Evaluating User Interaction with a Smart Armchair

Master's Thesis
submitted to the
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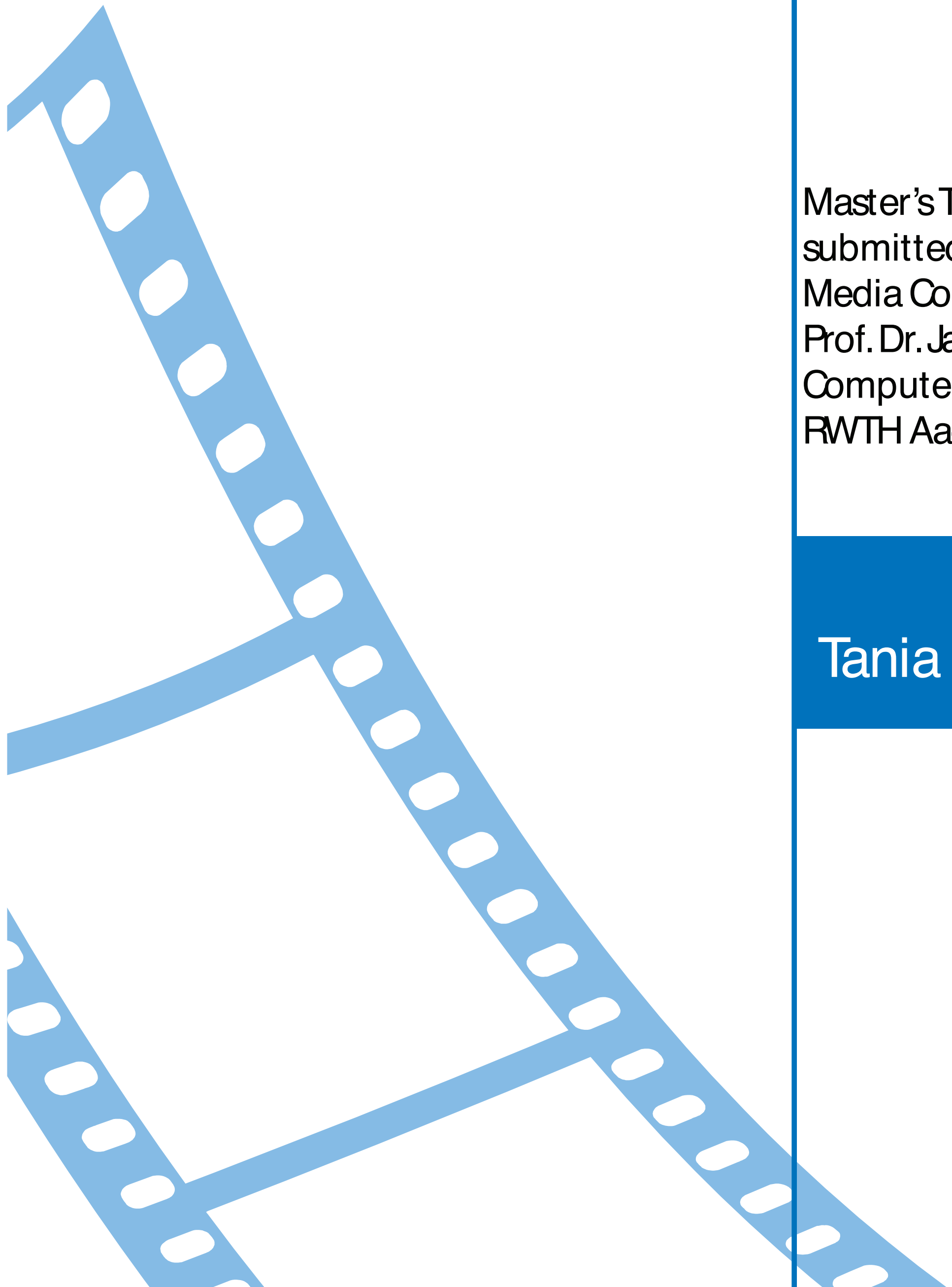

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Abstract

Our environment evolves and becomes smarter, we need smarter ways to control them. Technology is becoming more ubiquitous in our environments, advancing to focus on interfaces that fit better our constant changing surrounding. In this thesis we explore how an arm chair, a common object in many homes, can be augmented and used as a control interface in some home scenarios.

This thesis focus on the research performed to evaluate the user interaction with a smart armchair. In order to achieve this, we followed the subsequent methodology consisting of four steps: 1) an elicitation study to observe user's behavior, actions and interaction with a standard armchair; 2) design of a prototype that could be added to an armchair as input control; 3) preliminary study to understand the variables which affect users performance and preference during interaction; 4) a main user study to evaluate the prototype working on a standard armchair according to the proposed variables and testing application.

Evaluating the performance of the prototype and the variables tested in our elicitation and user studies, we found that a) users prefer using hand gestures over body-based gestures; b) users prefer 2 locations of the armchair to interact with: top of the armrest and outer side of the armrest; c)the stiffness of underlying surface (foam/ no foam) does not have an effect on performance; d) texture of fabric has no effect on input accuracy while performing but an effect on execution time in milliseconds; e) the location on armchair for interaction (see b)) did not affect performance, input accuracy or execution time. Overall we found that interaction with a smart armchair may offer a promising option as a new channel of control that breaks away from the regular remotes, mobile and tablets metaphors into a more natural interface which is already part of the environment, specially in armchair control and home media control scenarios.

Acknowledgements

First of all I would like to thank Prof. Dr. Jan Borchers for giving me the opportunity to be part of the i10 chair.

Secondly, I would like to thank my supervisor, Nur Al-huda Hamdan, M.Sc., for her constant support, patience and advice during this work time, her deep knowledge on the topic made this work a great learning experience.

To all the people who took time to participate in my user studies I also thank you, thanks for your time and feedback, it was a core part of my work.

Lastly, I would really like to thank my family, whom despite the distance have always been a source of support, motivation and inspiration, thanks for always being there and believing in me.

Chapter 1

Introduction

As a topic of interest, the development of human computer interfaces present in public, home and personal spaces has evolved in the last few years, thanks to the advance in capabilities of technologies such as smart textiles and wearables. This tendency asks for novel human computer interface systems to be developed around everyday objects that once were overlooked, by adapting available technology into their design and turn them into powerful multimodal interfaces. We have learned is possible to use some of the ubiquitous objects that surround us in our everyday environment in order to add another channel of control Corsten et al. [2013]. We consider this as an opportunity to break from standard remote, mobile and tablet metaphors into a more natural interface which is already part of the environment we live in.

Our environments are becoming smarter and we need smarter ways to control our homes.

Chairs are constantly present in our everyday life: in work environments as office chairs, at home as armchairs, sofas or recliners, even in transportation as seats, despite the time people spend on chairs and their presence in different settings in our environment, they have remained mostly static, passive, sensory deprived agents.

Use an ubiquitous object in order to add another channel of control.

The idea of transforming an ordinary chair into a perceptual haptic interface could be of great interest for new applications in many potential areas such as:

- Smart home environments
- Health-care
- Automobile industry.

When one hears the phrase smart home, chances are the living room immediately comes to mind. It makes sense, since for most people, the living room is essentially the nucleus of the household. It's the room where people is most likely to sit back and relax, watch television, listen to music or read a book. It's also the room where you're most likely to find technology from full-on home theater setups to automation and security systems. For reference we observed via the annual American Time Use Survey, the U.S. Bureau of Labor Statistics collects data on the amount of time Americans 15 years and older spend on leisure time doing the aforementioned activities to an average of 3.34 hours per day in 2016 AME.

Chairs are natural objects in our surroundings which can be augmented.

Researchers have investigated the possibility to augment everyday objects Xiao et al. [2013] by making touch-based interfaces on everyday surfaces. This method however relies mostly on flat surfaces as is based in the use of projectors and depth cameras. While many of this and other researches have focused on known touch-based artifacts that participants may be familiar with or devices that the participant can carry or have at hand Corsten et al. [2013], our research focus on the possibility of adding an augmented chair as a new channel of interaction with the participant, in our case a particular type of chair: an armchair.

Armchairs are mostly present in home environments which let us evaluate their potential usability in an area such as smart-home or intelligent home environments. We believe an armchair offers a suitable surface to easily interact with, where the participant can comfortably reach and perform a set of gestures to execute commands from the chair to some other device at their home. One of the most interesting aspects of creating a smart armchair is figuring out the technological aspect, find out which sensing technology would be more suitable for this purpose, and implement a detection algorithm so that we can produce a working prototype with sensors and develop a software that reads that sensor data. There is research on augmenting everyday objects but only a few have considered textile interfaces such as the Gabrics textile input controller Hamdan et al. [2016b] or Gardeene textile sensor curtain Heller et al. [2016]. Nonetheless we believe that the advancements in textile interfaces and technology gives us a great opportunity to create a textile input sensor which could be ubiquitously integrated into the fabrics of an existing armchair.

The idea of augmenting a chair and breakaway from their passive state is not new, with some researches on the subject dating back to 1999 in work by Streitz et al. [1999] with the idea to have a chair with built-in slate computers so that they could be connect and share information with people in other similar chairs, to more recent developments where a chair is able to sense different aspects of the person sitting on it, heartbeat, position, and communicate these reading to a computer exemplified in papers of Tan et al. [2001]and Anttonen and Surakka [2005]. We would look more into previous work done with and around chairs in the next chapter. Analyzing these previous works, we have seen attempts to figure out a place and usability for an augmented chair yet the home environment as a possibility has not been studied in-depth, hence our idea of turning an armchair into a new channel of interaction is of utmost interest and possibilities.

Figure usability environment for augmented chair, we propose home scenario.

The purpose of the research covered in this thesis work is to explore the viability and functionality of a smart armchair using the chair itself as opposed to embedding input devices on it. To find the use cases where it would be useful to control a system via the armchair, investigate the suitable technology such as a smart textile implementation to create a prototype model and explore the variables such as texture of the fabric, location on the armchair or any other aspect of the armchair itself that may or may not have an effect on user interaction with the model. From the results gathered from the research we intend to prove our initial idea as well as propose guidelines for the design of the smart armchair by understanding how a smart armchair would look like, how it would work like and how interaction with users would take place.

Figure 1.1: CommChairs proposed by the work of Streitz et al. [1999].

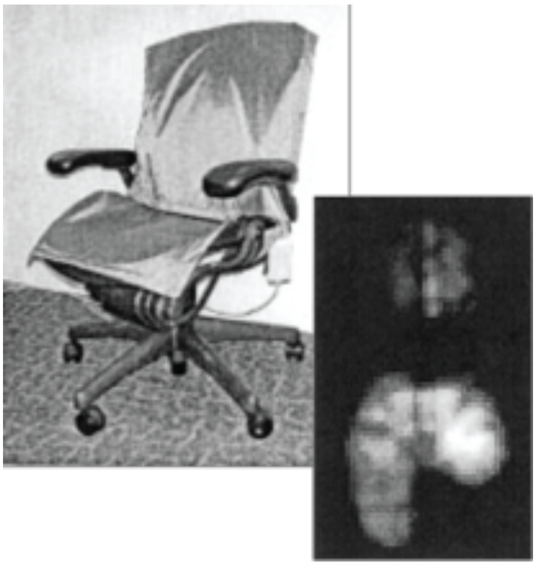

Figure 1.2: Sensing chair and pressure map for the posture according to the work of Tan et al. [2001].

Chapter 2

Related work

Over the last decade, there have been some reports on related research and prototypes of potential use cases for human computer interaction with chairs, whether to get some kind of information about the person sitting on it or to convey a message or feedback to the person sitting on it, that is why the classification between these cases could be done as passive and active states of interactions with chairs.

2.1 Passive User Interaction with Chairs

Sensor-based chairs to monitor and obtain certain information about of a person sitting on it have been developed around different sensor solutions and motivations. In a few psychological studies such as the ones performed by Anttonen and Surakka [2005] and Kärki and Lekkala [2009] regarding people's emotional response to music, visual and other media stimuli, chairs have been used as a method of unobtrusively measure the person's heart rate by means of electromechanical film sensors (EMFi), which consists of a plastic film that converts mechanical energy to an electrical signal and vice versa, Paajanen et al. [2000], embedded in an office chair's seat, backrest and armrest. The EMFi sensors are able to perceive the tiny mechanical movements caused by the activity of the heart and measure the heart beat accordingly.

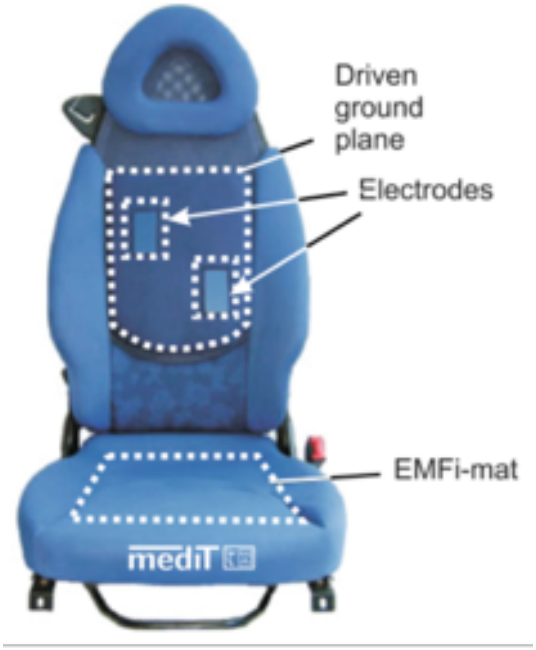

Figure 2.1: Car seat with sensors Walter et al. [2011].

Unobtrusive sensing performed with chairs: heart rate, position, postures, etc.

Another sensing based chair was developed by Tan et al. [2001] to sense and track sitting positions and postures of people and generate a posture recognition and classification system. The chair sensing system is comprised on two sensor sheets, where each sensor sheet has an array of 42 by 48 pressure sensing elements of body pressure, these were placed on the seat pan and backrest. Measurements resulted in a pressure map and grayscale image for data representation in real-time. The raw map obtained is noisy, however this noise is removed by convolution with a 3x3 smoothing kernel and for data representation a PCA-based classification algorithm is used; the implemented approach uses the eigenvectors of the covariance matrix of a set of training pressure maps.

