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Designing Mechanical Ears for a Theatre Setting

An Explorative and Experimental Study

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Abstract

Wearable computing and body extension are concepts that have become more and more popular in later years. In this thesis, I want to look at possible uses for wearables and mechanical body extensions in a theatre setting. How might one augment or extend the capabilities of the human body with technology, and how should the body and the technological extension communicate? These questions will be applied in the context of theatre and used to explore how wearable technology can be utilised in a theatre play to help actors make characters come alive.

By making a pair of mechanical elephant ears for the Children's Theatre at UKA 2015, a student festival in Trondheim, it was possible to test the problem statement in the desired setting. After having cooperated closely with actors and costume designers, the result was very positive. Both the actor playing the elephant and the play's instructor had much positive feedback. The close collaboration proved to be imperative for the success of the process and invaluable in developing a mechanical body extension that would work well on stage. Moreover, the process revealed the importance of considering movement mapping in the particular context of use, to achieve a satisfactory result.

After making a first version of the mechanical ears for the theatre play, I proceeded to make a second version of the ears with the goal to test how different mappings between user input and ear behaviour might be used to control the ears and how users would respond to this. The result was that the user preference concerning mapping for a mechanical body extension is highly dependent on who will use the body extension and in what setting they will be using it.

Sammendrag

Bærbar teknologi og kroppsutvidelser er begreper som har blitt mer og mer populære i senere år. I denne oppgaven vil jeg se på muligheten for å bruke disse konseptene i forbindelse med teater. Hvordan kan man øke eller utvide funksjonaliteten til menneskekroppen med teknologi, og hvordan skal kroppen og den teknologiske utvidelsen kommunisere? Disse spørsmålene vil bli evaluert i en teaterkontekst og brukes til å utforske hvordan bærbar teknologi kan utnyttes i et teaterstykke for å hjelpe skuespillerne med å gjøre rollene sine enda mer levende.

Ved å lage et par mekaniske elefantører for Barneteateret på UKA 2015, en studentfestival i Trondheim, var det mulig å teste problemstillingen i en passende setting. Etter å ha samarbeidet tett med skuespillere og kostymedesignere, var resultatene svært positive. Både skuespilleren som spilte elefanten og stykkets instruktør hadde svært positive tilbakemeldinger. Det nære samarbeidet viste seg å være avgjørende for å lykkes med prosessen og uvurderlig for å utvikle en mekanisk kroppsutvidelse som ville fungere godt på scenen. Videre gjorde prosessen det åpenbart hvor viktig det er å vurdere bevegelses-mapping for det spesifikke anvendelsesområdet for å oppnå et tilfredsstillende resultat.

Etter å ha laget den første versjonen av de mekaniske ørene for teaterstykket, gikk jeg videre til å utvikle en ny versjon av ørene. Målet for den nye versjonen var å teste hvordan ulike mappinger mellom brukerinteraksjon og ørebevegelser kan brukes for å kontrollere ørene, og hvordan brukerne vil oppfatte dette. Prosessen gjorde det tydelig at brukerens preferanser vedrørende mapping for en mekanisk kroppsutvidelse er svært avhengig av hvem som skal bruke kroppsutvidelsen og i hvilken setting de skal bruke den.

Acknowledgements

First, I want to thank everyone who participated in the user tests. I also want to thank the people from the Children's Theatre; the actor, Trond Stavås; the costume designers, especially Karoline Finckenhagen and Marte Tiller; and the instructor, Marlene Lindtner, for the cooperation. I also want to thank Trond Are Øritsland and the other people from IPD, who helped me with the design and construction of the ears. Special thanks to my supervisor, Dag Svanæs for supporting and motivating me through the entire process of making the ears and writing this thesis.

Dissemination

The theatre ears produced in this thesis work has been described as an example of mechanical body extensions in the following articles/publications:

- Demonstrated at the HCI'16 Conference: Svanaes, Dag, and Martin Solheim. "Wag Your Tail and Flap Your Ears: The Kinesthetic User Experience of Extending Your Body." *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems.* ACM, 2016.
- In an article int he science and technology magazine Gemini: `http://gemini.no/en/2015/12/the-professor-who-misses-his-tail/`

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Chapter 1

Introduction

1.1 Motivation

The primary motivation of this project is to experiment with interaction with mechanical extensions to the human body. The ideas behind this project are linked to the concept of the lived body as discussed in Svanæs (2013) and how the lived body can incorporate objects into it. The ideas that are introduced in Höök (2010) have also been a significant influence on the design process and design choices. These concepts and ideas are discussed further in Chapter 2.

1.2 Purpose

For this particular case, the mechanical extension of the human body is a pair of mechanical ears intended for use in a theatre setting. These ears should be controlled by the wearer's body and function in such a way that the wearer experiences the ears as part of him or herself.

The purpose of this study is to explore the use of mechanical body extensions in theatre and how interaction with the technology can be made to feel natural for the user. In the summary of Höök (2010), the author stresses the importance of doing research that is focused on the body experience and not only function.

> *"In my view, we need to return to being more concerned about our bodily experiences, returning to the care that ergonomics shows the body, but with a stronger focus on experience, and not only function."* (Höök 2010)

Few studies have been done on this particular subject, but there have been done research on designing for the body and creating alternative forms of interaction (Höök et al. 2015, Paradiso 1999). The problem with earlier research is that, as the Brain Opera from MIT, it does not go into the human side of the experience. Brain Opera is an exciting project where the researchers experiment with participatory music development, but in the article Paradiso (1999) only the technical solutions are discussed. This study will strive to merge the technology, theory, and philosophy and explore the problem area with a focus on the human experience and designing for the body.

1.3 Research Questions

The above-mentioned lead to the definition of the following research questions for this project:

RQ1: *What are important aspects to consider when developing mechanical body extensions for use in a theatre setting?*

RQ2: *How should a mechanical body extension be controlled to make the interaction feel natural?*

1.4 People Involved in the Project

A list of the people involved in the project and their role can be seen in Table 1.1. Of these people, the main stakeholders for the first version of the ears ears are the actor and the costume designers. These are the people that will be providing feedback on the prototypes. In addition to the people listed, seven people have been involved as test persons; these are not mentioned by name.

Parts of this project was done in cooperation with the Children's Theatre ('Barneteateret') at UKA 2015[1]. The assignment was to construct a pair of mechanical ears for use in the play 'Cirka absolutt nesten krusedull'.

Figure 1.1: Picture from the play 'Cirka absolutt nesten krusedull'[2]

[1]UKA is a bi-anual music and culture festival that is organised and carried out by NTNU students.

[2]Retrieved from `http://dusken.no/artikkel/25317/visste-du-at-jorda-er-en-satellitt/`

Name	**Role**
Dag Svanæs	Project Supervisor
Marte Tiller	Responsible for costumes for the Children's Theatre
Karoline Finckenhagen	Responsible for making the elephant costume
Trond Stavås	Elephant actor
Marlene Lindtner	Instructor for the Children's Theatre
Trond Are Øritsland	Contact person at Department for Product Design (IPD)

Table 1.1: An overview of the people who were involved in the project.

Chapter 2

Background

2.1 Literature Review

For the literature review I defined six eras of interest these are:

1. Existing products and prototypes
2. Philosophical foundation and theory
3. Measuring movement
4. Body extension technologies
5. Applications to theatre
6. User Experience (UX) and usability

Before carrying out the literature review, I defined several concepts that I wanted to explore. These concepts and alternative terms to describe the same concepts are listed in Table 2.1. This was done to define which search terms was to use in the literature search. By organising the different concepts and terms, it was possible to get an idea of how well the literature covered the desired themes. Table 2.2 gives an overview of the articles found through the literature search and which concepts they cover. From the overview, it is easy to get an idea of which concepts are best represented in the literature.

