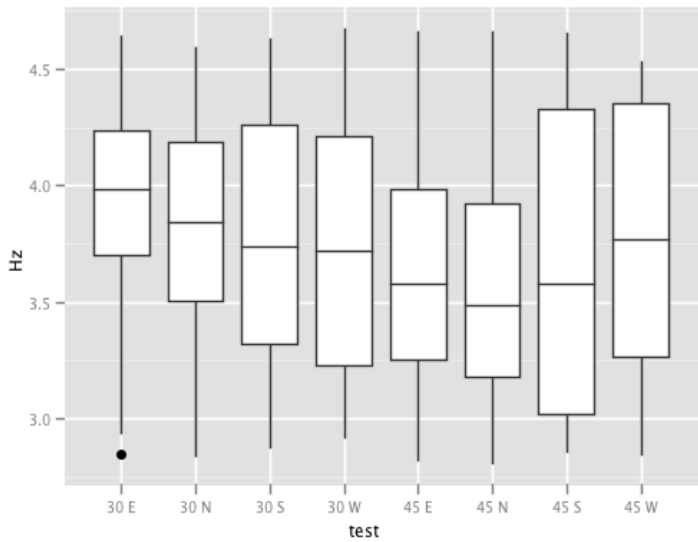

Figure 4.12: Frequency on the Y axis when the screen is tilted at 30 and 45 degrees

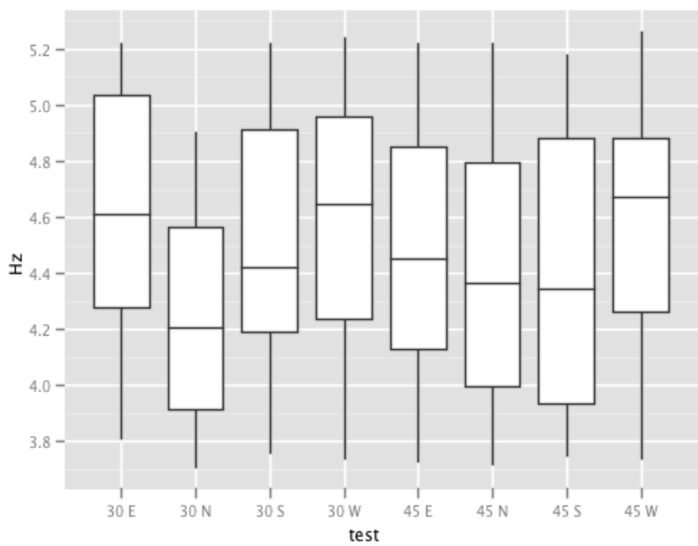

Figure 4.13: Frequency on the Z axis when the screen is tilted at 30 and 45 degrees

4.6 Keyboard layout effect on the users while typing

In order to determine the effect of the keyboard layout on accuracy of typing we used two different keyboard layouts. The first one was a landscape layout that used 3 rows of keys labeled with the letters of the alphabet, 9 keys on the first 2 rows and 8 keys on the second row, and the second one, a portrait keyboard where they keys were distributed 4 rows, top 3 rows each have 7 keys and the bottom one has 5 keys. The keys have a size of 96x96 pixels. Pictures with the layout of keyboard can be found in Annex A.

We calculate the accuracy of typing as the edit distance between the given string the user must input and the string the user has entered. The difference in the two strings is then calculated as the edit distance. The time the users were given to perform the test was 2 minutes and 30 seconds. There is no significant difference between the two layouts in regard to the edit distance , as you can see in the figure below. But, when using the keyboard in the por-

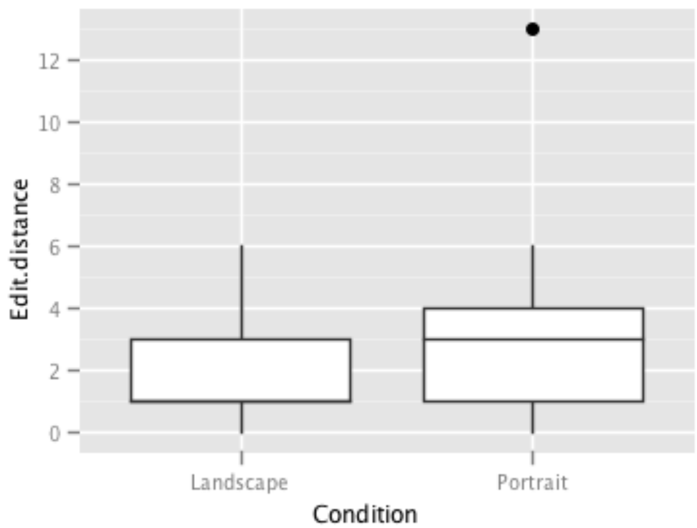

Figure 4.14: Edit distance sorted by the layout of the keyboard

trait mode there is an increase in typing speed calculated in words per minute , compared with the landscape mode because of the smaller distance between keys the users hand had to travel. Even thought the two layouts have similar re-