Other research by Hamdani and Fernando [2015] sensor-based systems have been applied to car seats in order to measure the heart signals of a person while driving, one study integrated a seat-belt with woven piezo-resistive cardiorespiratory sensors, while a second study by Walter et al. [2011] researched three different embedded solutions:

Figure 2.2: Overview of the system of the haptic Chair Nanayakkara et al. [2012] aid in train for the deaf.

capacitive ECG, mechanical BCG (based on EMFi sensors) and magnetic impedance monitoring sensors applied to the seat and backrest of the car seat. In the branch of healthcare a haptic chair was developed by Nanayakkara et al. [2012] as a potential aid in speech training for the deaf, as a medium of providing extra feedback to the students by generating vibrotactile stimulation from audio signals and delivering them to different part of their bodies through the chair.

2.2 Active User Interaction with Chairs

Chair-based interaction has been explored as an input device by Probst et al. [2014] to be used in the control of a computer while doing focused, perform a website search, or peripheral, control music player, tasks on it by using the chair movements (tilt right, left, back, front) and rotation as input gestures for the computer instead of keyboard and mouse.

There has also been a research by Steffi Beckhaus [2007] on the use of chairs, by mapping the aforementioned gestures,

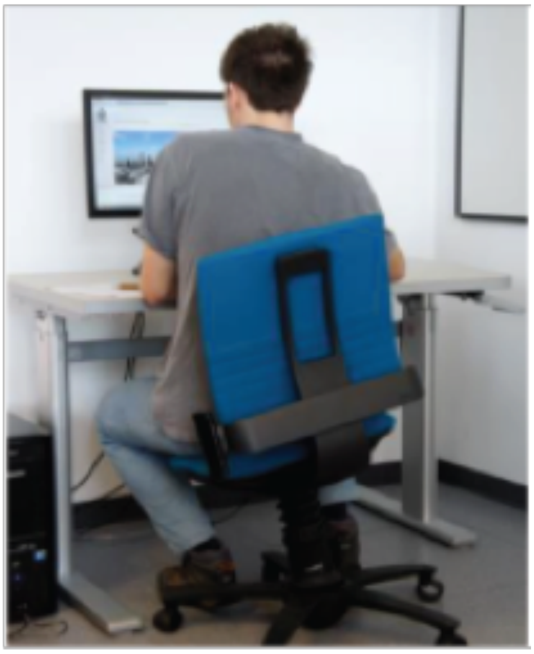

Figure 2.3: Office chair used as input control Probst et al. [2014].

Map chair movements to navigate in virtual environments or mouse cursor.

to navigate within 2D and 3D computer games and virtual environments, or to control the mouse cursor with it. In both 3D and 2D games, the use of chair gestures instead of a combination of buttons or keys in regular control input was meant to provide natural mapping to movement when first person character is playing. It was noted also when evaluating the use of a chair as mouse cursor that it intuitively maps to the positional task usually performed by the pointer on the screen and that if expanded with foot control it may complete all of the mouse capabilities.

While Probst et al. [2013] used the same principle of an interactive chair as means of controlling selected applications on a computer, to promote implicitly and occasionally the integration of light physical activity in an office environment. This last study was aware of the cons of using chair gestures in all applications at all times and merely suggest the addition of this capability on the chair as a mean of breaking every-day routine and include light physical activity during work hours. On a similar note, Endert et al. [2011] attempted to use a chair movement and translate

Figure 2.4: The ChairIO used as gaming input device Steffi Beckhaus [2007].

it into large-scale cursor movement for large size, high-resolution displays. The main idea was to take advantage of the user's natural chair rotation while going through the high-resolution display to map it into an action that creates an interaction in the workspace, so the rotation of the chair: clockwise or counterclockwise, generates relative mouse events that move cursor left and right.

Challenges: calibrate chair sensors, avoid accidental trigger, filter noise.

In all cases a set of sensors were integrated to the base of a regular office chair to perceive the tilting and rotation, then communicated those gestures to a computer. The main challenge for all was to calibrate the chair perception of gestures, too sensitive or not and suggest to do an adjustment per user and compensate for inaccuracies. Each team developed a detection and processing algorithm for the gestures which main complication consisted on differentiating intentional from unintentional gestures and filtrating noise perceived by the sensors.

Figure 2.5: Illustration demonstrating how chair rotation would translate to pointer in display Endert et al. [2011]

2.3 Haptic Chairs

Passive monitoring with haptic and audio alerts.

Multimodal interaction with chairs have been performed by sensing performed on the chair, processing of the information obtained and response generated by the chair to the user. Hurst et al. [2005] has developed a proposal for assisting the elders by means of enhancing a regular chair or building one from zero. In any of the two versions, the chair monitors the elders sitting position and movements and provide non-invasive feedback, alarms and notifications to them. A prototype based on the same work was implemented which includes sensors throughout the chair, processing by a microcontroller and offers response via vibration, and a second implementation by Forlizzi et al. [2005] includes audio response as well.

Figure 2.6: The Sense Lounger (left) exposed view of Sense Lounger's sensors (right) Hurst et al. [2005].

2.4 Augmenting Everyday Objects

As we briefly discussed in the Introduction 1 researchers have looked into turning everyday objects into interactive input devices. The WorldKit by Xiao et al. [2013] proposed using a projector and depth camera to turn surfaces including tables and doors into touch-based interfaces by drawing with their hands on the selected surface. In the work of Corsten et al. [2013] they presented a system where users can repurpose physical aspects of everyday objects such as a pen into an input device like a control by using a marker-free object tracking system. Using a webcam as detector and pattern stickers on the objects, the work of Cheng et al. [2010] suggests using everyday objects as auxiliary input devices in multi-task work environments. Whereas the research by Zaiţi and Pentiuc [2013] they focus on capturing glove-based hand postures in order to infer everyday object properties and based on that information, potentially use that object as an interface for augmented multi-party interaction applications.

Chapter 3

Body-based Interaction with Chairs - An Elicitation Study

SUMMARY

In this elicitation study, we investigate how 10 participants interact with a chair as an input control system. A regular armchair is used as a mockup for this study while we observe how participants link a set of actions to commands on the chair. The proposed mockup system did not attempt to recognize the users' gestures, instead the participants are asked to use the think aloud protocol while their behavior is recorded, afterwards from the recordings, notes are taken to consider where the participants can reach and position their body or hands on the armchair, what kind of gestures they are able to perform, which ones seem natural or comfortable to do and whether participants prefer a hands-free interaction or not. From this elicitation study we defined that hand interaction is considerably preferred by the users, while we also close up on two potential input interaction zones, the top of the armrest, outer-upper side corner of the armchair and outer-middle side of the armchair.

3.1 Objective

The main objective was to define position and input modality

Chairs are natural objects in our surroundings that could be augmented for: smart home control, supporting accessibility, in-car interaction among others. Turn an ubiquitous object, such as a chair, in order to add another channel of control. The overall objective of the study was through observing the participants' behavior interacting with a chair as an input control to help us define an hypothesis on where to position our input system on the chair, whether to use hand-based or body-based gestures as input modality as well as to define a basic user-defined gesture set to command and control tasks from the chair.

3.2 Setup

The experiment was in a room with the participant taking seat in the armchair that served as a model for the study. A set of four cameras was used to record the sessions to obtain the desired data, as the evaluator reviewed the videos and took notes about the participants' experience, comments and responses.

Based on a previously defined script A.1 the evaluator instructed each participant to envision themselves being at a comfortable scenario as their home's living room and being able to control smart home appliances from the armchair. A think-aloud protocol and rating for ease of use and comfortability was done by the participants. The evaluator used the following process:

1. Explain the set of commands in each scenario to the participant that would serve to control a smart device from the chair.
2. Per command the participant is given the chance to express which gesture they imagine they could perform that will issue the desired command and try it on the chair.

3. In each scenario the participant performed the last step twice as one time is intended to be performed with a hand gesture and the other with a body-based gesture. The participant is asked to change the order of the use of hand and body at random per scenario.

Each task was done twice, once per input modality (hand-based and body-based)

4. Ask the participant to rate their experience, ease of use and how comfortable they felt during the interaction per gesture.

5. The order of the scenarios presented to each user is changed per user, so that no two users have the exact same order.

For more information on the questionnaire used to obtain feedback from the user experience in each scenario please observe Appendix "Y".

Figure 3.1: Sketch of the evaluation setting performed for the elicitation study. The armchair where each participant is to sit and interact with, surrounded by a set of four cameras: front, left corner, right corner, one on the side of the participant dominant hand.

3.3 Tasks

In the study four scenarios were presented to each participant, each of the scenarios as well as the tasks involved in each one are presented as follows:

Scenario 1 - Armchair manipulation control
The armchair used as mockup is able to take on different positions and angles, four main positions were derived from it and the users were ask to perform a hand gesture and a body gesture that would allow them to change to each of the given positions.

10 participants, within subjects design. 4 scenarios, 20 tasks in total.

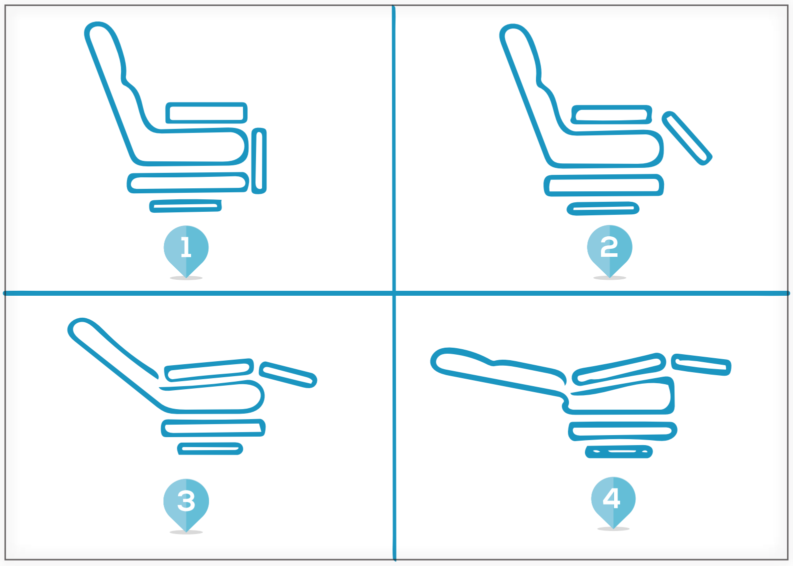

Figure 3.2: Armchair positions available in Scenario 1

Scenario 2 - Home indoor light control system
Control the living room light from the armchair, the participant is asked to perform a gesture per command, where the possible commands are:

- Turn on the light
- Turn off the light
- Dim gradually the light
- Bright gradually the light

Scenario 3 - Frequent contacts call control
Imagine the armchair is connected to the participant's mobile phone and can perform a call to any of the 3 most frequent contacts.

- Select contact
- Start a call
- End the call

All scenarios were referred to on literature on smart home control. Our view potential use of the chair as an ubiquitous input control.

Scenario 4 - TV Control
Control a TV that also happens to display an exterior CCTV system connected to the armchair and perform the following commands:

- Switch TV mode on
- Switch CCTV mode on
- Next selection/channel
- Previous selection/channel
- Volume Up
- Volume Down
- Enter Main Menu
- Unlock door from CCTV system

3.4 Participants

For the elicitation study we recruited 10 participants. They should preferably have previous experience with smart devices. To consider in the study: participants age, gender and whether they are right-handed or left-handed.

3.5 Results

Once the elicitation study was performed with all participants, the data was analyzed both in a quantitative and qualitative matter.

For the quantitative data analysis each referent (command) as well as the test variables (chair location, gesture type, scenario) were given a number ID. From the notes taken from the video recording of each participant, a consensus of the gestures was taken, identifying a total of 85 gestures performed, from which 41 corresponded to hand gestures, while the remaining 44 corresponded to body gestures. Each of this gestures was also given a number ID. Then according to what each participant perform per command, a referent ID was paired with a gesture ID to be later reviewed with agreement scores.

Quantitavie: input modality and location, agreement scores and average time per gesture. Qualitative: likert scales and subjective responses.

The results in different areas are detailed as follows.

3.5.1 Input Modality

These were the results observed regarding the input modality:

- High use of full hand and fingers to control, reminiscent of touch screen metaphors.
- Large hand gestures were performed on the larger parts of the armchair, such as the side.

- Hand gesturing preferred by participants in all scenarios except in the armchair manipulation control.
- Body gesturing perceived as more demanding and less accurate when compared to hand gesturing.
- Whenever body gesturing was required, it was mostly observed that users recur to elbows, upper back, calls and the back side of the foot.

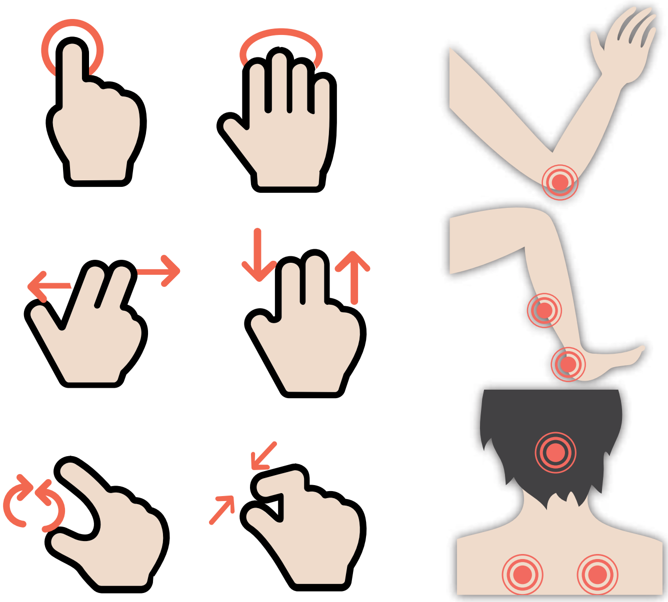

Figure 3.3: Left side: examples of the hand gestures performed by participants like tap, swipe, pinch and spread. Right side: highlight of the parts of the body preferred by participants when asked to perform body gestures.

3.5.2 Input Location

The following percentages regarding the participant interaction on the armchair regarding input location:

- The following percentages regarding the participant interaction on the armchair regarding input location:

- Hand-based control: top armrest 52%, outer side 30%, inner side armrest 10%, front armrest 4%.
- Body-based control: footrest 37%, top armrest 34%, headrest 11%, backrest 9%, inner side armrest 6%.
- Lower than 4% was disregarded in all cases.

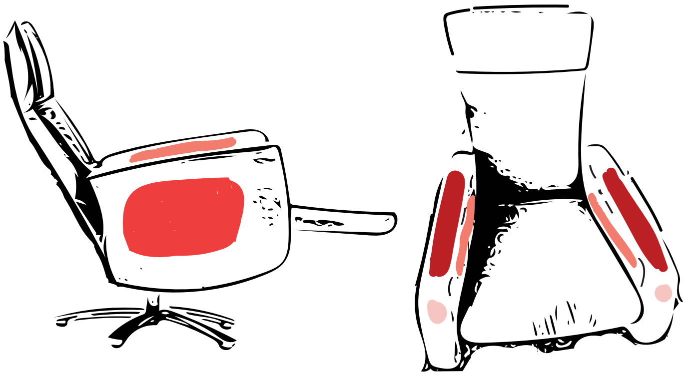

Figure 3.4: Hand input heat map: shades of red denote from more to less preferred input location by darker shades to lighter shades of red.