There are multiple articles concerning Concept 3, Body Extensions, but only one article about Concept 5, Theatre. Concept 4, Body extensions, is also represented in few of the articles. The overview highlights a significant challenge; there is a lack of literature concerning wearables and body extensions. There has not been done much research in this field; this is both a challenge and an opportunity for this project. The challenge is that there is not much directly relevant material to use as a background for the project. The opportunity is the chance to explore a new field of study.

Concept 1	**Concept** 2	**Concept** 3
Wearables; Smart Watch; Wearable computer; Fitness trackers	Lived body; Embodiment	Measuring movement; Body sensors; Sports trackers; Wearable sensors; Physical activity tracking
Concept 4	**Concept** 5	**Concept** 6
Body extensions; Prosthetics; Body enhancement	Theatre; Acting; Improvisation	User experience; Usability

Table 2.1: Concepts relevant for the study, defined for literature review.

2.2 Wearable Computing

Wearable computing has become an ever more relevant product group as computers, and sensor packs have grown smaller. The most popular wearable on the consumer market has been the fitness tracker, but this might change soon according to Statt (2015). The fitness tracker is a small, often screen-less, device that can track data such as; the wearers sleep quality, activity level, and pulse. The article Mann (2012) goes into detail on the less mainstream aspects of wearable computing. Mann describes his work that includes projects exploring self-monitoring where he wears a camera and films all he sees during a day. Mann also describes other body extension projects.

In Randell (2005) the author makes a short review of the state of

Articles	**Concepts**					
	1	**2**	**3**	**4**	**5**	**6**
(Alonso et al. 2014)	-	(∗)	∗	-	-	∗
(Atzori and Woolford 1995)	∗	∗	-	∗	-	-
(Chen et al. 2011)	-	-	∗	-	-	-
(Dayal 2012)	∗	∗	-	∗	-	-
(Honauer and Hornecker 2015)	-	-	-	∗	∗	∗
(Höök 2010)	-	∗	-	-	-	-
(Höök et al. 2015)	-	∗	∗	-	-	∗
(Junker et al. 2008)	-	-	∗	-	-	-
(Kwon and Gross 2005)	∗	-	∗	-	-	-
(Leigh and Maes 2016)	∗	-	∗	-	-	-
(Mann 2012)	∗	-	∗	∗	-	∗
(Mengüç et al. 2013)	-	-	∗	-	-	-
(Nawaz et al. 2014)	-	-	∗	-	-	∗
(Norman 1998)	-	-	-	-	-	∗
(Nylander et al. 2013)	∗	-	∗	-	-	∗
(Paradiso 1999)	-	(∗)	-	-	-	(∗)
(Patel et al. 2012)	-	-	∗	-	-	-
(Pijnappel and Mueller 2013)	∗	-	∗	-	-	∗
(Randell 2005)	∗	-	∗	-	-	-
(Sanches et al. 2010)	-	-	∗	-	-	(∗)
(Skjæret et al. 2014)	-	-	∗	-	-	(∗)
(Spelmezan 2012)	∗	∗	∗	∗	-	∗
(Statt 2015)	∗	-	∗	-	-	-
(Stewart et al. 2014)	∗	-	∗	-	-	∗
(Stienstra et al. 2012)	∗	∗	∗	-	-	∗
(Ståhl et al. 2009)	-	∗	∗	-	-	∗
(Svanæs 2013)	∗	∗	-	∗	-	∗
(Weiser 1991)	-	-	-	-	-	∗
(Yang and Hsu 2010)	-	-	∗	-	-	-
(Yang and Hsu 2010)	∗	-	∗	-	-	-
(Zhou and Hu 2004)	-	-	∗	-	-	-

Table 2.2: Overview of literature and concepts covered. (∗) Means that the article touches on the subject, while - means that it does not.)

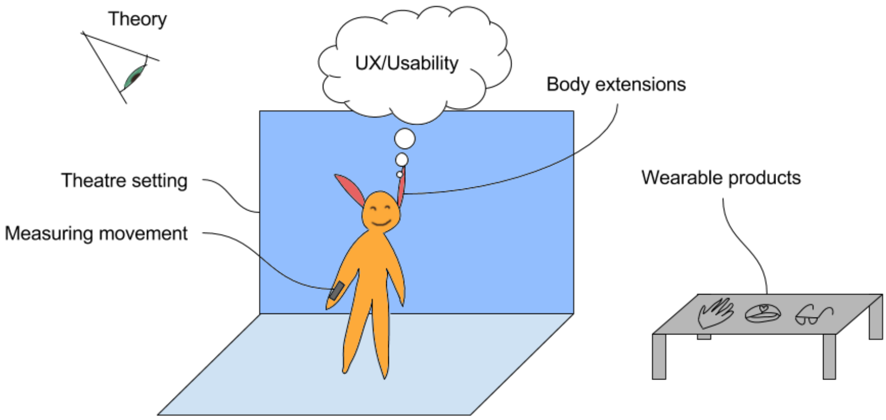


Figure 2.1: The six areas of interest

wearable technology and its development. This article is quite old in technology terms, but it gives a good overview of the major areas of development: Industry, military, medical and health, and personal assistance. In the section about further development, gaming is also mentioned. Today, gaming has become an important area for wearable computing. Of course much has happened since the publication of this article; smaller battery, screen, sensor, and microchip technologies have allowed for ever smaller devices. This development has lead to the popularisation of fitness trackers and smart watches. On a prominent technology website Statt (2015) claims that the popularity of fitness trackers will dwindle with the rise in availability of smart watches. The Apple Watch, an advanced smart watch, and the Fitbit Flex, a simple fitness tracker, are shown in Figure 2.2. The contrast between the colourful display of the Apple Watch and the minimalistic led lights on the Fitbit is quite striking, not to mention the difference in pricing. That is the big drawback with smart watches today; they are quite expensive and almost wholly dependent on a smartphone for processing power.

[1] Retrieved from: `https://www.apple.com/pr/products/apple-watch/Apple-Watch.html`
[2] Retrieved from: `https://investor.fitbit.com/press/press-kit/default.aspx`

(a) The Apple Watch[1].

(b) The Fitbit Flex[2].

Figure 2.2: The Apple Watch and the Fitbit Flex, examples of a smart watch and a quite basic fitness tracker.

Wearable computing can be used to create personal and intimate experiences. In Ståhl et al. (2009) wearable computing is used to create a personal diary that uses sensor data and data collected from the user's mobile phone to create a representation of the user's day. Apple has recently made a utilitarian approach to representing the user's life based on sensor data. The Apple Watch has a function where it tracks the user's activity and represents it as layered circles (Apple Inc. 2015). Apple's approach differs from Ståhl et al. (2009) because it does not filter the information and represent it in an interpreted manner. One of the test persons in the study described in Ståhl et al. (2009) mentioned this point; he said he found it frustrating that he did not know what was done with the numbers collected from the sensor and preferred to view the data in an XML sheet. On the Apple Watch, the circles are a visual representation of the recorded data; these numbers can be reviewed by the user on their iPhone. This observation highlights an important aspect of wearable computing, as well as all computing that involves user interaction: How much of the computation should be hidden? To what degree should the user be in direct control? What does the user need to know to have a meaningful and satisfactory interaction? In Weiser's vision of the 21-century computer, he argues that the computers would fade into the background and that the interaction with computers would be on a higher level Weiser (1991).

2.3 Designing for the Body

> *As human beings, we are aware of our body both as an object in the world and more directly as the lived body (le corps propre). The lived body is the body as experienced by a person as himself/herself, which is different from seeing the body in the mirror as an object among other objects in the world.* Svanæs (2013)

Designing for the body is an important aspect of this project. The ears should ideally assimilate themselves to the wearer's body to be conceived by the wearer as an extension of their body. The interaction should be as natural as waving your hand. Svanæs (2013) discuss the concept of the lived body, the author also discusses the 'toolness' of objects, an object's ability to cease to exist as an object and become a part of the user's lived body. An example that is used in the article is a blind man and his cane. For the blind man, the cane is not merely a cane or a stick. It is an extension of his body, extending the body's limits to be able to sense its surroundings.