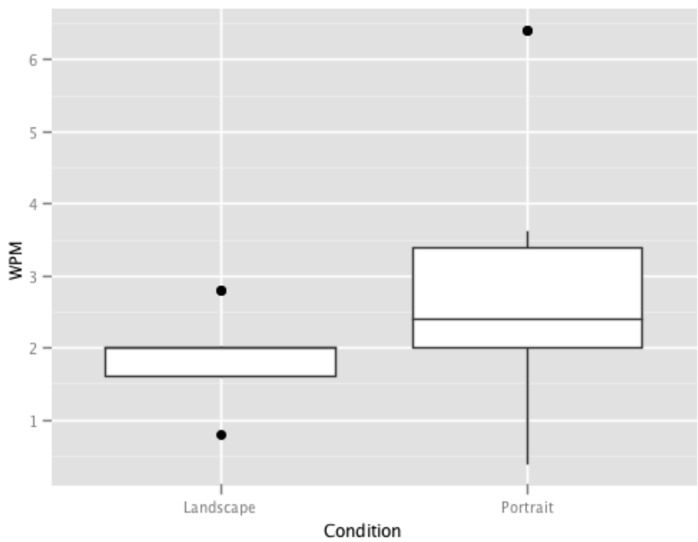

Figure 4.15: Input speed in words per minute sorted by the layout of the keyboard

sults regarding the edit distance, the portrait layout is better over the landscape layout because it allows the user to have a greater typing speed.

4.7 Time between consecutive touches

A consecutive touch is a touch even that happened during the same trial when the test required for the user to perform only one touch. We can see in the figure below that the direction of movement does not influence the time between consecutive touches, the times being similar. Also in the majority of cases the duration between the consecutive taps was under 0.2 seconds.

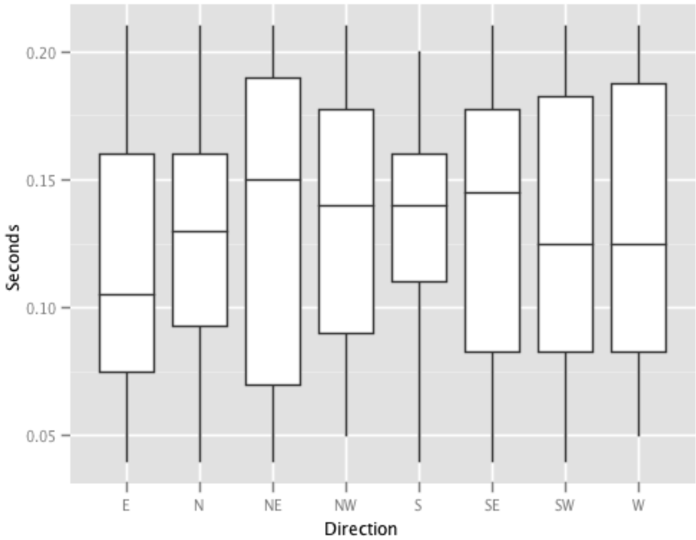

Figure 4.16: Time between consecutive taps sorted by direction

4.8 User feedback

After the experiments we have asked the users to provide us with feedback on the tests that they have performed. The questions were aimed to discover what they felt the system was lacking in or if they feel that certain actions or movements are more difficult to perform then others. A common answer was that the system lacked feedback and that it would be easier for them to know if they performed an action if the system provided them some indication of that.

Using the analysis design a set of rules were created in order to help designers create applications that are easy to use for persons that suffer from tremor, rules that will be presented in the next chapter.