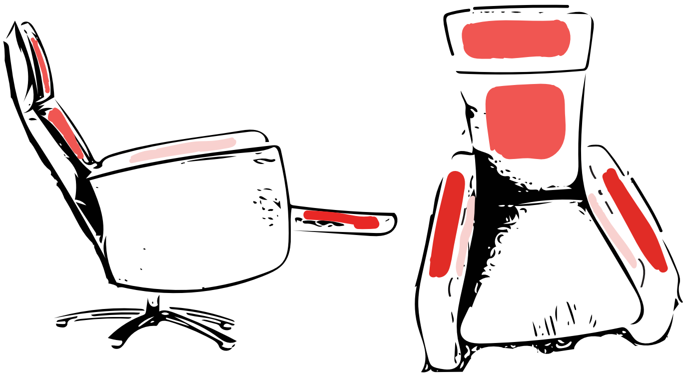

Figure 3.5: Body input heat map: shades of red denote from more to less preferred input location by darker shades to lighter shades of red.

3.5.3 Agreement Scores and Average Time

The data obtained regarding the gestures modality and location was analyzed with the Agreement Analysis Toolkit

(AGATe) as per Vatavu and Wobbrock [2015] and Vatavu and Wobbrock [2016] to obtain agreement scores with the following results:

Hand-based input considerably higher percentage in preference by the users.

- 70% preferred hand gesture over body gesture per referent
- 40% agreement on hand gestures that mapped to up/down or left/right motions such as: volume up, volume down, TV selection/channel next, TV selection/channel previous, dim light, bright light.
- 20% agreement in repeating same gestures for: volume, light dimming, channel toggle
- Overall 50% agreement rate of gestures above average in hand gestures whereas there is a 40% agreement rate in body gestures.

Regarding the time per gesture, two values were evaluated, gesture planning time and execution time, with the following observations:

Plan time took over twice as much for body-based gestures against hand-based, execution time was rather the same.

- Hand gesture plan time was in average 5.45 seconds, while the average for body gesture plan time was 12.65 seconds.
- Hand gesture execution time was in average 1.59 seconds, against a body-based gesture execution time of 1.83 seconds.

3.5.4 Qualitative Analysis

The qualitative analysis was performed after each gesture when the participants were asked to rate goodness of the gesture and easiness to perform it in a Likert scale form 1 to 5, considering 1 to be the less favorable score and 5 the best favorable score.

Likert Scales

- Hand gestures scored in average 4 in goodness(how good it matches the intended command) and 4.4 in easiness to perform.
- Body gestures scored in average 3.3 in goodness(how good it matches the intended command) and 3.2 in easiness to perform.
- When users were switched to a flatter position on the armchair, the goodness position diminished to 3.9 average for hand gestures and 2.7 average for body gestures.

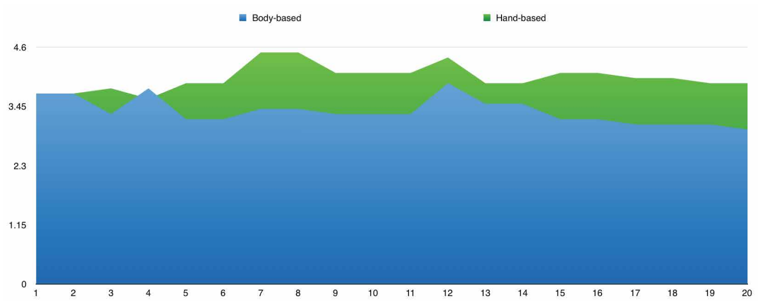

Figure 3.6: Likerts Scale 1 to 5 in Goodness of Gesture. Hand-based vs Body-based gestures referents 1 to 20.

Figure 3.7: Likerts Scale 1 to 5 in Easiness of Gesture. Hand-based vs Body-based gestures referents 1 to 20.

Subjective Responses
At the end of the study each participant was ask a set of questions regarding their overall experience with the chair and the proposed scenarios, obtaining positive feedback such as:

- ″I feel like it was more intuitive and makes sense.″
- ″Is easier and more comfortable to control from the chair.″
- ″I like the top of the armrest because is easy to reach, my hands are already there and I can manipulate it easily.″

3.6 Discussion

After observing the results of the elicitation study, we decided to focus on hand gesture control alone, discarding the use of other parts of the body. Considering this, we also chose to put our efforts in an input control that could work on the top of the armrest or the outer side of it, as those two are the best ranked positions by the participants. However such an implementation for a technical prototype would require to take in account that it should avoid accidental triggering and also that it could seamlessly adapt to a regular armchair. We also record that simple motion unistroke hand gesture would be preferred by the users as it provides a natural mental mapping as observe with the volume and channel toggle control.

From the results define: modality, position for input. Hypothesis about gestures and challenges

We defined from the elicitation study:

- Input mode for interaction with a smart armchair: hand input
- Positioning of sensors for input control on the chair: top of the armrest or outer side armrest
- Gesture guidelines: opt for motion hand gestures that can be mapped by the user

- Challenges: avoid accidental activation, easily adapt and integrate technology to an existent armchair

Once a deeper research on the gesture set and definition of the most suitable technology to do a technical implementation, a broader user study is performed.

Chapter 4

Design of an Interactive Armchair - Prototype

SUMMARY
To test our hypothesis obtained from the previous elicitation study there was a need to design and build the appropriate prototype that would work in the hypothesis conditions. One of the challenges was to define the technology to be used. We tested conductive thread in embroidery, capacitive sensors and fabric sensors, selecting the last one for the hardware part of the prototype. For the software side of it, an implementation of a gesture recognizer framework along with a Java coded routine was performed to complete our prototype.

4.1 Context

In order to get a better idea of user interaction with chairs to kick-off our research, a previous elicitation study was done, reported in the previous chapter. With the results we gathered information of where users are most comfortably interacting with the armchair: top of armrest, outer-upper side corner of the armchair and outer-middle side of the armchair; whether they preferred to use hand-gestures or body gestures: hand-gestures; which scenarios they imagine an armchair could be used as input control in a smart home: chair control and smartTV control; and a basic set of simple gestures to perform the tasks. With those results we worked on a prototype that would allow us to test usability and prove our hypothesis on user interaction with chairs.

Our intended overall goal is to prove the high potential of an interactive chair as an ubiquitous input device and give a sensible guideline for the input position, input mode/technique, input material features and technology as well as gesture design for interaction with chairs.

4.2 Choice of Technology and First Prototypes

One of our first prototype was built by using conductive thread and designing embroidery that would resemble buttons on the fabric, whenever the user would touch or make contact with the conductive thread it would trigger an action or a response on the connected microcontroller, in this case an Arduino, however we found this design to be highly prone to accidental activation.

First prototype: Conductive thread in-between embroidery with regular thread simulating buttons.

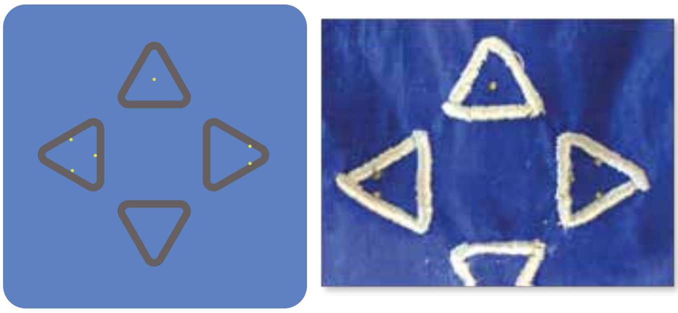

Figure 4.1: Left image: Design of embroidery buttons with knots of conductive thread in different positions. Left button has a knot on the middle of each side of the button shape, all 3 need to make contact with user, Top button has a knot of conductive thread in the middle of the shape, Right button has 2 knots near a corner of the shape, need to make contact with both to generate trigger. Right image: Actual implemented prototype with embroidery and conductive thread.

Our second prototype was built under the same button shape design embroidery but with the implementation of capacitive touch, by putting conductive material on the back side of the fabric and varying the resistance in the circuit so that only full contact with the hollow part of the button shape would generate a trigger. This attempt proved to be also highly prone to accidental activation.

Second prototype: embroider button with capacitive touch technology.

From the idea of the second prototype we decided to change from capacitive to resistive technology, where the hollow part of the button shape needed to be pressed with certain force to generate a trigger. Conductive material was placed right under each button and in a layer below, with a patch of piezo resistive fabric in between.

Figure 4.2: Implementation of prototype 3, a pressure sensor with the shape of triangular buttons embroidered in fabric.

The technology of the third prototype was better and easier to control with the microcontroller, Arduino Uno, it was also less prone to accidental activation, however interaction and gesture were limited to the design of the buttons and single presses. After consideration, we opted to follow this technology but make a more robust design, inspired by the work of Parzer et al. [2016] where flexible pressure input sensors called Flextiles were designed with two layers of zebra fabric and one layer of piezo resistive fabric. We applied the same technology as the Flextiles, but decided

Third prototype: embroider button with pressure touch technology.

to make with it a matrix to extend from a simple pressure sensor to a pressure input touch pad, allowing us to convert physical press inputs into x and y coordinates and then integrate an unistroke recognizer where these coordinates sets would be translated into gestures, the $1 Unistroke Recognizer by Wobbrock et al. [2007].

Fourth prototype: Resisitive pressure touch pad.

Figure 4.3: Implementation of prototype 4, a resistive pressure touch pad. Top image: layer involved, horizontal position zebra swatch, vertical positioned zebra swatch and piezo resistive fabric. Down left: front view of the pad setup, all layers at view. Down right: top view of the setup.

Arduino Uno and 3 swatches of conductive fabric, two swatches of 6”x6” Zebra fabric and one swatch of 6”x6” piezo resistive fabric.

The fourth prototype was more functional as the 8x8 matrix arrangement of the conductive zebra fabric and the Eeontex resistive fabric in conjunction with an Arduino Uno gave us a full working pressure touchpad. And with the integration of the unistroke recognizer we could limit the response on the microcontroller to given gestures, hence avoiding accidental triggers as the controller would only respond to predefined gestures. A simple Java application made in Processing was used to test our the touchpad and the $1 Unistroke Recognizer Wobbrock et al. [2007] integration with the following gestures: swipe, circle, rectangle and triangle.

Figure 4.4: Left image of an Arduino Uno, it was used to read the lines of the 8x8 matrix of conductive lines in the Zebra fabric. Right: Processing interface and GUI of test app developed that included the $1 Dollar recognizer and detect gestures, on the image a triangle was detected and draw on the GUI.

4.3 Implementation of Final Prototype

4.3.1 Hardware

After the idea of attempt four resulted successful, we adapted it so that if would comply with the testing scenarios for the user study to be performed afterwards. A non stretchable zebra fabric with thiner conductive and non-conductive lines was picked over the original 6”x6” stretchable Zebra swatches, this decision was taken as we required more lines and better accuracy, so less space between conductive lines was preferred and it was also observed that the stretchable property of the prior fabric kept on folding generating wrinkles that could generate noise on the gesture recognizer. The whole matrix patch was expanded from 8x8 to a 25x17 matrix equivalent to 32cm long by 17 cm wide, to allow for an elongated input that could allow the participants or users to have a broader interaction area. The Arduino Uno was interchanged for a Texas Instruments EK-TM4C1294XL microcontroller to permit the extended use of ports by the expanded conductive fabric matrix.

EK-TM4C1294XL and 3 layers of conductive fabric, 2 swatches Zebra non-stretch fabric (10”x7” and 12”x7”) and 2 swatches of 6”x6” piezo resistive fabric

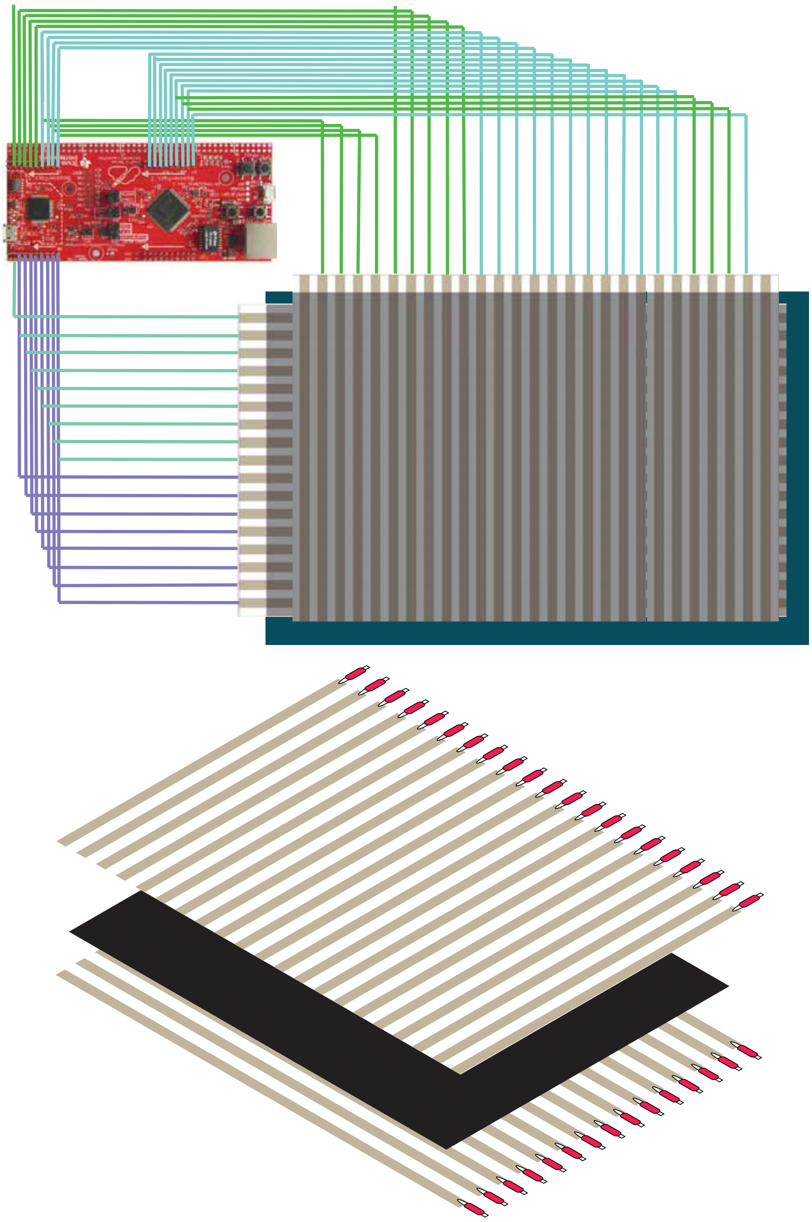

Figure 4.5: Sketch of final prototype implementation. Top: We can observe the matrix formation of the two zebra conductive fabrics, 25 vertical lines by 17 horizontal lines. Between the two zebra fabrics there is are two side by black piezo resistive material. Each of the zebra conductive lines is connected to a pin port of the Texas microcontroller.Bottom: We can observe the layers of Zebra conductive fabric and piezo resistive fabric and how they are placed.