In the article Höök (2010), Höök applies her experiences in horse riding to design. In the summary of the article, she gives a list of experience-oriented qualities that she extracted from her experiences in horse riding. Table 2.3 recounts the list from the article. She also encourages returning to a design approach which is more concerned with our bodily experience. In Höök et al. (2015) Höök answers her call. In this article, the authors design some products that aim to help people get more in touch with themselves. They apply meditative approaches called Feldenkrais to make products that are designed for the entire body. The article also mentions that part of the design is grounded in the experiences of Höök (2010).

When designing technology which is meant to be worn by a person, it is important to take into consideration how the piece of technology will conform to the wearer's body. The technology must be just obtrusive enough to be noticed and subtle enough for the wearer not to be distracted from their context of use. Good examples of

[1]Retrieved from: `http://web.media.mit.edu/~joep/TTT.BO/PandT-pics/Joep-chair-popularsci-lorez.jpg`

[2]Retrieved from: `http://people.ucsc.edu/~joahanse/onlineexhibit/thirdhand/`

1. Designing spaces for mutual wordless understanding between human and machine 2. Letting bodily learning take time and be a pleasure in itself 3. Putting more emphasis on the aesthetic pleasures of rhythm when designing for bodily interaction 4. Finding ways of describing experiences of bodily interactions that can serve as inspiration to design

Table 2.3: Experience-oriented qualities of horseback riding that are transferable to design (Höök 2010)

Figure 2.3: Sensor chair from the Brain Opera by MIT Media Labs[1].

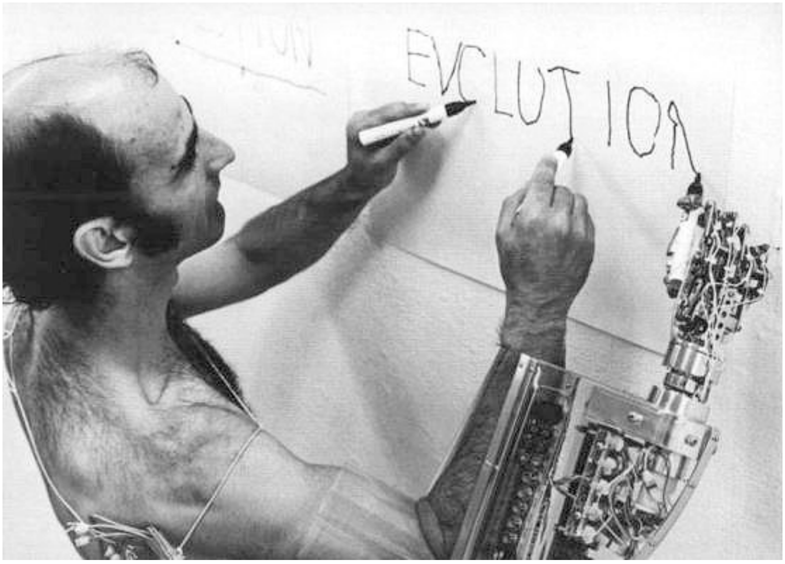


Figure 2.4: Stelarc with his third hand[2].

this are given in (Nylander et al. 2013, Pijnappel and Mueller 2013). These articles discuss the interaction between technology and body and how technology can enhance experiences and help people hone or acquire new skills.

This approach is quite new to development of wearable computing and tangible interfaces. Paradiso (1999) discuss the Brain Opera, a participatory music project from MIT Media Laboratory. In this article the main focus was on the technical solutions, the human factors seem not to have been of interest. The goal of the project was to include people, with little or no experience with playing instruments, in the making of music. This is a fascinating idea, but the article does not explore or reflect much on the human experience of the installation. This inclination could be because the Brain Opera was made in the early days of the movement to use computers and the body to create expressive art. In Figure 2.3 Paradiso is using one of the installations from the Brain Opera, the sensor chair.

Work on wearable technology and body extension is not limited to the practical and academic world; it has also been adopted in art. The artist Stelarc has been experimenting with extending the body, mostly his own, with technology since the 1960's (Stelarc 2015). His experiments are of a more artistic nature, and can be quite bizarre. He is, for example, growing a third ear on his arm (Dayal 2012). Through his art, he is raising some interesting questions concerning the relationship between the human body and mind, and technology. In an interview with CTHEORY Atzori and Woolford (1995), he talks of some of his art and his thoughts on the human body. He is of the opinion that the human body in becoming obsolete and that we have to use technology to make it keep up. Interestingly he mentions a point that is also made in Svanæs (2013), that one should not make too strong a distinction between the mind and the body. In Figure 2.4 Stelarc can be seen writing with his third arm[3], a body extension project that he did in the 1980's.

2.4 Cyborg

> *The term cyborg is not the same thing as bionic, biorobot or android and applies to an organism that has restored function or enhanced abilities due to the integration of some artificial component or technology that relies on some sort of feedback.* (wik 2015)

Cyborgs can be seen as an extreme version of wearable computing, where the technology becomes a part of the body. Both the work of Stelarc and Mann touches on this term. Stelarc with his third arm and other body extension projects. In Mann (2012), the author describes the Mind Mesh, which can help blind people see, by using a camera and electrodes connected to the brain, see Figure 2.5. Cyborgs are also a part of popular culture; Figure 2.6 depicts the character Jean-Luc Picard from the Sci-Fi TV series Star Trek as "The Borg". Comparing the pictures of Mann and Picard, it seems fantasy is not that far from reality.

[3]See `http://stelarc.org/?catID=20265`

[4]Retrieved from: `https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/wearable-computing` Section 23.8.1

Figure 2.5: Steve Mann wearing the Mind Mesh[4].

2.5 Mapping

Norman describes the concept of mapping this way: “Mapping is a technical term meaning the relationship between two things, in this case between the controls and their movements and the results in the world” (Norman 1998). He also talks about ‘natural mapping’; that is a mapping that relies on physical analogies and cultural standards. He uses the example of controlling sound volume. We have a cultural understanding of more volume being higher volume; that is if you add more volume the sound gets higher. Taste and colour, on the other hand, do not have the same additive properties. That means that the mapping between a control and these concepts will have to be constructed and learnt by the user. A classical Norman example of a natural mapping versus an arbitrary mapping is the stove top example, as seen in Figure 2.7. In this example, the natural mapping has a clear connection between the arrangement of the knobs and

[5]Retrieved from: `https://en.wikipedia.org/wiki/File:Picard_as_Locutus.jpg`

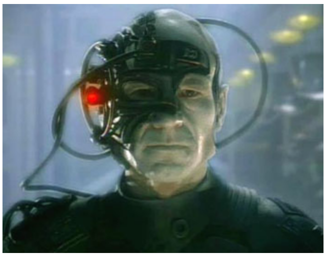
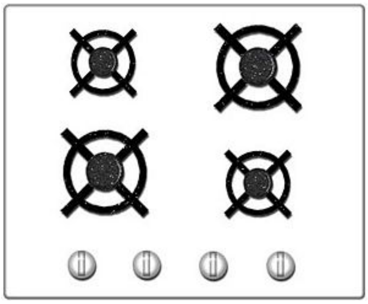


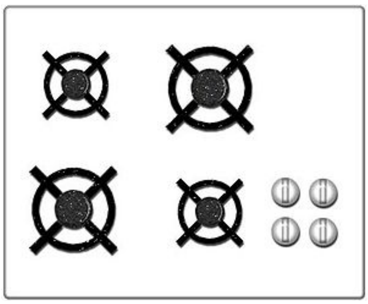
Figure 2.6: Jean-Luc Picard, from the TV series Star Trek, as Locutus after Borg assimilation[5].

the arrangement of the burner, while in the arbitrary example, that most of us have to live with, the connection is not as clear.