Chapter 5

Design Guidelines

The current applications for touchscreen surfaces are created for abled bodied user, users that suffer from disabilities must adapt themselves to the systems they are using. Design guidelines for persons with disabilities have been proposed for other types of interfaces, for example web pages such as the one from the Nielsen Norman Group[1] or traditional interaction interfaces. But for applications designed for touchscreen devices such guidelines are often general accessibility guidelines but they are not tailored for specific disabilities. Although research in this area is ongoing.

iOS Human Interface Guidelines[2] and the Android User Interface Guidelines[3] have general rules that designers should follow to increase accessibility for disabled users but these guidelines were created for small form touchscreen devices. But guidelines that were designed for small form touchscreens may not be adequate for large form device such as a touch screen table. Microsoft Surface 2 Design and Interaction Guide[4] , which was created for large surface touchscreen devices does not include any guidelines for accessibility.

[1] http://www.nngroup.com/reports/accessibility/

[2] http://developer.apple.com/library/ios/DOCUMENTATION/UserExperience/Conceptual/MobileHIG/Introduction/

[3] http://developer.android.com/guide/practices/ui_guidelines/index.html

[4] http://www.microsoft.com/download/en/details.aspx?id=26713

This lack of adequate guidelines creates a discrepancy in the user experience between able bodied users and users that suffer from disabilities. The aim of the proposed guidelines is to improve the usability for users that suffer from tremors.

The design guidelines are based on the data, user feedback and observations gathered during the user experiments and are focused only on users that suffer from tremors.

5.1 Design Guidelines

5.1.1 Feedback

One of the most common problems encountered by users that suffer from tremors is that, because of the tremor they do not realize if they have made contact with the surface of the touchscreen or not.

Providing the users with a feedback mechanism is one of the ways that designers can help users to determine if a contact, intentional or unintentional was made. The feedback provided to the user must be immediate, this is important especially because of the nature of tremor.

The mechanism used to provide feedback to the user that a touch as occurred can be a visual, auditive or haptic feedback. Each of these types of feedback has advantages and disadvantages.

Auditive feedback. While sound can be an useful tool to provide feedback to the users that a touch event has happened , because of the age of the group of people that are mostly affected by tremor they are also affected by hearing loss, 43% of persons over the age of 65 suffer from it according to Aging Society[5] , the auditive feedback may not be perceived by the user.

Haptic feedback. During the homing part of the hands

[5]http://www.agingsociety.org/agingsociety/pdf/hearing.pdf

movement towards a target the user, because of tremor, might accidentally touch the surface of the touchscreen. But the duration of such of unintended contact is very short so the user might not be able to detect the fact that such feedback has been initiated.

Visual feedback. When touching the surface of the screen graphical elements can be displayed that signify that a touch event has occurred. Even thought UI elements such as buttons, changing color, or text fields have provide the users with feedback, not all the UI elements have such mechanisms. But at the same time the visual feedback should not be invasive or distract the user from his task.

Combining multiple mechanisms of feedback might prove better. But the users should be allowed to choose and modify the settings of this mechanisms, e.g.. volume for auditive feedback, intensity for haptic feedback.

During the user testing we have not tested to see the influence of feedback on the users. Further test that aim to discover what is the best way to provide feedback to the users must be performed.

5.1.2 Disable the Interface Locally

Because of the oscillations induced in the users fingers by the tremor, user perform an action multiple times even though they only wished to perform it once, e.g.. pressing a button, as we have seen from the typing test where duplicated inputs were the cause of most errors during the test.

A mechanism to eliminate duplicated or unwanted touches is the disable temporarily the UI element which was activated by the touch.

Disabling the UI element after the first registered touch event will help reduce the number of duplicated inputs on that element. Based on the user testing where the test showed that the interval between the touches when multiple touches were registered for one action, disabling the

UI element for a duration of 0.2s should be sufficient since we shown that most repeat touches performed are less then 0.2s.

Because of the nature of tremor that makes accurate pointing not only the UI element that has been selected should be disabled but also other UI elements that are in the vicinity of the touch point.

In order to allow the user to perform gestures, the UI elements must be disabled only after a touch event was detected and the finger was lifted from the surface of the touchscreen.

5.1.3 Predictive interface

Accuracy in input is on of the biggest issues for persons that suffer from tremors when they try to interact with touchscreen devices. If we can predict what their next actions will be we can help them increase their accuracy.

Trying to determine the next action of the user is already deployed in user interfaces, the T9 predictive text input system used in mobile phones or the predictive systems used in smartphones tries to determine what is the word the user is typing and suggest alternatives to it.

Using a similar approach to try to predict the users next action. Fitts' law says that the bigger the size of a target the easier it is to press on it. But having the same UI element in with different sizes in the same interface disrupts the usability of the system. A solution to this problem is to make the tappable area of the predicted UI element larger. This would lower the error rates for inputs and at the same time keep the original appearance of the interface, so the same interface can be used for abled bodied users and also for users that suffer from tremor.