4.3.2 Software

Microcontroller Routine
Based on the Arduino Uno routine used in the fourth prototype, we expanded the routine to read and test in a loop each of the 25 by 17 pin ports where the lines of the conductive zebra fabric where connected and detect which of the lines had contact. The pin ports were enumerated and saved in an array, each pin is initialized as an output and in low mode. In the constant running loop each pin in the array is read to see if a contact with the line has been made and the value is represented as 0 no touch, 1 touch, which is printed by the serial in a linear string, each lecture separated by ":". This printed value is the one read by the Java gesture detection application.

25x17 matrix, per pin 0 no touch, 1 touch detected.

```
  Serial.begin(9600);
  Serial.println("Start...");

  for(int i=0; i < 42; i++){
    pinMode(array[i], OUTPUT);
    digitalWrite(array[i], LOW);
  }

}

void loop() {

  for (int i=0; i < 42; 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);
  }
  Serial.print(":");
  delay(200);

}
```

```
Done uploading.
        Setting PC to entry point.: 73%
Running...
Success
```

Figure 4.6: Screen of the Energia IDE with the microcontroller's routine. On screen we can see the loop where every pin is tested and we also see the window where on the serial port the tested pin values are being printed, a set of total 42 characters: 25 for the vertical lines and 17 for the horizontal are printed each lecture.

Gesture Recognizer Application
A Java based application in Processing was developed to

1$ recognizer with 8 unistroke gestures.

recognize a set of eight defined gestures based on our research. The set of 8 gestures were selected, considering the results obtained from the elicitation study and taking Vo et al. [2014], Surale et al. [2017], Bragdon et al. [2011] as references, and added to the recognizer template: swipe up, swipe down, swipe left, swipe right, circle, "x", "z" and left bracket. All this gestures can be performed in a unistroke and our $1 recognizer implementation was set to 60% similarity recognition percentage pattern. We also implemented in the application methods to detect gesture orientation, gesture size, starting and finishing points.

Figure 4.7: Screen of the $1 Dollar recognizer methods implementation. We observe 1. the creation of a oneDollar class instance. 2. template of the gesture to be learned and added. 3. bind the template to the detected method. 4. implement the callbacks.

This version of the prototype was selected to perform a preliminary study where the participant interaction was recorded by the application giving us valuable information. This preliminary study will be discussed in depth in the next chapter.

4.3.3 Enhancements and Final Release

Once the preliminary study was performed and the results analyzed, we took notes on how we could improve the prototype, so that we could also place it directly on an arm-

Detected gesture: swipe

Orientation: E

Max Distance X: 2.236068

Max Distance Y: 2.236068

Figure 4.8: Screen of the Gesture Recognizer App working. We observe the detection of a gesture and how the user's finger is draw following the motion of the gesture. The app prints the detected gesture, the orientation and the x and y axis length the gesture followed.

chair. To allow for better mobility, the standard connection of the microcontroller to the computer USB port had to be changed for a wireless approach, a Bluetooth module was added to the circuit and a lightweight 5V output power bank was chosen to power whole device.

Enhance it by making it wireless:include Bluetooth and power bank

Figure 4.9: Left: picture of the Bluetooth module connected to the microcontroller. Right: backside picture of the power bank we used for our prototype, technical specifications are visible.

On the software side, and for testing purposes, we decided to print the results of the gesture detection only on the terminal allowing the GUI to focus on the test application for the user study. This gives full interaction with the prototype to the user while using only one computer. The test part of the application is all in a class of it's own, and focuses mainly on the study scenarios and user interaction, the gesture recognition remains in the main of the program and works independently form the test class. As for the microcontroller routine, a change of initialization in the serial port was done so that it would send the data via Bluetooth instead of cable. The same was done on the Java program as to read the Bluetooth port instead of the serial port.

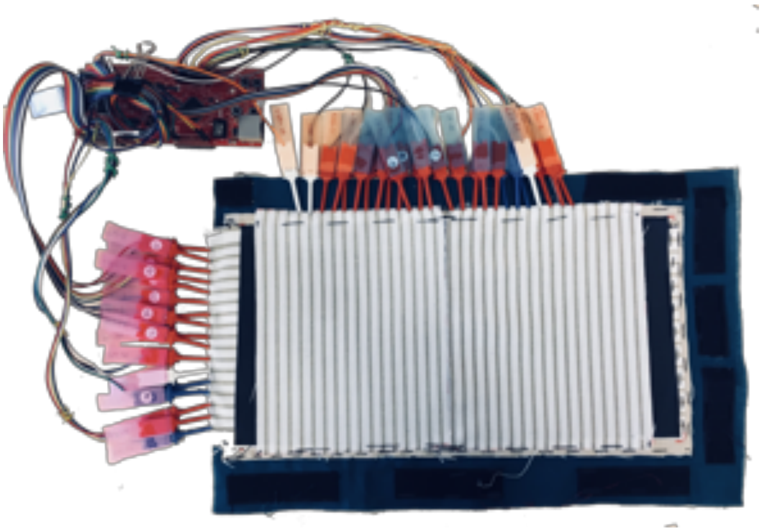

Figure 4.10: Top view of the final prototype implementation. We can observe the matrix formation of the two zebra conductive fabrics, 25 vertical lines by 17 horizontal lines. Between the two zebra fabrics there is are two side by side piezo resistive fabrics. The zebra conductive lines are connected to the Texas microcontroller. Each line is tagged with the position on the zebra fabric and the corresponding port on the microcontroller.

This final prototype was mobile and lightweight so that it could be placed and fixed on the armchair by the use of velcro. It can be placed both in the top part of the armrest as well as on the outer side of the armrest.

Chapter 5

Preliminary User Study

SUMMARY
Once the implementation of the final prototype was tested and the gesture recognizer application developed. A preliminary study was performed to evaluate interaction with an armchair.

Base testing scenario: place the prototype on a plank which has two stiffness of surface one with foam, one without a foam, vary the texture of fabric on top of the prototype and position the plank horizontally in front of the user and then vertically on the side of the chair. Vary this variables and have the user perform 8 different gestures.

This study was intended to allow us to test the positions on the chair from the elicitation study. Also to observe the performance of the suggested gesture set and how accurate a task is performed by measuring the recognition of each gesture by the software. Additionally to be able to gather which variables such as the stiffness of underlying surface on the armchair and the texture of the fabric of the armchair performs better in execution time and accuracy rate in an attempt to create different conditions that resemble actual armchair features and to observe the effect of each on the user interaction. The objective is to allow us to see whether all independent variables do have an impact and if so how much of an impact.

5.1 Aim

Determine the variables (texture of fabric, stiffness of underlying surface, position on chair) that affect users' performance (input accuracy & execution time), and their perceived preference when gesturing on an upholstered armchair.

5.2 Variables

In this section we recall the set of variables that were defined for the preliminary user study.

5.2.1 Independent Variables

The independent variables defined for the preliminary study:

- Texture of Fabric: 5 levels: 1 baseline: {Silk}; 4 main: {Blackout fabric, Linen, Canvas cotton, Leather} based on Hamdan et al. [2016a]
- Position on chair: 2 levels: Input location {top of table - horizontal; outer side of chair - vertical}. Based on the results of Elicitation Study section 3.5
- Stiffness of underlying surface: 2 levels: Surface {Foam, No Foam} based on Heller et al. [2014]
- Gestures: 8 total. 4 Simple gestures {swipe up, swipe down, swipe right, swipe left}, 4 Free form gestures {left square bracket, "X", circle, "Z"} based on Vo et al. [2014], Surale et al. [2017], Bragdon et al. [2011]

5 fabrics, 2 position, 2 surfaces, 8 gestures.

Figure 5.1: View of the 5 fabric texture samples used in the preliminary study. Botton left to top right view in the following order: white silk, red blackout fabric, blue linen, purple canvas cotton and black leather.

5.2.2 Dependent Variables

The dependent variables defined for the preliminary study:

- Execution time: how much time does it takes a participant to complete a task from when the floor push button is pressed to change the app gesture to when it is pressed again measured in milliseconds.
- Accuracy: how well did the participants performed the tasks.
  - Input accuracy measured from 0% to 100% according recognition match rate of the software vs the gestures presented during the study, e.g. gesture presented: ”X” and gesture recognized ”X” gives a 100% match rate.
- Orientation: spatial orientation of the performed gesture (nort, south, west, east).
- Size: how much space (wide) took for the gesture to be performed (matrix points).
- Task difficulty level perceived by the participant (Easiness - Scale 1 to 7).

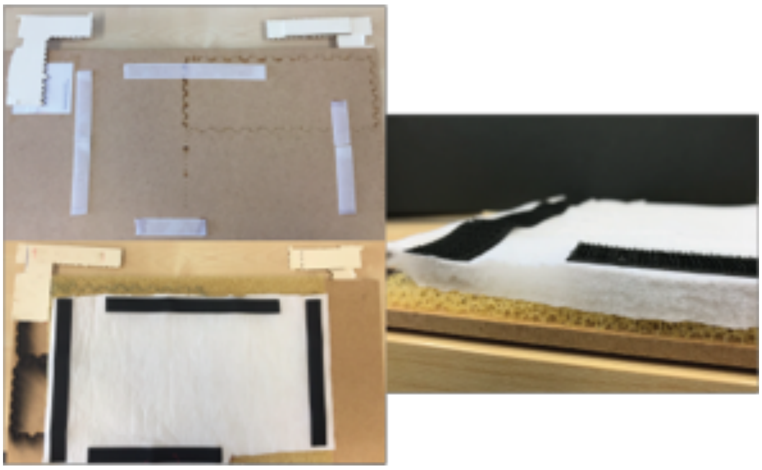

Figure 5.2: Implementation of stiffness of underlying surface variable. Top left: no foam surface (4 mm wood plank). Bottom left: foam surface (mixture of dry fast foam and compressed polyester). Right: side image of foam surface: Here we have a better view of the material conforming this surface, first a layer of 3 mm of dry fast foam followed on top by a 10mm layer of compressed polyester.

- Physical comfort while performing the task (Likert Scale 1 to 7).
- Effect of independent variables(position on chair, texture of fabric and stiffness of underlying material) on accuracy while performing the task (Likert Scale 1 to 7).

5.3 Setup and Apparatus

We asked the participants to take a seat on a standard office chair while a laptop was placed on a table directly in front on their eye point of view and the floor push button placed in front of the right or left foot according to the participant preference. A plank of wood containing on each side a variation of the stiffness of underlying surface was used to place our prototype. The prototype was initially placed on horizontal position in front of the participant.

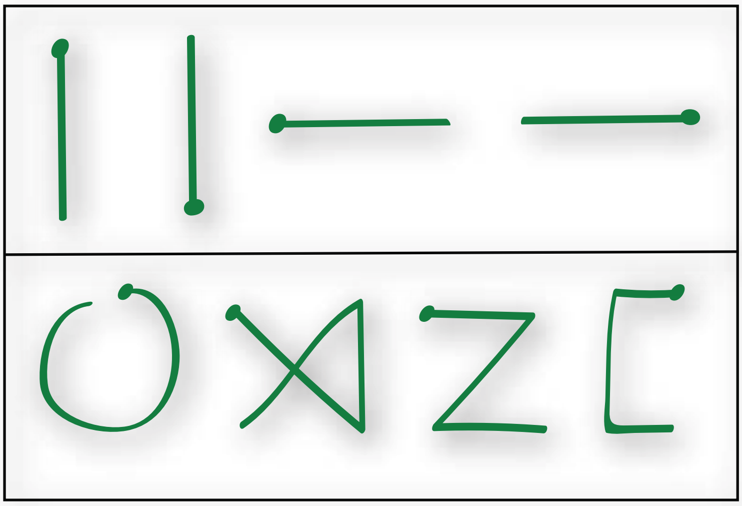

Figure 5.3: Sample of the gestures that were used in the preliminary study. Top left to right: swipe down, swipe up, swipe right, swipe left. Bottom left to right: clockwise circle, unistroke X, unistroke Z, left side bracket. *Dots denote where the gesture begins.

Hardware

The designed prototype 4.3.1, a floor plush button connected to a Makey Makey, a plank of wood with no foam and foam stiffness, 2 laptops and a desk chair.

Hardware Setup

Our prototype 4.3.1 of conductive and piezo resistive material placed on the plank of wood and connected to the laptop that presented the testing application 4.3.2 connected to a Makey Makey and a big push button placed on the floor in front of the participant foot, a second laptop for the researcher to overlook the microcontroller and gesture recognizer process 4.3.2 .

Software

The testing App (Processing app connected to the Makey

Makey) designed to present the participants with the tasks (gestures to be performed). A gesture recognizer software: Processing application that uses the $1 Unistroke Recognizer Wobbrock et al. [2007] to detect the whole set of gestures. All gestures′ data is tracked and saved for future analysis.

Figure 5.4: Picture of a participant while performing the preliminary study. The full setup of the study is visible as well as the hardware that was used.

5.4 Research Questions

- Which of the positions on chair used as input performs better? Which one was preferred by the participants?

- Which of the stiffness of underlying surface where the patch was placed performs better? Which one was preferred by the participants?
- Which of the textures of fabric used to build the patch performs better? Which one was preferred by the participants?
- Which complete set(texture of fabric + position on chair + stiffness of underlying surface) makes the ideal input scenario?
- Which gesture from our proposed set are performed faster and accurately? Which one are more prone to error or non-recognized by the software?
- When the position is varied, does the user changes his or her mapping of the gesture? Which direction?
- Does any of the factors: texture of fabric, stiffness of underlying surface, position on chair, gesture presents a particular challenge to the participant when performing?
- How was the recognition rate of the gestures by the software?

Evaluate on chair position, texture of fabric, stiffness of underlying surface and users' preference.