An example of mapping movement can be found in Svanæs (2013), in an example of scroll wheels on computer mice. The classic scroll wheel works by letting the user roll a wheel on the mouse, and the result is the page on the screen moving. If the user moves the finger upwards over the wheel the view of the page moves upwards, the reverse happens if the user moves the finger downwards. This interaction is a learned mapping. It relies on a natural understanding of being able to move a wheel around to create an up/down movement. Also, it enforces a specific metaphor for the movement. Moving the view of the page up and down, by moving the finger up and down over a wheel. This view has been challenged by touch screens where the metaphor is to move the content within the display of the device. That is by putting the finger on the screen and moving the finger up, you grab the content and move it, which is the opposite of the classic scroll mapping. Laptops also use a touch interface for interaction, the trackpad. This surface is quite similar to the touch screen, a similarity that makes it natural for the user to expect the same interaction metaphors. This similarity has led Apple to introduce what they call 'natural scrolling', where they adopt the touch screen metaphor of moving the content within the frame. The name 'natural scrolling' is quite miss leading when it comes to mapping, as this also is a learnt mapping. The difference is that they rely on different metaphors.



(a) Arbitrary mapping between knobs and burners.



(b) Natural mapping between knobs and burners.

Figure 2.7: Natural versus arbitrary mappings[6].

Figure 2.8: The inverted steering bike[7].

In the video Sandlin (2015) the author performs an interesting experiment. He learns himself to ride a bicycle with reversed steering. He already knew how to ride a normal bike, and try the reversed steering to see how the mind and body adopted to the new mapping. It took him eight months to learn how to ride the bike, and after having learnt how to ride the reversed steering bike he needed some time before being able to switch back and ride a normal bicycle again. The mapping for bicycle steering is direct. The handle bars are turned as much as you want the front wheel to turn. The relationship between turning the handlebar to the right to turn right is logical and a natural mapping. However, the reversed steering can also be said to be a good mapping. The turn of the handlebar is still the same as the turn of the wheel, only in this mapping, you extend the arm on the side that you want the bike to turn. Both mappings are learnt mappings. You have to teach your body and mind to use it.

[6]Retrieved from: `https://en.wikipedia.org/wiki/File:Old-style-kitchen-stove.jpg` and `https://en.wikipedia.org/wiki/File:Stove-square.jpg`

[7]Screen capture of video found at: `https://youtu.be/MFzDaBzBlL0?t=3m31s`

2.6 Tracking the Body

A significant use of wearable technology is to have it track the body. Body tracking can be used to monitor a person's health, to interpret hand gestures like sign language or to interface with computers. Many papers describe the use of wearable sensors for healthcare purposes, many of them citing an increasing part of elderly people in the population. Much of the research into wearable sensors and body tracking that were found in this literature search are aimed at medical applications (Skjæret et al. 2014, Chen et al. 2011, Yang and Hsu 2010, Zhou and Hu 2004, Patel et al. 2012).

For this project, the most interesting aspect is tracking of the body's posture and movements to use this data to control a pair of mechanical ears. There has been done research into different approaches to tracing the body by various means. Zhou and Hu (2004) looks into some of these approaches. The most precise way of tracking movements is by monitoring the body using cameras and picture analysis. This technique makes it possible to track and identify subtle movements quite precisely. However, the technique demands that the tracking happens in a quite strict environment. The background should preferably be blank, and the person that is being tracked should be alone in the picture to make the tracing as precise as possible. Also, the person being tracked can not be obscured. To track the body without observing it from the outside, but rather measure the body itself is less precise. Research has been done into using stretch sensors mounted on the body to gauge the bend of joints. In Mengüç et al. (2013) this approach is applied by using stretch sensors to measure the movements of a person's legs. The sensors are attached to a pair of stretchy training pants. This approach makes it possible to measure the body's movements almost as precisely as if external tracking had been used. Another method of tracking body movement on the body is by using Inertial Measurement Units (IMUs). An IMU is a sensor device that uses an accelerometer in conjunction with other sensors like magnetometer and gyroscope to provide measurement of directional movement. This method is less accurate than the other two, but the technology is much cheaper and easily available. The method involves using algorithms to analyse the data from one or multiple IMUs worn by a person. In Junker et al. (2008) this approach is applied to identify specific gestures based on analysing movement data from IMUs by using machine learning to teach the system to recognise gestures.

2.7 Tracking and Feedback Technologies

In this section, different technologies for tracking the body and providing feedback to the user will be reviewed. Stewart et al. (2014) propose a wearable designed to provide haptic feedback on the wearers roller-skating technique to improve their skills in Roller Derby. There is a multitude of wearables designed to improve the wearers technique and provide instant feedback to the wearer. There has been done research into applying this to Snowboarding, as discussed in Spelmezan (2012). Research has also been done into using feed-forward to influence the behaviour of users and teach them proper tooth brushing technique, as discussed in Alonso et al. (2014). Stienstra et al. (2012) discuss a technology that tracks the wearers during speed-skating to provide auditory feedback on weight distribution on the skate. In Skjæret et al. (2014) and Nawaz et al. (2014), three exergames for the elderly are reviewed. These games are a modified version of Dance Dance Revolution (DDR), The Mole by SilverFit, and LightRace in YourShape: Fitness Evolved.

The aim of the different technologies is to measure different kinds of physical activities. The measurement is done with sensors, but the sensors do not always capture the desired activities correctly. In the case of the three exergames described in Skjæret et al. (2014) and Nawaz et al. (2014), not all of them succeed in measuring the exercise correctly. This tendency is discussed in Skjæret et al. (2014), where movement specialists identified that the users could move in a way that diminished the effectiveness of the exercise and still be accepted by the system as a correct move. Analyses like this is a challenge with all body measurement. There is a relationship between recording precise movements and the complexity of the technology. This issue is discussed in Section 2.6; this challenge is present in all of the projects described in Table 2.3. The Roller Derby tracking wearable has not yet been completed, but according to the experiences made in the Snowboarding project described in Spelmezan (2012) it seems probable that the readings and feedback might be wrong or delayed at some times. The Snowboarding technique sensor and feedback project worked differently for different persons. However, in some cases, the wearer reported that the haptic feedback came at the wrong time and was more disturbing than helpful. It says in the paper that the feedback was correct only some 90% of the time. This number seems unfeasibly low, as the body is highly sensitive to this kind of feedback and even the smallest deviation could feel disturbing.

In the paper Leigh and Maes (2016) the authors describe a project where they made what they call a "Body Integrated Programmable Joints Interface". The item that they made is a body extension which a user can wear on the wrist; it gives the wearer control of two additional mechanical digits. A wearable controller called the MYO Armband is used to manipulate the body extension. The armband detects how the wearer moves his arm and hand and uses that to control the motions of the body extension.

The authors of Leigh and Maes (2016) suggest that this body extension, or rather a finished product using lessons learnt from the project, might help wearers carry heavy objects, or assist them with other manual tasks. The paper also suggests using the product as a "User interface on-the-go". When the body extension is deployed the two arms follow the command issued by the users hand and arm gestures. However, if the user makes a gesture indicating that the arms should retract, they curl around the wrist like a bracelet.

[8] Retrieved from: `https://thlodestone.s3.amazonaws.com/press/Thalmic-Labs-Press-Kit.zip`

[9] Screen-dump from the video found here: `https://vimeo.com/165186676`

Figure 2.9: A MYO Sensor like the one that was used for the project described in Leigh and Maes (2016)[8].