While text input will be one of the areas where this type of predictive interface is especially useful, using prediction can be useful while filling forms for example, where the field that follows the one you are currently editing has a increased tappable area or if you reach the last area the Confirm and Cancel buttons also will have their tappable areas increased.

5.1.4 Keep controls close to the user

Tremor increases when the user must perform actions that involve moving his hands away from his body. This is not a issue for small form touchscreen devices because the distance the users hand has to travel is small. But for large form devices where the users hands travel long distances the increase in tremor affects accuracy and also the time which it takes for the user to reach the target.

Traditionally, applications such as web browsers or data editors have controls close to the top of the window. On small form touchscreen devices having the controls for a application all over the screen is not an issue because of the small distance a users hand must travel to reach the controls but for large form touchscreen devices having the same approach to the user interface of having the application controls on the screen is troublesome for the users with tremors because of the effect of distance on tremor.

Instead we should remove the need of the user to perform actions away from his body since screen real estate is much more available in large form touchscreen devices as it is in the small form touchscreen devices. Building applications where the controls are closer to the user would help reduce the tremors on the users hand.

For example, traditionally web browsers have the web address text field and navigation buttons at the top of the webpage, but those controls can be move to the bottom of the page on large form touchscreen devices in order to make them more accessible to the user. Similarly with controls for data editors where on top of the application window we have the menu and shortcut buttons for the application.

5.1.5 Remap Gestures

As the result of the sliding tests show the ease of movement users experience is differs from user to user and also from the direction the users is performing the sliding gesture towards, movements away from the body are slower then the ones performed towards the users body.

Since a gesture might be easier to perform for an user then for another the current gesture input provided by the systems might not be adequate for all the users with tremors.

Users should be allowed to choose the what actions are performed by each gesture, and if the gestures that are provided by the system are not satisfactory for the users then they should be allowed to input their own gestures for those actions. For example instead of using sliding UP to scroll down on a page, for a user it might be more comfortable to use another gesture for this action, such as sliding LEFT or RIGHT, or if he wants he should be able to add a new gesture such as a circular motion for this action.

5.1.6 Hand rest area

Seeing that when users are in contact with the surface of the screen the tremor they exhibit is smaller. The system should allow users to be able to rest their hands on the screen, using a system similar to the one used by Yuan et al. [2005] based on the shape and size of the contact area of the hand with the screen to determine what part of the hand is in contact with the screen and act accordingly.

The other elements of the user interface can be focused around this area, the controls for the applications can be designed to be accessible in a small area around the contact point. For example if two hand contacts are determined to have taken place then a keyboard would appear on the screen above the position of the contacts to emulate the position of a physical keyboard in relation with the hands, or if a user is using a music application, when he rests his a hand on the screen his music playlist appears close to the point of contact so he can scroll through it without moving his hand.

This would enable the users to have an increase in accuracy in inputs that do not require for large movements, e.g.. typing on a keyboard, or gestures like sliding trough a list.

5.1.7 Allow custom sensitivity

Because of the high sensitivity of the touchscreens users with tremors have problems using them, and one of the biggest issues they encounter is the problem with unwanted touches generated by them because of the oscillations induced in their fingers by the tremor. Sensitivity should be defined as a combination between the time and area of a contact with the screen that is registered by the device as a touch event.

Because of the small time and pressure required in order to trigger an touch event on touchscreens the unwanted and accidental touches caused by tremor create problems. Douglas et al. [1999] The problems users might encounter are duplicated input results when the user presses the same user interface element more the once or erroneous input results when the user, while moving his hand to the target, touches the screen in an unwanted position. As we have seen in the result of the tapping and typing tests.

The current sensitivity settings that are used by touchscreens set with able bodied users in mind. But for users with tremors such settings cause the system to be improperly adapted for their use and cause the issues stated above. Douglas et al. [1999]

The system should allow for users to chose the sensitivity of screen. Time of contact and size of contact area should be variables that should be able to be set by the users so they can adapt the device according to their own preferences in order for them to have a better user experience.

5.1.8 Time is not your friend

The tremor a user experiences increases with time while performing certain types of input such as time based input where the user must make and keep contact with the surface of the screen for a longer period in order to perform an action such as opening a contextual menu or selecting an element the screen. AS we have seen during the tapping tests.