5.5 Study Tasks

The experimenter is in a room with the participant. The performance of the participant interacting with the touch pad data is recorded by the designed software gesture recognizer application, previously described in this chapter. The execution of a gesture corresponds to a task.

1. The experimenter presents the study setup and test application to the participant. The startup setup is with the hard surface, silk fabric and horizontal position. The app is presented to the participant on the computer screen as well as the input button on the floor to control the app sequence.

2. Once the participant is familiar with the setup and the application basic control, he or she is asked to do a training phase. In this phase the application works as it will during the study, however no log of the user gesture is performed.

3. When the participant feels confident performing the gestures, the participant signals the experimenter so part 1, baseline, of the study begins.

4. For part 1 three of the independent variables remain static, texture of fabric, position and stiffness of underlying surface, the gestures are presented in a previously randomized sequence, the sequence containing all eight gestures needs to be repeated by the participant 4 times.

Users repeat each gesture 4 times per each iteration of the other independent variables(texture of fabric × stiffness of surface × position)

5. After part 1 is completed, the application shows on screen the start of part 2. In part 2 of the study, the independent variables that were static in part 1 will now became active, stiffness of underlying surface, position and texture of fabric which corresponds to the setting scenarios for our touch pad will be varied by the application and set on screen so the experimenter can set the input touch patch accordingly. The patch will be connected to another computer where it will record the data recognition of the gestures performed by the participant.

6. The test application has a list of the eight gestures, which is updated and varied each change of the other independent variables, the sequence per combination of variables is to be repeated 4 times.

7. To signal the completion of one task the participant will step on the floor-button and the next task/gesture is presented. This step is repeated until all the gestures of one set if performed.

8. Once the repetition of the set of gestures is completed the app updates the position variable and another full set of gestures is presented and should be completed according to the last two steps.

9. When both positions are tested, the application will signal a change of texture of fabric and the last three

steps are performed once more.

10. Once all fabrics are tested a change of stiffness of underlying surface is required and the full round considering the last four steps is performed. This will be done until the set of gestures is tested on the four textures of fabrics, considering all positions and the two levels of stiffness of underlying surface.

At the end of the study, participants filled a questionnaire regarding subjective preferences to the texture of the fabric, the position and stiffness of underlying surface, as well as their perception of the fabric haptic touch and feel.

5.6 Experimental Design

The order of the position on chair, texture of fabric, stiffness of underlying surface and gestures will be varied between participants. For each position participants will perform the complete set of gestures, then switch position and update a new order of the set of gestures, both position tested, the fabric is changed, where a position and updated set of gestures occur, when all fabrics are done, the stiffness of underlying surface variable is switched and the other variables tested with it, until all combinations are tested.

544 trials per participant, 5 participants in study, total final samples = 2720

In general, the design of the experiment is as follows per participant:

- Baseline = 1 position × 1 fabric texture × 1 stiffness of surface × 8 gestures × 4 repetitions = 32 trials.
- Main = 2 positions × 4 fabric textures × 2 stiffness of surface × 8 gestures × 4 repetitions = 512 trials.
- Total = 32 baseline + 512 main = 544 trials.

5.7 Participants

For the preliminary study we recruited 5 participants aged between 20 and 30 years old(3 males, two females). None had previous experience with smart furniture nor smart textiles. We took note on the dominant hand, one left handed, all others right handed.

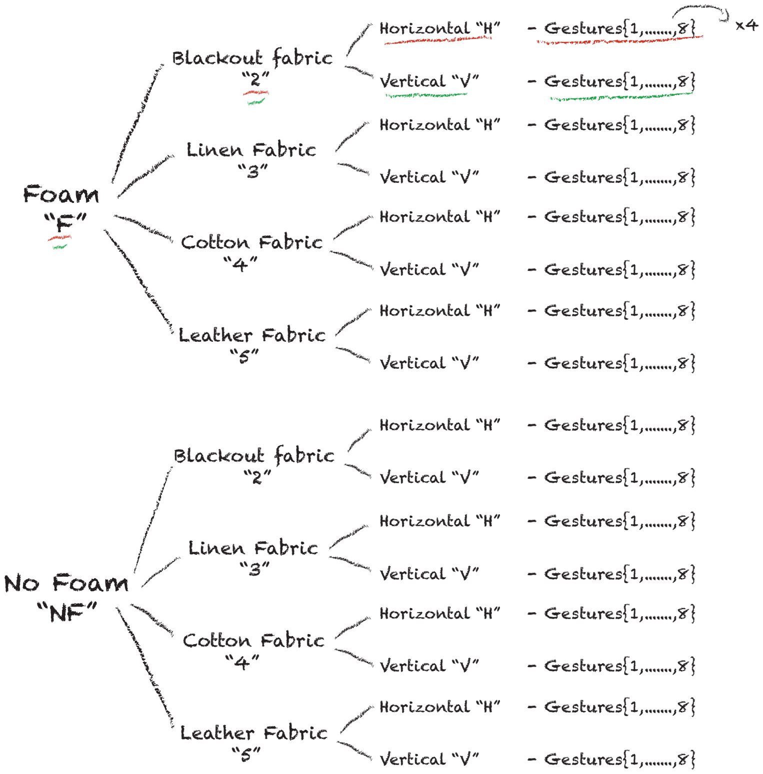

Figure 5.5: Diagram of the experimental design. The test application follows this design, once a full branch is tested, it moves to the next, and the values within levels are randomized between users. As an example the red underlines what would be a full round, once it is done, the ones underlined by green would follow, and so forth.

5.8 Results

5.8.1 Quantitative Results

Execution time

We found a significant effect of all the independent variables (TEXTURE OF FABRIC, POSITION ON CHAIR AND STIFFNESS OF UNDERLYING SURFACE)on the *execution time*, when evaluated each on an individual level using ANOVA the results were all of P<0.05. Individually this were our findings: in TEXTURE OF FABRIC the mean *execution time* =2982.37ms and stdev=1547ms, post hoc shows Silk texture had a significant impact with over 1000ms over the mean of the group, in POSITION ON CHAIR the mean *execution time* =2793.76ms and stdev=1584ms, post hoc vertical position had more impact with around 500ms more than horizontal position and in STIFFNESS OF UNDERLYING MATERIAL the mean *execution time* =2774.3ms and stdev=1597ms, post hoc no foam was 200ms slower than execution with foam.

Significant effect on execution time: texture of fabric, position and stiffness of underlying surface.

Input Accuracy

We found no significant effect on TEXTURE OF FABRIC and STIFFNESS OF UNDERLYING SURFACE on *input accuracy* when evaluated on ANOVA the results were both of P>0.05. On the other hand we found that POSITION ON CHAIR had a significant effect with P<0.05. A closer look into the results show us that the POSITION ON CHAIR the mean *accuracy* =43.8% and stdev=48%, from which post hoc revealed that group element with most effect was vertical position with lower accuracy rate over 11% lower than the accuracy rate on horizontal position.

Significant effect on accuracy: position

Orientation

Of the 5 participants, 3 maintained the same orientation of North, East, West, South when performing the gestures both when the input was placed on horizontal and vertical position. The other 2 participants even though they had the same orientation model on horizontal position, they had difficulties when it came to the vertical one, this was mainly reflected in the execution time per gesture, as each time they had to perform on vertical it took them time to make their mind which orientation they wanted to follow.

Size of Gesture
The size of a gesture was measured by the number of matrix points it consisted of, when a gesture was performed on the touch pad, the set of point of x and y in the matrix were stored in an arrays and send to a method which detected starting and ending points. When analyzing the size of the gestures performed by the participants, we found the following results:

- Distance in X: average 11.53 points, median 12 points.
- Distance in Y: average 8.6 points, median 9 points.

In the X direction 25 lines of points were available, so the 11.53 points represents a 46% of use, while in the Y direction 17 lines or points were available, where the 8.6 points represents a 56% of available spaced used.

5.8.2 Qualitative Results

Likert Scale is a point scale used to allow the participant to express how much they agree or disagree with a particular statement.

As mentioned before, after completing all the tasks, the participants were handed a questionnaire which allowed them to address their experience and preference regarding the variables they were exposed to during the tasks. To address their subjective response they were asked to rank the variables in three aspects in a Likert scale from 1 to 7, they were also asked to select the fabric hand referent by Winakor et al. [1980] which better suited their tactile sensory experience when performing a task on a particular fabric.

Likert Scales
We asked them to rank in a Likert scale of 1 to 7 the effect of fabric, position and surface in physical comfort, easiness to use and accuracy. The following are the results obtained.

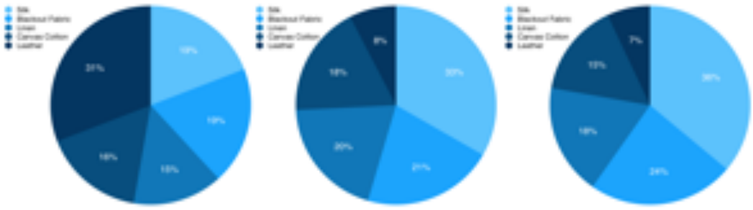

Figure 5.6: From left to right: Scale 1 very uncomfortable, 7 very comfortable .Leather fabric was considered the most comfortable while Linen and Canvas Cotton fabrics were the least comfortables.Scale 1 very easy, 7 very difficult. Leather was the fabric participants felt they could perform the gestures with easiness and Silk the one where it was the most difficult.Scale 1 no effect, 7 high effect. Participants felt Leather had no effect on them performing the gestures while Silk and Blackout fabric did have an effect in their accuracy.

Figure 5.7: From left to right: Scale 1 very uncomfortable, 7 very comfortable. Horizontal position was consider in high percentage more comfortable than the vertical position. Scale 1 very easy, 7 very difficult. Vertical was considered more difficult to perform a task on by more than triple the percentage of the horizontal position. Scale 1 no effect, 7 high effect. Participants felt the vertical position had a huge effect on their performance of a task, while almost no effect on horizontal position.

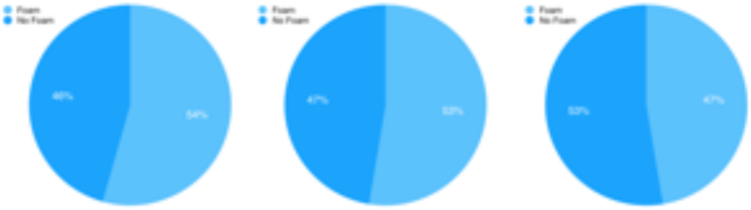

Figure 5.8: From left to right: Scale 1 very uncomfortable, 7 very comfortable. Participants favored slightly more the foam over the no foam surface. Scale 1 very easy, 7 very difficult. Participants considered it was easier to perform the gestures on no foam, however the difference in percentage is very small with the foam surface. Scale 1 no effect, 7 high effect. The effect on their accuracy was less with foam although difference with the other surface is almost no considerable.

Hand-of-Fabric

The users were also asked to select the referent of the hand of fabric Winakor et al. [1980] which better suited each of the fabrics according to their sensory experience, giving us the following results:

The hand of fabric refers to the “feel” of the fabric against your skin.

- Fabric 1: Smooth, Flexible, Thin, Fine, Sleazy, Soft, Light, Silky, Limp (Completely for all)
- Fabric 2: Smooth, Flexible, Thin, Fine, Sleazy, Soft, Light, Silky, Limp
- Fabric 3: Medium Smooth, Flexible, Thin, Semi-coarse, Semi-firm, Between soft & hard, Semi-light, Between silky & scratchy, Semi-limp
- Fabric 4: Semi-Rough, Between flexible & stiff, Between thin & thick, semi-coarse, semi-firm, hard, between light & heavy, semi-scratchy, between limp & crisp
- Fabric 5: semi-rough, semi-stiff, semi-thick, between fine & coarse, firm, hard, heavy, scratchy, semi-limp
- Fabric 6: rough, semi-stiff, thick, coarse, firm, hard, heavy, scratchy, crisp

5.8.3 Discussion

After observing the quantitative and qualitative data analysis performed on our results, we concluded that two of the independent variables (position on chair and texture of fabric) were worth continue looking into and evaluating the upcoming results, however the impact of the stiffness of underlying surface on the gestures performed, as the numbers proved it non-significant in success rate and backed up by the subjective responses of our participants they did not perceive any difference on comfortability, easiness and effect on performance, also taking into consideration that there is a pre-existing stiffness of underlying surface equivalent to the foam scenario, we decided to remove this variable for our main user study. For the texture of fabric, we also decided to remove one of the in-group variables, the silk fabric, as it was the least preferred by users, it also gave the the biggest execution time, and on a realistic environment, is not a fabric used in furniture, nor armchairs.

Chapter 6

Main User Study

SUMMARY
After analyzing the results of the preliminary user study, we decided to focus on the variables that remained intriguing for the purpose of our research. Then we proceeded to test the usability and viability of our prototype on an average armchair.

Armchair scenario: place the prototype on top of the armrest and outer side of the armrest as per the results of the elicitation study, user performs the set of 8 gestures in these positions while alternating the fabrics.

We expanded the population of the main user study to test out the observation done in the preliminary study. With a focus idea on what to look for. From data obtained on the performance of the participants we analyze and evaluate to see the impact of our proposed independent variables on our measured dependent variables. The results are portrait with the help of tables and charts.

6.1 Objective and Intended Use of Study Findings

The study results will feed our research in making a sensible guideline for a smart chair. The variables tested so far has given us details in term of : stiffness of underly-

Evaluate variables and usability of prototype. Objective: define guideline for smart chair.

ing surface, position on chair, texture of fabric, technology, gestures. We expect that the final results of a more focused study with a bigger population can give us definitive data with which we can evaluate the impact of each one of the independent variables, as well as which combinations of the aforementioned variables, hold on the interaction and usability of the input method we proposed to be used on the chair. Our intended overall goal is to prove the high potential of an interactive chair as an ubiquitous input device.

6.2 Variables

According to the findings of the preliminary study, we removed the stiffness of surface variable as it did not hold any significant impact in our findings, we also reduced our samples of textures of fabric, the one discarded had a negative score both in accuracy and user perceived rating, while it is also highly unlikely that such a fabric, silk, would be used in a standard home armchair. In general the independent variables and dependent variables implicated in our study are:

6.2.1 Independent Variables

IVs:4 fabrics, 2 positions, 8 gestures

- Texture of Fabric: 4 levels: 1 baseline: {Blackout fabric}; 4 main: {Linen, Canvas cotton, Leather}
- Position on chair: 2 levels: Input location {top of armrest - horizontal; outer side of armrest dominant hand - vertical}
- Gestures: 8 total. 4 Simple gestures {swipe up, swipe down, swipe right, swipe left}, 4 Free form gestures {circle, "X", "Z", left square bracket} all presented indifferently in the same set.