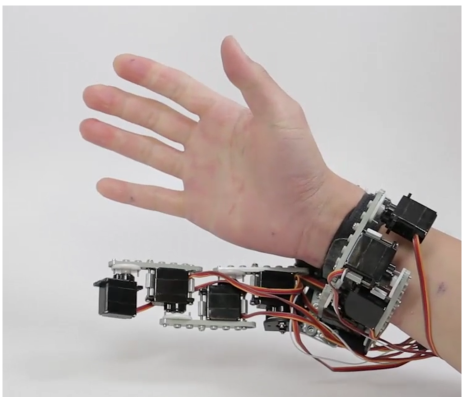


Figure 2.10: The Body Integrated Programmable Joints Interface described in Leigh and Maes (2016)[9]

Name	Roller Derby	Snowboarding
Sensors	IMU	Accelerometer
Actuators	Vibration, haptic feedback	Instant haptic feedback
Display/app	n/a	Data logging on computer
Measures/targets	Precision muscles in legs	Posture and weight distribution
Processing	Signal processing. Real-time feedback	Instant feedback
Aim	Training	Training

Table 2.3: Similar projects and technologies, table 1 of 5

Name	Brush and learn	Speed-skating
Sensors	Accelerometer	Pressure sensors
Actuators	Responsive handle, haptic feedback	Auditory feedback
Display/app	n/a	n/a
Measures/targets	Brushing technique	Weight distribution on skate
Processing	Signal processing. Real-time feedback	Instant feedback
Aim	Training	Training

Table 2.3: Similar projects and technologies, table 2 of 5

Name	The Mole	Light Race
Sensors	3-D motion-sensing camera	Kinect motion-sensing camera
Actuators	n/a	n/a
Display/app	Game on TV screen	Game on TV screen
Measures/targets	Core muscles	Core muscles
Processing	Immediate feedback from game	Immediate feedback from game
Aim	Training	Training

Table 2.3: Similar projects and technologies, table 3 of 5

Name	Body Integrated Programmable Joints Interface	DDR
Sensors	MYO Armband[10]	Dance mat
Actuators	Mechanical arms	Auditory feedback
Display/app	n/a	Game on TV screen
Measures/targets	Movement of arm and hand	Core muscles
Processing	Immediate movement by actuators	Immediate feedback from game
Aim	Body extension	Training

Table 2.3: Similar projects and technologies, table 4 of 5

Name	Captain Nemo costume	Fat man costume
Sensors	Distance sensor	n/a
Actuators	Lights and vibration motors	Smoke machine
Display/app	n/a	n/a
Measures/targets	Measures distance to 'enemies'	n/a
Processing	n/a	n/a
Aim	Interactive costume	Interactive costume

Table 2.3: Similar projects and technologies, table 5 of 5

2.8 Interactive Costumes in Theatre

The paper Honauer and Hornecker (2015) describe two interactive costume projects. The focus of the article is to look at challenges and requirements for interactive costumes. Additionally, the paper examines how classical theatre organisational structure can, or rather can not, support the interdisciplinary cooperation between technical staff, costume designers, and actors, needed to build and use interactive costumes.

The first project described in the paper is a project that the au-

[10] See: https://www.myo.com/

Figure 2.11: Picture of costumes made by Honauer and Hornecker and their students. A) Octopus costume. B) Captain Nemo costume. C) All costumes together. D) Diver costume. Picture from Honauer and Hornecker (2015)

thors did with their students. The students made interdisciplinary teams consisting of students both from technical, and design and media studies. The project was self-driven; no actors or other theatre stakeholders were involved in the projects other than to hold workshops for the students to learn about the problem area. At the end of the project, they organised a workshop where actors were invited to try the costumes that the teams had made. The costumes were inspired by Jules Verne's story "Twenty Thousand Leagues Under the Sea", they used lights, motors, and sensors to make the costumes interactive. The actors that tested the costumes provided very positive feedback. They felt that most of the time the costumes helped them get into and express their role.

The second project is a collaboration between the authors and a professional theatre company. In a sense, this project is simpler as it involved only two costumes, where one of the costumes only needed a small technical unchallenging modification. The other costume needed more work than the first and even ended up not functioning properly. In the end, the modifications that were made to make the costumes interactive were removed for the premiere of the play. The challenges that the authors faced when working on the interactive costumes were not primarily technical; the biggest challenge seems to have been working with all the stakeholders. The authors had problems with the technical personnel not bothering to answer their questions, the actors giving poor feedback and being very negative to the idea of making their costumes interactive. From the article, it seems that the traditional organisational structure of the theatre worked against the authors and made it hard to get the multidisciplinary collaboration they needed to make the project succeed.

The paper concludes that it is important to find a way of involving the technical staff, costume designers, and actors as early as possible. Also, all of the stakeholders have to work together and share responsibility. From the second project, the authors concluded that it was important to involve the actor from and early stage. The paper also finds that it is important to give the actors time to rehearse with the interactive costumes to learn how to use them and become more confident with using them. The article calls for future research into involving the actors earlier in the project in an iterative, fully user-centred or participatory process.

> *"One of our suggestions for future research is to involve actors early-on in iterative design. But how would we go about this? For a fully user-centred or participatory process they should be involved already during ideation."*
> (Honauer and Hornecker 2015)

Chapter 3

Methodology

3.1 Overall Research Approach

Oates (2006) has been used to structure the content of this chapter. The book describes how to plan and conduct research projects related to information systems and computing. To illustrate the elements needed in a research project Oates (2006) provides a diagram showing the different elements needed and the relation between them. Figure 3.1 is a modified version of this illustration. The highlighted boxes are the elements used in this research process.

Section 3.2 contains the *Strategies* that are relevant for this project. Section 3.2.1, 3.2.2, and 3.2.3 describe the strategies; *Design and Creation*, *Experiments*, and *Ethnography* from Oates (2006). The rest of the section describe other related strategies that are pertinent to the project.

Section 3.3 describe the *Data Generation Methods* that are related to the strategies outlined in the preceding section. This section also contains information about *Card Ranking*, which is not described by Oates (2006), but is used in this project.

Section 3.4 describe the *Data Analysis* concepts that are relevant to the data generated by the data generation methods discussed in the preceding section.

Section 3.5 evaluates *Validity Issues* related to the research process and the methods and strategies discussed in the chapter.

The final section, Section 3.6 describes how the various strategies and methodologies chronicled in this chapter can be used to make a research design suited to answer the research questions for the project.

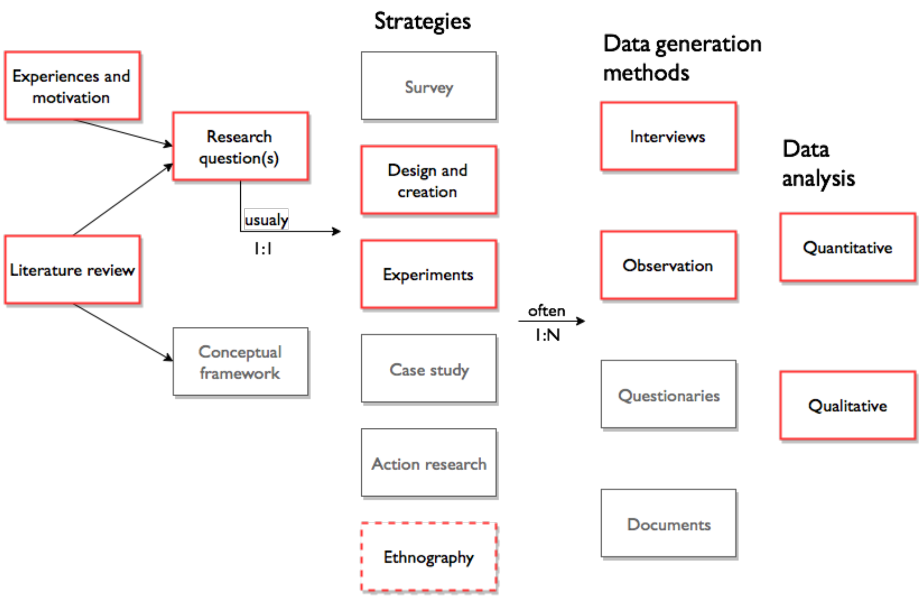


Figure 3.1: A figure from Oates showing possible elements of a research process, the highlighted rectangles shows which elements are in my research process.

3.2 Research Strategies

3.2.1 Design and Creation

Design and creation, also called 'research trough design' is described in Oates (2006) this way: "The design and creation research strategy focuses on developing IT products, also called artefacts". The strategy is typically a problemsolving approach using an iterative approach and the idea of 'learning via making' to develop a solution to the problem.

