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Thesis
submitted to the
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Contents

List of Figures

List of Tables

Abstract

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Acknowledgements

Thank you!

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of technical terms or short excursus are set off in coloured boxes.

EXCURSUS:
Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition: *Excursus*

Source code and implementation symbols are written in typewriter-style text.

`myClass`

The whole thesis is written in Canadian English.

Download links are set off in coloured boxes.

File: myFile[a]

[a] http://hci.rwth-aachen.de/public/folder/file_number.file

Chapter 1

Introduction

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Chapter 2

Related work

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Chapter 3

Hardware Prototype and Software Development

In this chapter we first describe the basic differences between the two most popular touch input technologies and which is best suited for wearable scenarios. Then we proceed with showing several iterations of the hardware prototypes using pinstripe and the corresponding software. Furthermore we describe the disadvantages and improvements of each iteration. The results of two user studies are discussed afterwards.

3.1 Resistive vs. Capacitive Touch

Advantages and Disadvantages of Resistive and Capacitive Touch Technology

The two most popular touch input technologies are resistive and capacitive. Both serve the same purpose but the underlying principle differs making them more or less suited for wearable computing.

3.1.1 Capacitive Touch

Characteristics of Capacitive Touch

ToDo: find simple explanation of capacitive touch.

The advantages of capacitive touch is the easy support for multi-touch input and the almost no need to press down the area of the sensor. The main disadvantage is the human body itself, since it generates its own capacitive field which makes it hard to detect the intentional touch. This flaw is intensified by the movement of the textile due to body movement. **TODO: source! Especially for earlier findings why it is worse than resistive**

3.1.2 Resistive Touch

Characteristics of Resistive Touch

Resistive touch technology uses two separated layers of striped electrodes such that it is arranged to a matrix. The spacing material in ordinary resistive touch screens is either an air filled chamber or a non-conductive material which separates both layers while no external force is applied. Therefore one can operate it with a stylus or with gloves since no conductivity is required. On the one hand this solves the main disadvantage of the capacitive method regarding wearable computing, on the other hand it is still prone to deformation and thus to unintentional contacts.

Going for Resistive Touch

After taking all characteristics into account we decided to go for the resistive touch technology, because we can drop all considerations of capacitive noise caused by the human body.

3.2 System Design

MSP430 for first prototype

ToDo: exact specification of pinstripe and micro-controller und den gripper probe Klemmkabeln!!

All prototypes presented here are using pinstripe, a fabric with separated conductive lines. For the first prototype we were using the Texas Instruments MSP430G2452 micro-controller. Each row and column of the pinstripe has to be connected to a *digitalRead* pin of the micro-controller. The MSP430 controller has 16 of these pins but only 14 can be used since two pins are used for serial communication. This results in a matrix resolution of 7 by 7 at maximum.

Resolution in pinstripe context:
When speaking of a certain resolution of our prototype, we talk about the number of connected rows and columns. Since the pinstripe fabric is of a static size, the higher the resolution the larger the prototype gets.

Definition: *Resolution in pinstripe context*

We are using the TI EK-TM4C1294XL for the advanced prototypes. This board has the ability to connect more than 40 pins for *digitalRead* to operate a 20 by 20 pinstripe matrix. The board is connected to a Computer via USB for serial communication.

Programming Environment: Energia IDE and Processing to gather, send and process input data

For programming the micro-controller we are using the Energia IDE[1]. It is an easy to use IDE to upload programs to the TI micro-controller. The micro-controller itself is solely responsible for sending the data of the sensor to the computer via serial communication. Meaning that it tests a pin against ground for each other line and column. A *1* is written to the serial-port when it is connected to another line or column and *0* otherwise. This is done for each pin where *numberOfPintripes* is the number of all lines and columns. For each prototype an integer array is declared and can easily be commented and uncommented depending on the prototype. The where the pin numbers are sorted such that the first pins correspond to the x-axis and the last pins to the negative y-axis. After all pins were tested we send a line-break to determine the end of the current input.

```
void loop() {
 for (int i = 0; i < numberOfPinstripes; i++)
     {
   pinMode(array[i], INPUT_PULLUP);
   delay(2);
   state = digitalRead(array[i]) ? '0' : '1';
   pinMode(array[i], OUTPUT);
   digitalWrite(array[i], LOW);
   Serial.print(state);
 }
```

[1]http://energia.nu

```
  Serial.println();
  delay(3);
}
```

We are using Processing[2], a Java based IDE, to structure the input stream from the micro-controller for further analyses. This includes several programs which either displays the raw touch points for debugging purpose or filters and interprets the sensor data. The changes of software are described along with each hardware iteration.

3.3 Early Testing

better note something here

After deciding to go for the resistive approach, the essential challenge is to find a spacing material with certain characteristics. The material should

- be flexible by means of being wearable.
- reliably separate the pinstripe fabric while no touch is intended.
- concede rather easily when intended force is applied.