Figure 6.1: Top view of the 5 patch of texture of fabrics that were used for the user study. From left to right: Blackout fabric (red), Linen (blue), Canvas cotton (purple), Leather (black).

6.2.2 Dependent Variables

- Execution time: how much time does it takes a participant to complete a task from when the floor push button is pressed to change the app gesture to when it is pressed again measured in milliseconds.
- Accuracy: how well did the participants performed the tasks.
  - Input accuracy measured from 0% to 100% according recognition match rate of the software vs the gestures presented during the study, e.g. gesture presented: ”X” and gesture recognized ”X” gives a 100% match rate.
- Orientation: spatial orientation of the performed gesture (nort, south, west, east)
- Size: how much space (wide) took for the gesture to be performed (matrix points)
- Task difficulty level perceived by the participant (Easiness - Likert Scale 1 to 7)
- Physical comfort while performing the task (Likert Scale 1 to 7)
- Effect of independent variables on accuracy while performing the task (Likert Scale 1 to 7)

6.3 Study Setup

For the study environment we placed the reference armchair with a small table in front where the computer with the test and recognizer application was set. By the footrest of the armchair the push button is located so that the participant can easily reach it. The prototype input patch is placed on the armrest of the dominant hand of the participant, the patch is to switch position according to the testing phase of the application. The cover of the patch is to be interchanged according to the test setting of the application.

Make realistic scenario, place prototype input touch pad on demo armchair.

The participant was asked to sit on the reference armchair. He or she was asked to press on the push button to control the application while performing the task displayed on the screen of the computer.

Figure 6.2: Sketch of the study setup for the user study.

6.4 Research Questions

The scope of this study was centered on the final prototype we designed while being placed on an armchair the we used as reference since our preliminary study. Regarding this testing environment and the previous results obtained from the preliminary study, the research questions were formulated as follows:

- What is the mental model and spatial orientation a user creates when he or she is performing a gesture on top of the armrest and the outer side of the armrest? Is it the same in both positions? One for each?

- Other than the spatial model, does the position has influence in execution time or input accuracy rate while performing a task? Is it more about the user comfortability and reach capability when it comes to interaction?

- Does the texture of fabric used in the input patch has a significant effect on the time and accuracy with which the gestures are performed? If not, does the preference of one fabric over another has to do with user perception and personal taste?

- Of the set of gestures performed, does all gestures hold a similar rate of accuracy and execution time? Were there some considerable difference in performance of a particular gesture?

- When evaluating the overall performance of the users, which variables have a more considerable impact? If an effect was noted does is it caused by a variable independent form the other or is there a correlation of more variables that needs to be considered?

6.5 Study Tasks

The study consisted on the two following parts:

- The fist part was a baseline test scenario, here the variables remained static while a full set of the 8 gestures was presented four times. The blackout fabric was selected to be the static texture factor.

- For the second part, each of the variables(texture of fabric and position on chair) is changed in a dynamic matter so that the user experiences all the combinations possible and performs a set of gestures with four repetitions per each combination.

Users repeat each gesture 4 times per each iteration of the other variables(texture of fabric × position on chair)

The task to be executed by the participant in both parts is the same, the participant must press the push button to request the application in the computer to present a gesture of the set, the participant then must do this gesture on the input patch, afterwards he or she presses the push button again to request the next gesture in the set and so on until all repetitions are done. After a set of repetitions is completed a variable is updated so that a new combination of factors is tried, a full set of gestures then is performed until all combinations of the variables are tested. Each time a variable is updated the gesture set order is changed.

Figure 6.3: Images of the user study. On the top right we observe the setup with the input patch prototype located on top of the armrest. On the bottom left we see a user performing a task while the input patch is located on the outside part of the armrest.

6.6 Experimental Design

In general, the design of the experiment is as follows per participant:

- Baseline = 1 position × 1 texture of fabric × 8 gestures

× 4 repetitions = 32 trials.

- Main= 2 positions × 3 textures of fabrics × 8 gestures × 4 repetitions = 192 trials.
- Total = 32 baseline + 192 main = 224 trials.

6.7 Study Population

A total of 13 users (10 males and 3 females) participated in the user study. The age range of the participants was between 23 and 29 years old. None of this participants were present or involved in the previous preliminary study to discard the possibility of a learning curve that could affect the results of this study. Each participant was given an identification number, their identity remained anonymous, all material where data was collected was marked only with the ID number.

224 trials per participant, 13 participants in study, total final samples = 2912

6.8 Data Collection

To collect the data, the application which included both the test settings and the gesture recognizer, did four log documents of each participant session. Of the four logs, two have the records display the data in a user read format, while the other two have the same data in a raw format separated by pipes to be read by scripts to collect the relevant information and analyze it in tables. One log records the task presented to the participant with all the variables presented at the moment task, as well as a timestamp of the time when the participant started such task. The second log records the output data of the $1 dollar recognizer implementation in the application, detected gesture, as well as other significant values programed in the application as size, direction and a timestamp, to match with the timestamp of the test app records.

4 logs total, 2 logs in gesture recognizer, 2 in test app setting. Of each pair, 1 raw data, 1 read format data.

Additionally, a questionnaire was presented to each participant, in it we gathered information regarding the demographics of the participants as well as qualitative information about their experience in the user study, each participant was asked to rank in a likert scale of 1 to 7 the tasks regarding comfortability, easiness and effect in accuracy regarding each of the independent variables.

Figure 6.4: Example of a sequence of gestures presented in the test application. From top left to bottom right the sequence is as follows: "X", swipe down, left bracket, swipe up, circle, "Z", swipe right and swipe left. Each of this sequences is to be repeated 4 times and the sequences changes each time another independent variable [stiffness of underlying surface, position on chair, texture of fabric] is updated.

6.9 Results

The acquired data from the participants while using the test application was analyzed in a quantitative and qualitative manner.

6.9.1 Quantitative

Execution time
We analyzed the data to see which of the level of each independent variable has a considerable impact in the execution time. We found that the POSITION ON CHAIR at margin of significant effect on the *execution time* with P=0.059.

Whereas the TEXTURE OF FABRIC presented a significant effect with $P<0.05$, with a deeper look on the results we have that the TEXTURE OF FABRIC mean = 2809.72ms with a stdev=1474ms, from which the blackout fabric was the one with the biggest *execution time* mean.

one-way ANOVA lets us determine whether the difference in means are statistically significant or not.

We also performed a 2-way ANOVA to evaluate simultaneously the effect of two grouping variables on the *execution time*, the pair of variables tested were as follows:TEXTURE OF FABRIC and POSITION ON CHAIR, TEXTURE OF FABRIC and gesture, POSITION ON CHAIR and gesture, in this case we also considered the gestures to evaluate if any effect was present independently or in group with another variable, the result of gesture alone was considered non-relevant for our current scope as we are not aiming to define a gesture set yet. Of the pair TEXTURE OF FABRIC and POSITION ON CHAIR, we observed that POSITION ON CHAIR had no significant effect while TEXTURE OF FABRIC had significant effect and the interaction with one another is non-significant with $P>0.05$, from there we proceeded with the pair TEXTURE OF FABRIC and gesture, here we observed that both variables have a statistical significant effect and with $P>0.05$ non-significant interaction effect, lastly we reviewed POSITION ON CHAIR and gesture pair, in this results we saw that the position had no significant effect while the gesture did and the interaction between the two is at the margin of $P=0.05$ with $P=0.07$ there might be slight effect of gesture over position.

Position on chair: margin of significance, texture of fabric: significant effect.

Input Accuracy

We analyzed the data to see which of the levels of each independent variable has a considerable impact in the input accuracy of the tasks. We found that neither POSITION ON CHAIR nor TEXTURE OF FABRIC had a significant effect on the *input accuracy* with $P>0.05$. We decided to then observe the performance of gesture with a result of $P<0.05$ which means that the gesture set did have an effect on *input accuracy*. The mean of gesture accuracy is 57% where the set of simple gestures (swipes) has an average of 80% accuracy while the complex gestures had 34% accuracy.

We also performed a 2-way ANOVA to evaluate simultaneously the effect of two grouping variables on the *input accu-*

racy, the pair of variables tested were as follows:TEXTURE OF FABRIC and POSITION ON CHAIR, TEXTURE OF FABRIC and gesture, POSITION ON CHAIR and gesture, as mentioned before and considering the individual result on *accuracy* we also considered the gestures to evaluate if any effect was present independently or in group with another variable, the result of gesture alone was considered non-relevant for our current scope as we are not aiming to define a gesture set yet. Of the first pair and consistent with our results above POSITION ON CHAIR and TEXTURE OF FABRIC had no significant effect and the interaction with one another was also non-significant with P>0.05, from there we proceeded with the pair TEXTURE OF FABRIC and gesture, here we observed that both only gesture has a statistical significant effect and with P=0.03 a significant interaction where the relationship between *accuracy* and TEXTURE OF FABRIC depends on the gesture, lastly we reviewed the POSITION ON CHAIR and gesture pair, in this results we saw that the position had no significant effect while the gesture did and the interaction between the two is at P=0.22 is no significant at all.

Only gesture set variable presented significant effect.

Orientation

We evaluated the mental orientation the participants had while performing the gestures, we illustrate the 4 options of orientation marked with cardinal points according to how the gesture was performed in Figure 6.5 and Figure 6.6. According to those orientations and the users input we observe the following:

- All participants maintained the same orientation while the touch pad input was on top of the armrest (horizontal) for all the gestures.
- Participants varied the orientation while the touch pad input was on the outer side of the armrest (vertical), however a majority of participants agreed on using orientation 2.
- If we break down the gestures as simple(swipes) and complex (circle, X, Z, bracket) we observe that in some cases, a same participant use to orientations, one when performing simple gestures and another while doing complex ones.

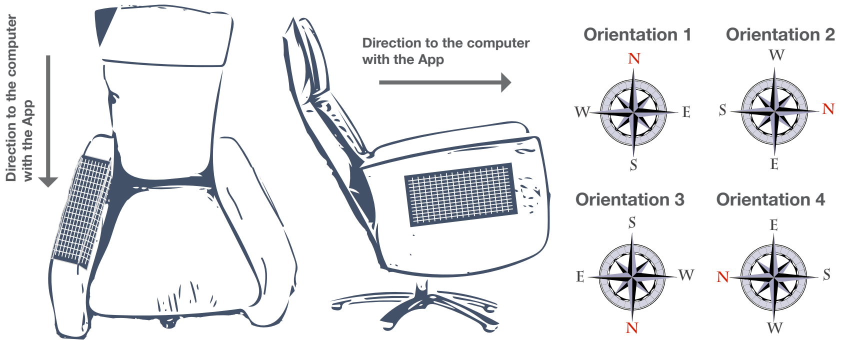

Figure 6.5: Image of the chair with the touch pad on top of the armrest, on the outer side of the armrest and the orientations with the cardinal points, there is a reference to the direction of the test App as well as the axis considered for the prototype.

Figure 6.6: Image of the orientation that had the most percentage of agreement between users according to the position of the chair: top of the armrest is orientation 3 and outer side of the armrest is orientation 2.

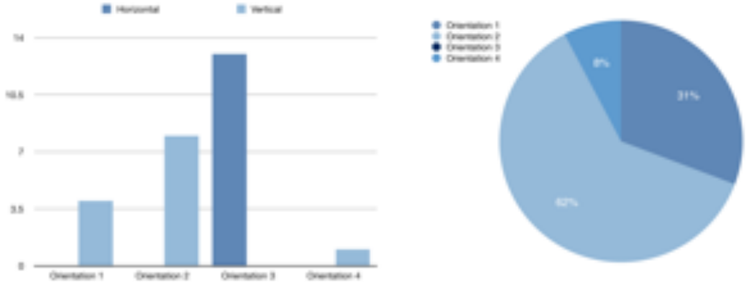

Figure 6.7: Left to right: Bar chart of orientation used by participants while the touch pad was on top of the armrest (horizontal) and outer side of the armrest (vertical) position. We observe orientation 3 solely used on horizontal, while on the other case, the number is split by orientation 1,2 and 4. Pie chart: here we look deeper at how is the percentages of each orientation while the touch pad is on vertical position. Orientation 2 takes the majority with 62%.

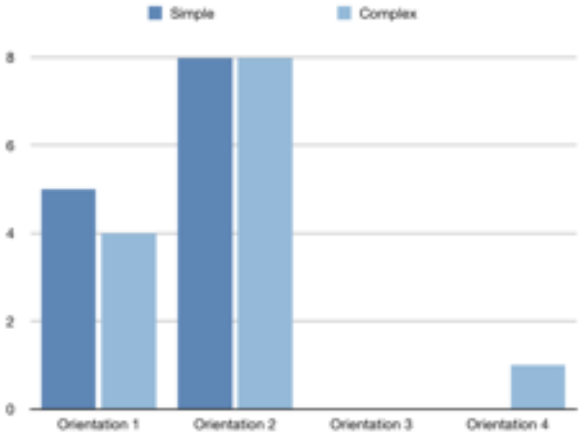

Figure 6.8: Bar chart of orientation used by participants while the touch pad was on on the outer side of the armrest (vertical) split into simple(swipes) and complex(circle, X, Z, bracket) gestures. Orientation 2 was used equally in both set of gestures by those who committed to this orientation. Orientation 1 came second with simple gestures, while we see that when in came to complex a further split in orientation was done.

Size of Gesture

Whenever a gesture was performed and recognized, an array list collected the points in the touch pad matrix from where the gesture started to where it ended both in axis-x and axis-y. From this array list we measured the distance in point in x and y. The axis reference is placed according to a front view of the touch pad when designed and is static despite the touch pad being in horizontal position on top of the armrest or in vertical position on the outer side of the armrest, as it can be seen in Figure 6.9. We observed the following results:

- With the touch pad on top of the armrest, in axis-x the average was 13.4 and median 13, in axis-y the average was 9.1 and median 10. This measurements are the equivalent to length 13 cm and height 8.5 cm.
- With the touch pad on the outer side of the armrest, in axis-x the average was 14.4 and median 15, in axis-y the average was 10.5 and median 12. This measurements are the equivalent to length 14.5 cm and height 9.5 cm.