The suggested data collection methods for the design and creation strategy are interviews, observations, questionnaires, and documents. Data generation methods are discussed further in Section 3.3.

To evaluate the product, or artefact, that is the result of the development methodology guided by the design and creation strategy Oates (2006) suggests providing a set of criteria that can be used to judge the outcome of the process.

3.2.2 Experiments

An experiment in academic research is described in Oates (2006) as "[...] a strategy that investigates the cause and effect relationship, seeking to prove or disprove a causal link between a factor and an observed outcome." When using the experiment research strategy, the researcher starts by defining a hypothesis that is to be tested, then the researcher goes on to make experiments seeking to prove or disprove this hypothesis. An important aspect of all research that also applies to experiments is reproducibility; the experiments need to be thoroughly described and documented to be reproducible and thereby scientifically sound.

When conducting experiments, some factors have to be controlled and observed to secure a viable result. Some of these are variables, independent and dependent; controls; observation and measurement; and internal and external validity Oates (2006).

3.2.3 Ethnography

Ethnography is the study and description of peoples or culture Oates (2006). An ethnographical study typically involves spending much time in the field observing and studying a culture and how people interact. Much of the work involved in an ethnographical study is to describe and evaluate what has been observed, and how the observation influenced what was observed and how the ethnographer's perception of what was being observed influenced the way it was recorded.

3.2.4 User Centred Design

The Design and Creation research strategy are related to an iterative process described in Oates (2006), pages 111-112. This process is quite similar to the iterative design process detailed in the ISO 9241-210 (ISO 2010) standard for user-centred design. The ISO standard defines the iterative User Centred Design (UCD) process; see Figure 3.2. The process starts with planning the design process. Then it moves on to Understand and specifies the context of use; this is the first of the four steps in the iteration. The second phase is Specify the user requirements, then comes Produce design solutions to meet user requirements, and finally Evaluate the designs against requirements. After the final step, the process is either finished and the user requirements fulfilled, or the process moves on to either of the three other phases, depending on what is needed.

The UCD process is designed to aid in conducting processes and projects that have a defined user or user group. The process is supposed to make it easier for the team or person running the process to involve the user or users throughout the development process. When running a process like this, it is helpful to invite the user to participate from the start and during the entire process. By doing this, the user can help adjust the requirements and goals of the development process so that the finished product is as close as possible to what the user wants. It is much easier to make adjustments during the process than to fix the problems when the product has been finished.

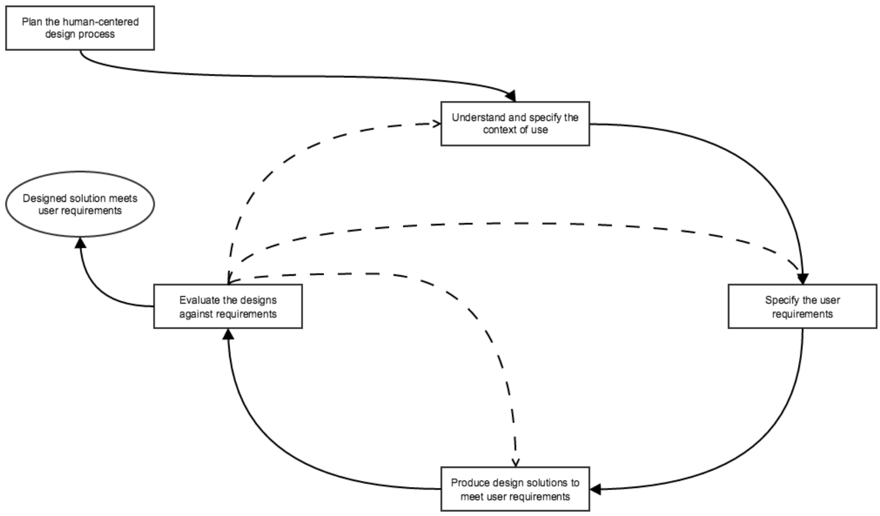


Figure 3.2: The User Centred Design process as depicted in ISO 9241-210.

3.2.5 Prototyping

Prototyping involves making fast, simple, and cheap versions of the product one wants to make. A prototype can be intended to test one or multiple functionalities that eventually will be combined and refined into a finished product. Prototyping is a useful tool to aid the developers in testing functionality without using too much time making a solution that eventually could be scrapped if it does not work as intended. Prototypes are used both in physical construction and software development. In both cases, investing money in making a product that might not work is a risk. By decreasing the investment cost and time to make the product the risk involved is also diminished.

3.2.6 Usability Testing

Usability tests are carried out to inform the design of the product that is being tested. By involving the users and letting them provide feedback, useful information about potential improvements can be gathered. There are multiple ways of performing user tests during the entire development process. User tests can be carried out on early prototypes to inform further prototyping, and when the product is ready for market a final test can confirm or reject this.

3.3 Data Generation Methods

3.3.1 Interviews

Interviews are a qualitative data generation method, which according to Oates (2006) is well suited in cases where the researcher wants to explore less quantifiable aspects of a person's experiences. Oates (2006) provides the following list of situations where a researcher ought to consider interviews as a data generation method:

- Obtain detailed information;
- Ask questions that are complex, or open-ended, or whose order and logic might need to be different for different people;
- Explore emotions, experiences or feelings that cannot easily be observed or described vi pre-defined questionnaire responses;
- Investigate sensitive issues, or privileged information, that respondents might not be willing to write about on paper for a researcher that they have not met.

Interviews are commonly used in research projects using the following research strategies: case study, ethnographies, surveys, and design and creation.

There are multiple considerations to make when planning and conducting interviews. When planning the interview, the researcher needs to be mindful of what kind of information they want to elicit from the interview subjects. Moreover, the researcher has to have an idea of what kind of discussion or conversation they want to have with the subject; this can significantly influence what information can be obtained from the subject.

There are three types of interviews that a researcher might want to consider:

- Structured interviews: Use pre-determined and identical questions a for all the interviewees.
- Semi-structured interviews: The interviewer uses a list of pre-determined questions as a guide to creating a more open and reflective conversation with the interviewee
- Unstructured interviews: The interview is more like a conversation on a specific topic, not guided by pre-defined questions.

Because the interviews are a quite personal exchange, it is important to consider the interviewees' experience of the situation to make them feel at ease and be able to respond to questions without the interaction between the interviewer and the interviewee influencing the interviewee's responses. It is important to keep the interviewees informed about their rights and how the data collected will be used. In general, the researcher should take all possible measures to make the interviewee feel comfortable and at ease in the interview situation.

When doing an interview one should record the conversation and responses that the interviewee makes to be able to analyse the interview later. At a minimum the interviewer should keep field notes, writing down the interviewee's responses and any additional questions or observations. It might also be a good idea, if the situation permits, to record the interview on audio or video tape. This, of course, should only be done with the interviewee's express permission.

3.3.2 Observation

In the Oxford Dictionary of English, the verb to observe is defined this way: "notice or perceive (something) and register it as being significant". That is what it is when used as a data generation method also, but when using observation in a scientific context, it is important to formalise the process. Observation can be employed with any of the research strategies discussed in Oates (2006). Observation can both be used to observe people and the interaction between them; it can also be used to observe objects, both physical objects and software programs.

There are many approaches to observation, Oates (2006) lists multiple tactics in the chapter on Observations, in the book one aspect is emphasised especially; the distinction between overt and covert observation. As the names imply, covert observation is to observe a subject without the subject being aware. While in overt observation, the subjects are aware of being observed. The two approaches have different advantages and drawbacks. If someone is being observed without being aware of it, he or she might behave in a way they would not if they knew they were being watched. This observation technique could uncover interesting insights. On the other hand, it is ethically dubious to use people in a research project without their knowledge. If the observation is done overtly, people might change their behaviour, but it also allows the observer to ask the subject questions and gain insights that way. Also, by having the consent of the subject being observed the research is more ethical than it would for covert observation, and the risk of aggravating the subject is much lower.