ToDo: Find names of the fabrics and materials

ToDo: insert picture here

Combine materials to improve results

We start by trying some leftovers from recent research projects. Then we place the materials between the pinstripe fabric to examine different behaviors. We glued both layers of the pinstripe fabric to sheets of paper to eliminate stretching and curling of the fabric. Some of the the materials are cut with a laser-cutter. We cut equidistant circular holes to provide space for the pinstripe layers to connect. We attached 4 by 4 pinstripes to the MSP430 microcontroller. For displaying where a touch is present, we created a simple program with Processing. Almost all available materials are not well suited for our purpose, since they are either too thick, thin or stiff. When combining up to two materials, which are leading to permanent contacts on their own, the results are improving. Nonetheless it is

[2] http://processing.org

still susceptible to the slightest bend and therefore not well suited. Therefore we are using foam for the latest prototype.

3.4 The Prototype

When

3 mm foam as spacing material

Chapter 4

Evaluation

In this chapter we will take a closer look at the performance of the 14 by 14 prototype. Since the prototype is designed as a wearable, we are interested in its behavior under certain changing conditions. We conducted a user study to test the physical limitations of our prototype.

Testing the 14 by 14 prototype

4.1 Physical Limitation Study

The human body is in motion almost all the time and the clothes we are wearing are not fixed to the skin. This *looseness* and the changing subsurface are variables that may influence the performance of our prototype. Another variable is the *friction* of the overlaying material. Depending on the fabric and method of fashioning, it can, more or less likely, happen that the user slips of the touch-sensing area, or experiences an unpleasant feeling in the operating finger. Furthermore the *softness* of the underlying surface may influence the performance of our prototype. The human body has different softness almost everywhere. The amount of muscles, adipose tissue, and so forth also differs from human to human. This, in the first place, affects the pressure needed by the user. Then there are the different levels of curvature. Our prototype has flexible spacing-material to separate the pinstripe layer. After a certain amount of bend

Independent variables: friction, softness, looseness, and curvature the material starts creasing, causing some permanent contacts. In this study we will test our prototype in conditions which aim to simulate the in field circumstances. To test to which degree of bend the prototype breaks we used different foams with the same height but different softness.

4.2 Study Design

The participants had to perform 8 different gestures in different conditions. To control the curvature, we used aerosol cans with 53 mm diameter and 66mm diameter. As a baseline we also used the table with a flat surface. When we tried to perform gestures on a curvature below 53 mm we got permanent contacts immediately. To fixate the aerosol cans we build stands using a laser cutter. The prototype was fixed with duct tape to the surface of the cans and . To achieve the curvature with the foam, we used a book and wrapped the foam around the cover and clipped it in a vise. The fabrics (jeans, cotton,) were pinned with needles to the prototype. Nevertheless, there is still a certain amount of movement due to the flexibility of the fabrics. Since we aim to build a textile touch pad for eyes-free interaction, the user can not see the output on the screen.

ToDo: brown farbric?
ToDo: insert pictures

The conditions, at least curvature and softness, were chosen at random. In order to shorten the time of the study, we tested all fabrics consecutively changing the order. Some prior testing has shown that the foam with a density of todofind that paper with the numbers xxxxxx and xxxxxxx perform alike. Thus we dropped the foam with higher density after the first participant tested both foams in one condition without significant differences in terms of input error.

The participants were filmed while interacting with the prototype. Furthermore the screen with our program was captured to determine the by eye, whether the gesture was recognized correctly or, if not, should have been recognized correctly. Additionally, our program created two log-files for every condition. One logged the filtered data and one the raw sensor data. Both files logged the time it took to perform each gesture.

4.3 Study Procedure

After the user arrived we introduced her to our prototype. We explained the basic functionality and demonstrated how the output looks like. Then we let the user test the eight gestures and some freestyle strokes. This was done without foam or any additional fabric. We pointed out that a certain amount of pressure is essential for our prototype to recognize the touch. When they felt familiar enough, about 2 minutes of testing, we prepared the first condition.

For each condition we setup a GoPro Hero 3 to capture the prototype and the acting hand of the user. When we were ready to start recording the screen and setup, we told the user to continue. Since the user cannot see the output during the study, we told the user when insufficient pressure was applied or when the touch-sensing area was left. In both cases we most likely recognized one or two wrong gestures. We represent the number of wrong gestures with an x in the respective chart.

When one condition is completed we asked the user about their impressions of the fabric, softness, and curvature.

4.4 Participants

4.5 Results and Analysis

Chapter 5

Evaluation

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Chapter 6

Summary and future work

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6.1 Summary and contributions

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6.2 Future work

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Appendix A

TITLE OF THE FIRST APPENDIX

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Appendix B

TITLE OF THE SECOND APPENDIX

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Bibliography

Index

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