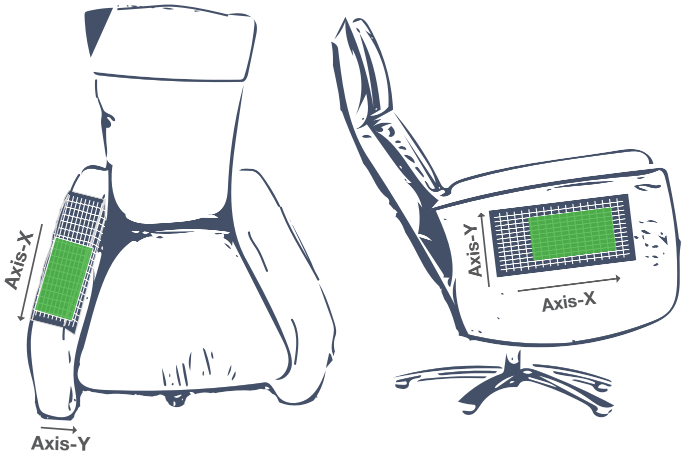

Figure 6.9: Left: green area denotes the actual area of actively used space 13 by 8.5 cm of the prototype on top of the armrest. Right: green area denotes the actual area of actively used space 14.5 by 9.5 cm of the prototype on top of the armrest.

6.9.2 Qualitative Results

Once all tasks were completed, the participants were handed a questionnaire which allowed them to address their experience during the study as well as their perceived preference regarding the variables (texture of fabric and position on chair) that they were exposed to during the tasks. To address their subjective response they were asked to rank the variables in three aspects(comfortability, easiness and effect of the variable on the task performed) in a Likert scale from 1 to 7. At the end of the questionnaire there was also an available space, open for them to express additional thought on their experience with each variable on the tasks.

Likert Scales: Texture of Fabric
We asked them to rank in a Likert scale of 1 to 7 the effect of fabric in physical comfort, easiness to use and accuracy. The following are the results obtained.

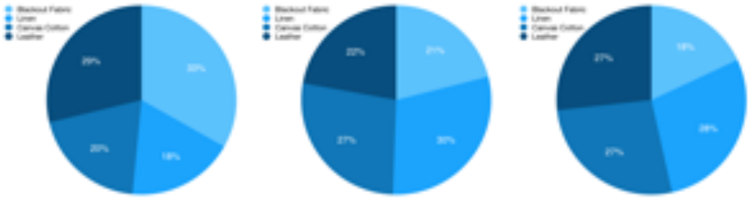

Figure 6.10: Here we present percentage charts regarding the Likert Scales. From left to right: Chart of Comfortability, scale 1 very uncomfortable, 7 very comfortable. The most comfortable was the blackout fabric, followed closely by leather, and the least comfortable was the linen. Chart of easiness: scale 1 very easy, 7 very difficult. Percentages don't vary extremely, yet the two considered more difficult were linen and canvas cotton, with leather and blackout fabric considered more easy to perform on. Chart of effect on accuracy: scale 1 no effect, 7 high effect. It was considered it had less effect on their accuracy the blackout fabric, while the other three split the percentages almost equally on the effect.

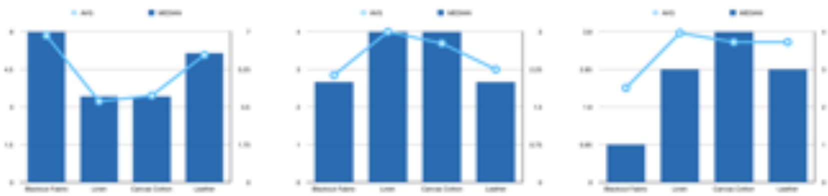

Figure 6.11: Chart of average and median regarding the Likert Scales. From left to right: Comfortability: we observe better ratings for blackout fabric and leather, observe both in average and median. Easiness: we see that leather and blackout fabric are also considered the two most easy to perform on, average values slightly above the median. Effect on accuracy: least effect blackout fabric, most effect canvas cotton, average value above all medians except on cotton fabric.

Likert Scales: Position on Chair
We asked them to rank in a Likert scale of 1 to 7 the effect of position in physical comfort, easiness to use and accuracy. The following are the results obtained.

Figure 6.12: Here we present percentage charts regarding the Likert Scales. From left to right: Chart of Comfortability, scale 1 very uncomfortable, 7 very comfortable. Horizontal was considered around 20% more comfortable than the vertical position. Chart of easiness: scale 1 very easy, 7 very difficult. Vertical is considered more difficult to perform on 60% vs 40% on horizontal position. Chart of effect on accuracy: scale 1 no effect, 7 high effect. Vertical position has close to double the effect on accuracy when compared to the horizontal position.

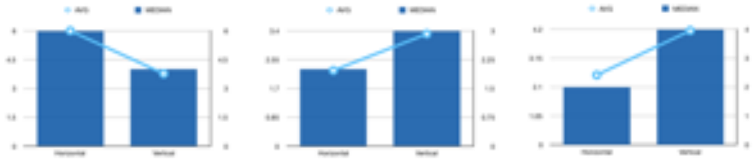

Figure 6.13: Chart of average and median regarding the Likert Scales. From left to right: Comfortability: we observe better rating of horizontal over vertical position. Easiness: we see that vertical is almost double in number on difficulty over horizontal. Effect on accuracy: least effect horizontal, median slightly above, more effect vertical, almost 2 point difference in between.

Chapter 7

Discussion

Taking into consideration the results obtained from both Preliminary and Main user studies as well as our observations from the Elicitation study. We took the following notes and conclusions.

7.1 Scenarios to Control Smart Devices

When we performed the elicitation study, four plausible scenarios to introduce the use of a smart armchair were presented to the participants. After the study was completed, they were asked to ranked the scenarios and furthermore give their opinion or commentary on each one of them. We give a brief commentary on what we observed in each scenario.

7.1.1 Chair Manipulation

Was preferred by the majority of participants, according to their comments it felt like it was completely related to what the user was already doing, seemed natural to them as user is already in the chair. It was considered more intuitive and comfortable when the action can be performed directly on the chair instead of using an additional control.

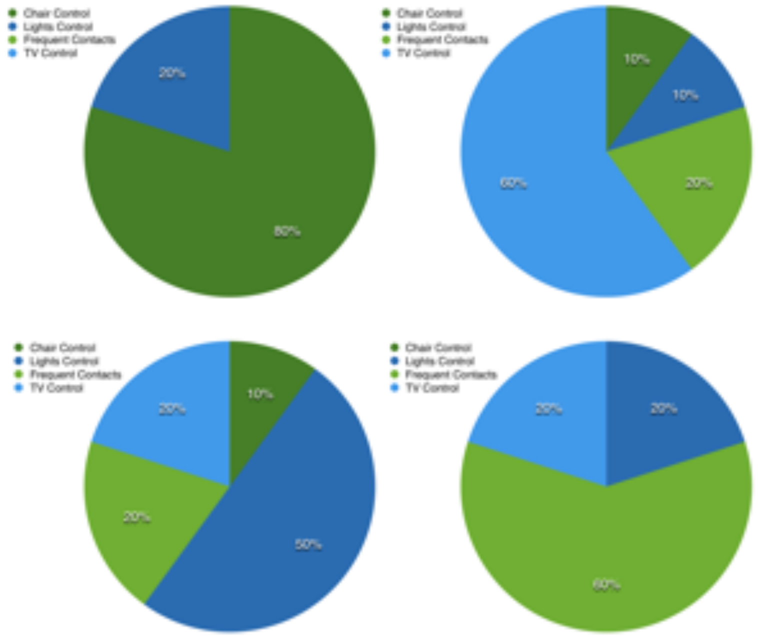

Figure 7.1: From left to right, top to bottom: Pie charts of percentages in user preference and ranking of scenarios: 1st, 2nd, 3rd and 4rd place respectively.

7.1.2 Lights Control

Scenarios ranked in order: Chair control, TV control, Lights control and Frequent contacts.

This scenario ranked third in our poll, but was favored by participants as a mean of not having to stand up to switch the lights. The control of the proposed tasks of dimming the lights, or brighting them up, as well as completely turn them on and off was easily mapped by the participants to sliding gestures either on an horizontal or vertical axis, 70% of the population ,which gave them a mental model of increasing and decreasing an action.

7.1.3 Frequent Contacts

This scenario was the least preferred of the sample, participants argued that with todays smartphone technology and the lack of use of calls against texts or chats made this scenario highly unlikely to play out in real life. Of the comments we received from the participants they mention that it seemed unnatural, not useful and that it made no sense in user's mind.

7.1.4 TV Control

This scenario was our second ranked on the poll, since one of the activities that can be regularly performed while sitting on a couch or armchair is to watch TV, including movies, streaming services, etc. It made sense to the participants to be able to control or perform tasks directly on the chair. Our scenario presented a regular TV service with controls such as channel and volume, this were easily mapped by the users to swipes in horizontal or vertical axis, horizontal for channels while vertical for volume for example.

7.2 Gestures to Control Tasks

The set of gestures we tested, based on documentation consulted on unistroke gestures, proved rather successful in both preliminary and main user study. Of the set of gestures, the subset that can be named as simple gestures: swipes down, up, left, right, had a tendency to score better in both execution time and input accuracy, when measured in levels with the subset of complex gestures: X, Z, circle and bracket. Both this measurements prove higher performance by a difference of 1000ms in average in execution time mean between the subgroups and a considerable difference of 80% against 40% input accuracy of simple gestures against complex one. We recommend that the recognizer implementation of gestures that fall in the later category to be revised, which set of gestures that fall in this category scores better, and saved for tasks that are less common to perform or that require an absolute intention in performing it as their nature difficulty makes them less prone to accidental triggering. Whereas the gestures in the simple category be used for common and repetitive tasks.

Simple gestures had better performance over complex gestures in time and input accuracy.

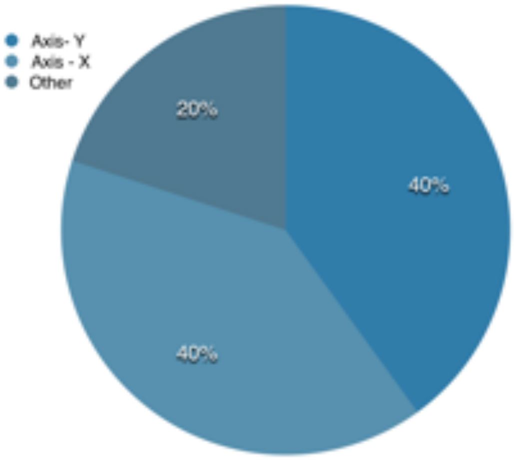

Figure 7.2: Pie chart of gestures swipe in axis regarding tasks in lights control such as dimming down and bright them up to the point of on and off of lights.

7.3 Input Location

Top of the armrest was favored by the participants.

After analyzing the behavior and commentaries of the participants involved in our three studies, we observed that the majority favored always, placement on top of the armrest (horizontal position) over placement on the outer side of the armrest (vertical position). This percentage of preference and perceived easiness of one over the other decreased however as we approach our main study with the input placed directly on the mockup armchair, the main reason behind this as some of our participants mentioned was because on top of the armrest the area to perform the gestures was perceived as smaller when compared to the area of the outer side of the armrest where access to the full extent of the touch pad was granted.

When the effect of input location was measured on execution time and input accuracy, we observed that none of the two proposed locations (top of the armrest and outer side of the armrest) hold any significant effect. And comparing the input accuracy results from the preliminary study where the horizontal placement of the input patch was in front of the users as a baseline was of 48% to the top of the armrest with %58 and outer side of the armrest %55, we see that the placement directly on the chair performed slightly better. The only measurable result that set apart the two locations was the mental orientation model that participants had when performing gestures on either position, on top of the armrest all participants had 100% agreement on orientation model while on the outer side of the armrest a 62% agreement on orientation happened. From this results we advise designers that although both locations are suitable to place the input touch pad sensor, to be mindful of the gesture set proposed as on the outer side user's mental model can vary, we would also recommend on the software side the integration of a gesture recognizer that is able to get the gestures notwithstanding the orientation of the gesture itself, similar to the one that we used for our prototype ($1 Unistroke Recognizer Wobbrock et al. [2007]).

Figure 7.3: Picture of the armchair as it was used for the main user study with the prototype placed on top of the armrest.

7.4 Design for Technical Implementation

Prototype size according to position on armchair, keep it wireless.

From our experience with the prototype on the preliminary and main user studies, we observed that of the total area of 25 by 17 lines for the matrix, gestures performed by the participants averaged was 14 by 10 lines, which would suggest that we minimize the design to a smaller matrix, a resulting input rectangular area of 16 cm in length by 12 cm in height would be suggested for the prototype if it is placed on top of the armrest, as we saw in the results, a starting average gesture point in line 8 and an average ending point in line 20 on top of the armrest. However for the prototype placed in the outer side of the armrest we would suggest keeping a broader model like the one we used for our prototype as the users tended to vary more their starting point when a broader space is available, a considerable number of users started in average their gesture in 5 while ending it in point 13 while another considerable number started in average in point 9 and ended it in point 18. The enhancement to make it wireless by integrating the Bluetooth device and power bank proved successful and added to the mobility of the prototype. The possibility of having a solution that works both powered by an AC adapter and a power bank could be an enhanced feature so that users can choose their preference according to the use and placement of the chair. Instead of the current microcontroller board and cabling, the use of compact Printed Circuit Board (PCB) with a microcontroller integrated to hold all the connections with conductive thread to the pressure touch pad prototype in order to provide a seamless integration to the armchair.

All fabrics tested suitable for real-life implementation.

Regarding the texture of the fabrics and based on our results from the main study on input accuracy that supports that all tested fabrics (Blackout fabric, Linen, Cotton Canvas and Leather) are suitable for implementation. As per the perceived performance of the textures we also observe that the preference and comments given by the participants were prompted by their personal like and perception on touch and feel of the fabrics' texture. One that in both studies scored well and above the others in our qualitative polls was leather, which also happens to be a common fabric used on furniture, couches and armchairs.

Chapter 8

Summary and future work

In this chapter we take a look back in the work done in this thesis and give thoughts and ideas on how further work and research can be done in this area in the future in aim of expanding the knowledge and results that have been gather so far by this particular research work.

8.1 Summary and contributions

When we started this thesis we had an idea that chairs could work as a great new form of input control. They are almost everywhere: homes, offices, hospitals, even transportation, they have remained passive elements where comfort over usability has been the main matter at hand when taking about them. Yet many questions remained about how we could achieve the design of a smart chair, which technology to use, which type of chair would be the most appropriate, where could we use it, which scenario fit best and most importantly how would users be able to interact with it.

To have a starting point and after we have read about previous work done on the matter of intelligent and/or augmented chairs, we opted to choose a recliner armchair as the model of chair that would be suitable for our research, one because it provides the most areas of any chair to interact with: armrest with inner and outer sides, broad backrest, headrest and seat with legrest/footrest. Second, it is ideal for the smart home scenario that we had in mind as to where it could be useful.

Elicitation study help defined input location and modality.