When making observations as a data generation method, it is important to record what is being observed, similarly to when conducting interviews. In addition to the observer noting what was observed it is a good idea to keep notes of any thoughts that the observer made and an analysis of what occurred. When conducting observations it is also important to consider validity, when using the human mind and senses as a scientific instrument the data collected is prone to be biassed. When making observations, it is important for the researcher to be aware of this and reflect on how the researchers own perception of the observed can influence how the observation is recorded or recollected.

3.3.3 Card Ranking

Card ranking, also known as card sort, is an exercise used to collect quantitative and qualitative data in a user test setting. The test involves using cards depicting different elements that the researcher wants the test person to evaluate. The test person is presented with the cards and then asked arrange them according to preference or some other relevant parameter.

Card ranking may not be the most robust quantitative data generation method as suggested by Alsos and Dahl (2008). The article indicates that the method is best suited as a tool to encourage reflection on the solutions represented on the cards.

> "*It [the card ranking exercise] provoked second thought, re-evaluation, and offered the possibility for test participants to compare strengths and weaknesses of the various solutions.*" (Alsos and Dahl 2008)

3.4 Data Analysis

3.4.1 Quantitative

Quantitative data is numerical data, according to Oates (2006), most commonly collected from experiments and surveys. This type of data is mostly used by positivist researchers, but as always this is not a rule, as interpretive and critical researchers might generate quantitative data also.

Data analysis is done to search for patterns to use those to draw some conclusions about the problem area. To analyse quantitative data statistical methods have to be used to determine if the patterns that a researcher or reader might see from the data has any statistical significance.

Oates (2006) emphasises four types of quantitative data. These are nominal, ordinal, interval, and ratio data. The descriptions of these data types are described in Oates (2006) as follows:

- Nominal data: Describe categories and has no actual numerical value. For example, checking a box to indicate gender in a survey. This type of data is also known as categorical data.
- Ordinal data: Numbers allocated to a quantitative scale. For example, answering how much you agree to a statement on a scale from "completely disagree", "do not agree", "agree", "completely agree".
- Interval data: Similar to nominal data, but now measurements are made against a quantitative scale where the differences, or intervals, between points on the scale are consistently the same size. It is possible to state the difference between two data values precisely.
- Ratio data: Like interval data, but with a true zero to the measurement scale. For example, people's age or height.
- Oates (2006) also mentions discrete and continuous data.

Statistical methods and validity related to analysing quantitative data will be discussed in Section 3.5

3.4.2 Qualitative

Qualitative data, in contrast to qualitative data, is non-numerical, this includes amongst others words, images, and sounds. This type of data is typically generated by case studies, action research, and ethnography, according to Oates (2006). It is also the main kind of data used and analysed by interpretive and critical researchers, but positivist researchers can also generate it. Quantitative methods can be applied to qualitative data by, for example, counting the number of times interviewees mention a topic. However, mostly quantitative data analysis requires the researcher to analyse and interpret the research data to find patterns that the researcher finds relevant. The problem is that unlike quantitative data; qualitative data can not use statistical methods to verify or disprove the researchers' hypotheses.

3.5 Validity Issues

3.5.1 Considering Research Validity

When conducting a research project, it is important to keep validity in mind, to make sure that the results and conclusions drawn from the research can be considered accurate. When determining the overall research strategy of a research process, it is important also to evaluate how to preserve the validity of the data generated by the process. Validity is an issue for both qualitative and quantitative data.

3.5.2 Internal Validity

According to Oates (2006), Internal validity is the measure of to which degree the recorded results of the research is a product of the researcher manipulating the independent variable, or if it is some other factor.

3.5.3 External Validity

External validity is a measure of how generalisable research is. A research project has high external validity if it is possible to reproduce the same results under various circumstances.

3.5.4 Ecological Validity

Ecological validity concerns experiment where a user tests a product or system outside of the context where it is intended to be used. Both Dahl et al. (2010) and Lew et al. (2011) argue that this could pose a threat to the validity of the experiment. Lew et al. (2011) state: "There are two primary types of HCI experiments: 1) Research Experiments for which the goal is to explore theories of interaction and produce new knowledge, and 2) Design Experiments, for which the goal is to evaluate interfaces and produce new designs." The Design

Experiments are most vulnerable to problems with ecological validity, where a solution is developed for a particular context. Research Experiments seeks to abstract away the context and is not interested in one specific context of use.

3.5.5 Construct Validity

"Construct validity is concerned with whether we are measuring what we think we are measuring" (Oates 2006). To evaluate the construct validity of research, the results of the research should be correlated with other results or other information to see if the results are consistent.

3.5.6 Triangulation

To make sure that what is observed or recorded is accurate it is possible to use triangulation, which is to use other experiments to test the same aspect. By doing additional trials it is possible to backup the results from one experiment with results from another, making the validity of the results higher.

3.6 Research Design

3.6.1 Research Question 1

RQ1: *What are important aspects to consider when developing mechanical body extensions for theatre.*

This question will be answered by completing the development of the elephant ears, ears version one, and reviewing the process. The lessons learnt from the process will be considered in the discussion chapter.

The research strategy that will be used to answer this research question is *Design and Creation*. Although, in Oates (2006), the

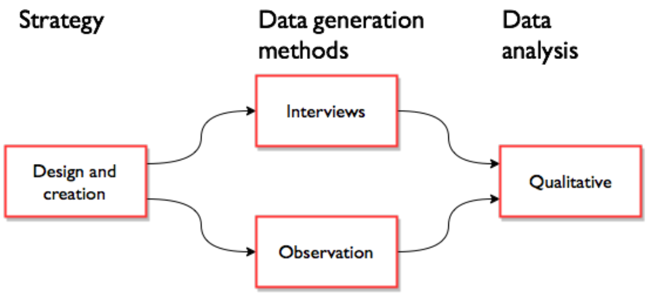


Figure 3.3: Research plan for research question one

methodology is aimed at developing information systems, the general idea can be applied to the largely physical construction tasks in this project. The strategy emphasises 'learning via making', which is a good description of the aim of project related to this research question. The suggested process for design and creation is an iterative approach; this approach is quite similar to the UCD methodology. Because of the importance of involving the user in the design process, this is what has been chosen for this project. The suggested data collection methods for the design and creation strategy are interviews, observations, questionnaires, and documents. For this project interviews and observation will be applied. To evaluate the success of the final product, some evaluation criteria have to be established. As this project is to use a UCD approach it is natural to establish these in cooperation with the user(s). The project is also somewhat related to the *Ethnography* strategy as the product will be tested in a real theatre setting and a part of the research will be to observe and see how the actor uses the ears in a real setting.

The main data collection method for the project is interviews. I will interview both the actor playing the elephant and the instructor for the play. The interview format will be semi-structured to let the interviewees reflect on the product and the different aspects to its applications to a theatre setting. The purpose of the interviews will be to discover what the subject thinks about the product and whether or not the product worked as expected. Data will also be collected through observation. The product will be used on stage, observing how the actor uses the ears in his performance could provide valuable information.

The project to develop elephant ears for theatre does not have quantifiable outcomes. The analysis of the results will thus be qualitative. The main data source for the evaluation will be interviews and observation. According to the methodology presented in Oates (2006), the analysis process will have two steps, data preparation and data analysis. In the first step, the data will be ordered and written down. As the main part of the data will be in the form of recorded interviews the discussions from the interviews will have to be written down. In the second step, the data will have to be reviewed and segmented.

Cooperative design, or participatory design, will in addition to Human Centred Design, be used in the design and construction of the ears. This choice has been made to involve the actor and costume designers in the design process. The system will only have one main user, the actor. However, for the creation of the ears, the costume designers are the main stakeholders. They have to be involved to make sure that the product is constructed in such a way that they can sew the fabric ears onto the mechanical skeleton. The actor who will use the ears will have to be involved in the process, not only to influence the design, but also to get comfortable with using the ears before using them on stage. Moreover, he needs to give feedback on how he likes wearing and controlling the ears so as to make a solution that works optimally for him.