Users with tremors should be provided alternatives for this time based input. Using gestures for input is already used in the user interface but this should be expanded to replace the time based input. Since gestures can be constructed from a large variety of movements and they can be accurately recognized Epps et al. [2006] they are a viable alternative to the time based inputs.

Using time based actions or interfaces that require a user to make and keep contact with the screen for long periods of time is not advised. An alternative to time based input are the usage of gestures to trigger the actions.

Chapter 6

Summary and future work

This work produced a design guideline for system and application designers aimed at improving the usability of touchscreen devices for users that suffer from tremor. The guidelines are based on the data gathered from the experiments, the user feedback and observations during the tests.

6.1 Summary and contributions

As the current technology enabled generations are getting older, and the current older generations are starting to adapt technology more and more, problems that are connected with old age and the ability to perform actions start to appear where new technology and older persons connect.

Until recently the most popular interaction methods with devices were the traditional mouse and keyboard but now because of several factors such as increase in popularity and decrease of productions costs. Touchscreen have started to be adapted both as a display and input method.

With this increase in popularity also issues with using them have appeared, on of the most affected groups of persons are the elderly. Because of age specific health issues, such as tremor, loss of hearing, loss of sight, the elderly have problems using touchscreen enabled devices.

Accessibility is an important factor in developing usable applications. Currently the accessibility guides for touchscreen devices are either general guides or lacking completely from the design guidelines for such devices. The need for design guidelines focused on specific aspects of accessibility are needed.

In order to create such guidelines test were held where users would have to perform tasks that are similar to tasks they would perform during the normal usage of a touchscreen device.

The research questions were identified and in order to gather data user tests were performed. The tests that they performed were tapping, sliding, typing, pinching and zooming. An system that consists of an iPad, on which the tests were performed, and Vicon motion capture system was used. On the iPad the software for the tests was installed and used, besides running the tests the users had to perform the software also recorded the actions the users performed when the user was in contact with the surface of the screen. The Vicon system was used to record the users hand movements when the users hand did not touch the screen. The Vicon system recorded the position of several reflective markers, that were attached to the users hands, using infrared cameras.

The tests were performed by elderly persons that suffered from tremors.

6.2 Future work

The system focused on the usage of only one hand, and one finger, the index finger of the users, in performing the tasks the users have been assigned. Studies that investigate the effect of tremor when users use more then one finger or more then on hand to interact with the screen must be performed.

Tests aimed at discovering what are the best ways of providing feedback to the user must be performed. The result of the test should be used to complete and expand the

The guideline should be expanded using conclusions gathered from the data generated by the tests where the users use multiple fingers or two hands to interact with the screen.

Because of the different type of tremors that persons can suffer from and because the way they manifest, the guidelines should be adapted for different types of tremor.

Appendix A

Keyboard Layout

Figure A.1: Keyboard layout in portrait mode

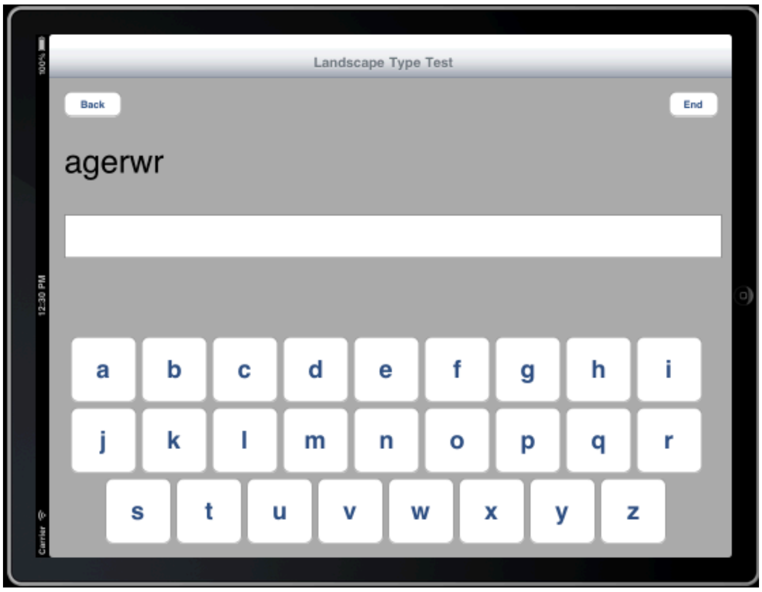

Figure A.2: Keyboard layout in landscape mode

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Typeset March 21, 2012