Once we had picked our mock up armchair to start our research, we needed insight in how users could interact with it, so an elicitation study was performed, this proved to be helpful in paving the way for our research, the findings of this study gave us insight on user's behavior while sitting, where they were able to reach on the armchair, which parts of their body they used and how they imagined they could perform the required tasks only using the chair. From the results obtained in the elicitation study, we were able to narrow down our initial incognitos, propose new hypothesis and work on a prototype that could help us prove them. After testing some technologies, the final prototype was designed with a concept similar to the Flextiles Parzer et al. [2016], expanding their pressure sensing nature to make a matrix touch pad where we could read x and y coordinates of a gesture and give these sets of coordinates to the $1 Unistroke Recognizer Wobbrock et al. [2007] we implemented in our Java application, to recognize the set of gesture we proposed based on Vo et al. [2014] Surale et al. [2017] Bragdon et al. [2011].

Prototype functionality evaluated in preliminary and main user studies.

With the prototype at hand and working, we proceeded to test our hypothesis regarding position on the chair, stiffness of underlying surface, texture of fabric and gestures on a preliminary study 5. An hour long in average study was performed with 5 participants, we logged their interactions and performance in the tasks on our application. From the logs we gather enough information to discard the stiffness of underlying surface variable for the main user study and focus on the other three variables to see the impact of each one per group and also if correlation between them had any effect on performance. These reformed research questions were covered on our main user study 6, with a population of 13 participants, none of which had previously performed in our preliminary study to avoid a learning curve. Following the same scheme from the preliminary study, we asked users to perform gestures in a set which varied each time the independent variables combination, texture of fabric and position on the chair was updated. Each set was repeated 4 times to allow us to gather enough samples. We logged the participants interaction and from there we evaluated the performance of the task, on execution time, input accuracy of task being performed, size and orientation of gesture. The analysis of the results if further discussed in Discussion 7.

Guidelines: input location, set of gestures and technology to implement smart armchair.

As for the design guidelines, by our results we suggest that a technical implementation like the one we performed is able to work on any of the fabrics we tested, which are common on tapestry of armchairs. For input location on the chair we would suggest the top of the armrest near to the middle, for tasks that involve the control of any other smart device, similar to our proposed scenarios of light control or home media control. For the control of the armchair itself, for example a recliner, the outer side of the armrest would be suggested as it implies less gestures, bigger in size, which user would perform only on occasion. In general the size of gesture provided no trouble in being recognized and performed on top of the armrest, which on our mock up chair was of 9 cm which is relatively narrow, hence our prototype of 25 by 17 lines could easily fit this and armchairs with broader armrests. Orientation proved that on top of the armrest, when the sensor is placed on horizontal position, overwhelmingly all users kept the same orientation model and perform all gestures in the same direction.

Based on our observation of the participants interaction and performance in all three of our studies and with the guidelines proposed above, we can suggest the use of the smart chair in scenarios such as:

Smart Home: Drapes and Temperature Controllers

From what we saw with the control of the lights scenario, actions as turn on and off, as well as increase and decrease can be easily mapped by the user to the input control of the chair. Drapes require actions as closing and opening, on a full scale or continuously until reaching the point of desire. Temperature controls include actions such as on/off, heat or cool system, levels of the system in place. Actions for both this controls can be implemented with unistrokes gestures and connected to one of these devices.

Home Media: SmartTV, Home Sound System
After analyzing participants in the TV control scenario we can mention that participants were able to create a mental model of the control system on the chair and perform the require tasks easily. Although the set of actions we require was limited as we presented a basic TV system control, this set of controls could be easily extended to match current existing smartTV controls in the market with the help of unistroke gestures as tasks as going through content and select are fairly repetitive, which don't usually go beyond 10 gestures.

8.2 Future work

Improve resolution of touch pad and refine cabling design.

There are still interesting areas left to explore for future work regarding the smart armchair, the zebra patches we used helped us do a matrix touch pad with a resolution good enough for our studies, the use of patches where the density and resolution of the matrix could be upgraded would be a welcomed improvement, if tested on the whole with the $1 Unistroke Recognizer Wobbrock et al. [2007] in order to observe if it helps raise the input accuracy in execution of tasks in order to generate a more robust prototype. On the technical implementation front, our prototype still lacked a cleaner design on the cabling part, we used micro test hook pincers to plug the patches of zebra fabric to the microcontroller, perhaps a design where instead of cables conductive thread is used could make the patch easier to integrate in the fabrics of the armchair, the microcontroller and circuit connections could be easily transfered to a Printed Circuit Board (PCB) to be later cased in a box and placed beneath the armchair, but attached to it, so that it does not affect the design of the armchair itself and also can be easily accessed to in case of troubleshooting or reprogramming. As suggested on the Discussion7.4 the possibility to power the prototype both by AC and a power bank should also be left open.

Evaluate prototype on smart home scenario.

While our prototype and the studies performed with it showed a significant potential to the smart armchair, an usability study with one of the scenarios previously proposed, lights control, or home media for example, where the user not only perform the gestures themselves but learn them and attempt to control a task by using them would show the true capabilities of the smart chair in a home environment. A study of this nature not only would let us examine the performance of the prototype on a real life environment, but it will also allow us to observe the impact of accidental or unintended triggering, when we did our initial research, the papers we read Probst et al. [2013] Probst et al. [2014] Endert et al. [2011] make a point that accidental triggering and noise were two of the aspects which cause them trouble, we believe to this point that the use of gestures which does not include tap or presses could avoid to an extent, however we don't know to which degree and whether is reasonable for users in a real life environment.

Measure and avoid noise and accidental trigger.

It would also be interesting to investigate what would happen if we were to transfer our model to other type of couches, e.g. sofas that can fit two or three persons, in that case where should the interaction be (one side only, both sides so the two persons have access to it?). Also it could be intriguing to look at different armchairs that have diverse sizes and shapes to them and notice if that affects our current findings.

Appendix A

Appendix for Body-based Interaction with Chairs - An Elicitation Study

Appendix A contains the script used during the Elicitation Study as well as the questions asked during and after the study.

A.1 Script

We prepared the following script that the evaluator will pursue with the participant: "The purpose of the study you are about to take part of is to explore user interaction with a smart armchair. This is an elicitation study in which no technology thus far is involved, please remember that we are looking to have an eyes-free experience. I will describe a general environment for you and from there different more specific scenarios will be presented."

For the general environment: "In your living room you have an armchair that allows you to control other smart devices remotely connected to each other, all while sitting on

it. The chair is smart and will be able to detect how you are moving on it and translate your movement or gestures into commands. I will give you several scenarios in which I'll ask you to control a particular device in your home using only the smart chair. In each scenario you should perform a set of commands to control tasks according to the situation. I'll ask you to perform the commands in each scenario twice: one using your hands and the other using any part of you body but your hands. Please note that the while the smart chair can detect your body and hand movements it does not respond to voice commands or mid-air gestures."
Note: for the hands allowed scenarios ask participants if while performing the task they imagine having any haptic feedback from the chair or any form of tactile signifier that could help them manipulate the chair. E.g. hardware controls that can be feel through the furniture's surface or that are on the furniture's surface, different texture on the control area, or others.

Note: for the hands-free scenarios incentive participants to imagine themselves in situations where their hands are occupied so the use the body is preferred, e.g. the participant is eating popcorn while watching the TV or the participant is reading a book and does not want to use the separate his/her hands from it.

"For the first scenario I would ask you to imagine being at home and you would like to rest, so you go and sit on your armchair. The chair is able to take on different positions"(the evaluator will proceed to show an image/sketch with the different positions of the chair, it includes different positions for the backrest and footrest), "so you can change the current position to each of the ones presented in the visual aid. In order to do this, you can perform any movement or gesture directly on the armchair to switch between positions, note that the backrest and the footrest move independently form each other: You are starting from position 1, now please switch to position 'x' what would you do?,then please switch to position 'y', now how could you switch to position 'z'?, can you proceed to position 'w', now please switch to position 'v', finally from that position, how could you return to original position number 1?"

Questions

"For the second scenario I would ask you to picture yourself sitting comfortably on your chair, for some reason you would like to adjust the lighting system of the living room. Now using the same armchair your sitting on you can control this system. How would you turn on/off the lights. Let's assume that the system can dim gradually the lights to a level that is most comfortable for you, how would you instruct the system to dim the lights?"

Questions

"For the third scenario I would ask you to imagine yourself at home on your chair, you decide to call a friend or family member. The armchair happens to have a connexion to your phone and has in memory your 3 most frequent or favourite contacts. Where do you image in this scenario the contacts could be placed on the armchair for you to select? How could you pick one and start a call? Once the call starts it works the speaker mode on your phone. Once finished how would you end the call?"

Questions

"For the fourth scenario I would like to imagine you want to watch a movie on your smart TV, I would ask you to control the TV with the armchair. Now please proceed to turn on the TV. Once On you are able to navigate on your smartTV menu, available you can switch between a video streaming service e.g. Netflix, regular/open TV, and your own intercom with CCTV system (security video surveillance). How would you navigate through this options on the menu and select your desired option? Let's say you want to play a movie from the streaming service. What would you do to choose a movie? Then how will you instruct the movie to play/pause? Next I will ask to fast forward or rewind the movie you are playing. Now how could you stop the movie and then return to the main menu? Let's now go to the regular TV service, how could you change the channels? How would you increase/decrease the volume of the TV and how will you mute/unmute? Lastly I'm going to ask you work with the CCTV system, let's assume you hear the doorbell and want to see who it is, you switch to the CCTV and see it is a friend, you are able to open the main door with the chair, how would you do that?"

Questions

Questions

Ask after each gesture type (body or hand).

- On a scale from 1. . . 5 how would you rate the goodness/fit of this gesture for this command?
- On a scale from 1. . . 5 how would you rate the easiness/comfort of this gesture?

One answer per referent:

- Preferred gesture type (body vs hand)

*Make the chair a little flatter.

- Ask: what gesture will be better and more comfortable when you are in this position?

A.2 Post-study Questionnaire

Haptic Feedback

For the chair control scenario, how do you compare using these two patches if they were integrated in the chair? (place in central location, test out all scenarios, respond to requests to move the patches or rotate them, get final verdict: patch1, patch 2, gestural interaction is preferred? why?)

Overall Experience

Answer the following question with Strongly Agree•Agree•Undecided•Disagree•Strongly Disagree

- Interacting with the armchair was interesting?
- Interacting with the armchair was interesting?
- Interacting with the armchair could be useful?
- I imagine I would use such a chair like this at my house?

Scenarios

Rank the scenarios based on likeliness to control using an armchair? Explain why you pick ″*X*″ scenario first and ″*Y*″ scenario last.

Are there any other scenarios where the smart chair will be useful for? (smart homes)

Locations

What parts of the chair do you think can be interactive?

On the surface of the chair, how would you layout the commands based on frequency of use?

On the surface of the chair, if different then previous, how would you layout the commands based on importance?

Gesture Types

In which cases would you imagine using the body and not the hands for interaction? (tired, your hands occupied. . . etc)

Which body parts do you have more control over?

Do you see any limitations of using the body movement for control?

Do you have any concerns about having a smart chair in your home?

How concerned about accidental activation?

In your opinion, which group of people will benefit more of this chair?

Voice Systems

When would you think using a smart chair is a better choice than a voice system at home?

Appendix B

Appendix for User Studies: Preliminary & Main

Appendix B contains the questionnaires presented to the participants either at the end of the preliminary study or the main user study depending on which one of the two they took part of.

B.1 Participant Information

Right after the completion of either the preliminary or main user study the participants were asked to fill a questionnaire for demographics:

Personal Information

- Gender: Male/Female/Not Disclosed
- Age:
- Occupation:

Further Questions

1. Dominant Hand: Right/Left
2. Have you used gestural interfaces (beyond touchpad, smartphone and tablets)? If yes, please specify
3. Have you used smart furniture? If yes, please specify
4. Have you used smart textiles? If yes, please specify

B.2 Preliminary Study Questionnaire

Questionnaire presented to each participant upon completion of the study.

Characteristics of Texture of Fabrics

Please fill the following according to your haptic experience with the fabrics presented to you by the tester.

(a) Fabric #1
(b) Fabric #2
(c) Fabric #3
(d) Fabric #4
(e) Fabric #5

You will have time to experience each fabric and describe it with the following scales (7 points).

1. Smooth(1) to Rought (7)
2. Flexible (1) to Stiff (7)
3. Thin (1) to Thick (7)
4. Fine (1) to Coarse (7)

5. Firm (1) to Sleazy (7)
6. Hard (1) to Soft (7)
7. Light (1) to Heavy (7)
8. Scratchy (1) to Silky (7)
9. Limp (1) to Crisp (7)

Questions regarding your user study experience with the fabrics

Rank each of the 5 fabrics in a scale of 1 to 7 according to:

1. Physical Comfort (1 least comfortable to 7 most comfortable)
2. Ease to use when performing gesture (1 very easy to 7 very difficult)
3. Accuracy performing gestures on (1 very accurate to 7 not very accurate)

Questions regarding your user study experience with the position on chair

Rank each of the 2 positions (horizontal and vertical) in a scale of 1 to 7 according to:

1. Physical Comfort (1 least comfortable to 7 most comfortable)
2. Ease to use when performing gesture (1 very easy to 7 very difficult)
3. Accuracy performing gestures on (1 very accurate to 7 not very accurate)

Questions regarding your user study experience with the stiffness of underlying material

Rank each of the 2 stiffness (foam and no foam) in a scale of 1 to 7 according to:

1. Physical Comfort (1 least comfortable to 7 most comfortable)
2. Ease to use when performing gesture (1 very easy to 7 very difficult)
3. Accuracy performing gestures on (1 very accurate to 7 not very accurate)

B.3 Main Study Questionnaire

Questionnaire presented to each participant upon completion of the study.

Questions regarding your user study experience with the texture of the fabrics.

Rank each of the 4 fabrics in a scale of 1 to 7 according to:

1. Physical Comfort (1 least comfortable to 7 most comfortable)
2. Ease to use when performing gesture (1 very easy to 7 very difficult)
3. Accuracy performing gestures on (1 very accurate to 7 not very accurate)

Questions regarding your user study experience with the position on chair

Rank each of the 2 positions (on top of the armrest and on the outer side of the armrest) in a scale of 1 to 7 according to:

1. Physical Comfort (1 least comfortable to 7 most comfortable)
2. Ease to use when performing gesture (1 very easy to 7 very difficult)

3. Accuracy performing gestures on (1 very accurate to 7 not very accurate)

Other comments

(a) Other thoughts regarding the fabrics used:

(b) Other thoughts regarding the positions:

(c) Other thoughts regarding the study:

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