3.6.2 Research Question 2

RQ2: *How should a mechanical body extension be controlled in order for the interaction to feel natural.*

This research question will be answered by developing a pair of mechanical ears and through user tests evaluate different mappings between sensors and ear movements.

The research strategy that will be used to respond to this research question is experiments. By using prototyping to develop a pair of mechanical ears, experiments using rating cards and usability testing

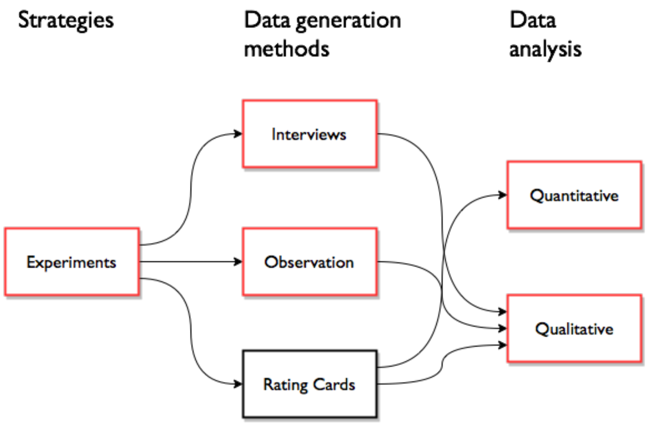


Figure 3.4: Research plan for research question two

together with observations and interviews for data generation will be employed in answering the question. Experiences made from answering the first research question, especially the construction experience will be useful for both the prototyping process and subsequent data gathering and analysis. To evaluate the interaction between the wearer and the ears, usability tests will be carried out on a set of test persons. The usability test will involve the test person trying different mappings with the ears. After having tried the ears, the test persons will be asked to complete a card ranking exercise. The test is done to generate some quantitative data in addition to qualitative data from discussing the rating the test person chose. The card ranking exercise also makes the test person reflect over the different modes; this effect from cart ranking is discussed by Alsos and Dahl (2008). After having completed the card ranking, the test persons will be subject to a semi-structured interview. This interview style was chosen in order to let the test person discuss his or her experience rather than just answer some set questions. Semi-structured interviews also make it possible to ask follow-up questions to explore interesting statements made by the interviewees during the user test, the card ranking, or when answering a previous question in the interview. During the testing, the test person will also be observed, and any interesting observations noted down as field notes. It was not feasible to film the test session; this might have influenced the subjects, and it was judged to be just as interesting just to observe and make field notes. The observation style was overt, as the subject was completely aware of being watched, this was a user test after all.

The data generated by the chosen research process is both quantitative and qualitative. The card ranking exercise provides quantitative interval data that potentially can be used to make a statistic evaluation of the different mappings. Although the data generated, as stated in Alsos and Dahl (2008) might not be very well suited for statistical analysis. The interviews, observation, usability tests, and card ranking discussion produce qualitative data that an be used both to evaluate the ears directly, and to assess any statistical results from the quantitative data analysis. The qualitative data also has to be analysed and evaluated. The analysis will be done by recording the interview and rating card sessions and by taking notes of important comments the test subjects make. The recorded data will then be analysed to look for common themes and feedback that are relevant to the projects research question.

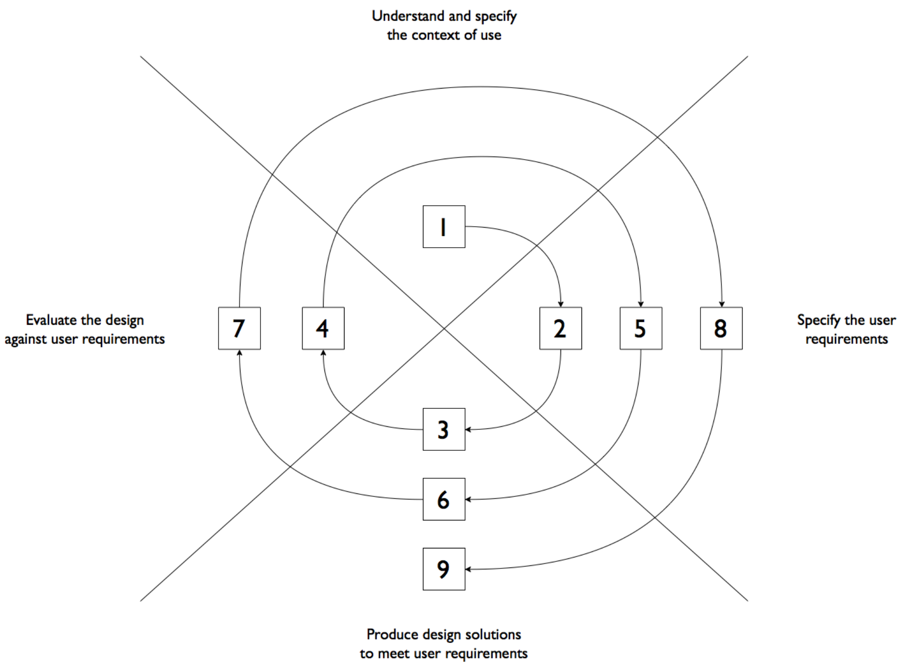
Chapter 4

Constructing the First Version of the Ears

4.1 An Iterative Approach

As discussed in Section 3.6 the development process for this project is iterative and user centred. The UCD process was realised through multiple meetings with the stakeholders for the project. Figure 4.1 illustrates the iterative process used in this project. Each section in this chapter will be dedicated to a step in the project's iterative process. A Gantt diagram of the process can be seen in Figure 4.2. The Gantt diagram uses the same letter codes as Figure 4.1.

Through the entire process, but especially in the initial phase, the evaluation criteria for the ears were established. This is discussed further in Section 5.1.



1. Meeting with costume designers and actor.
2. Meeting with costume designers and actor discussing the ears.
3. Make simple prototype using strips and remote control for servos.
4. Show the solution to the costume designers.
5. Discuss the prototype and suggest improvements.
6. Make new prototype with better attachment of servos.
7. Show the solution to the costume designers.
8. Discuss the prototype and suggest improvements.
9. Make the final version.

Figure 4.1: An illustration of the iterative process applied to the project.

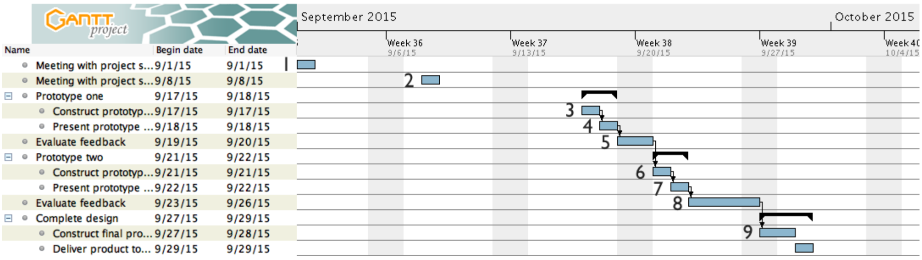


Figure 4.2: The Gantt diagram for the process

4.2 Meeting with Costume Designers and Actor

The first meeting was held in my supervisor's office. Marte Tiller, the person responsible for the costumes for the Children's Theatre explained what she had in mind for the ears. How big they would be, how they should move, and how the actor using them would behave in the role. Different ideas and approaches were discussed by holding servos against the head and trying to imagine how they would be attached and how they would move the ears.

After the first meeting, Marte introduced me to the actor who would play the elephant, Trond. We talked a bit about the ears, he seemed very interested and was positive to the project. He also agreed that it was important that he was involved and got to try the ears before he used them on stage to get familiar with them.

After this process, we had created a shared understanding of the context of use. The actor had explained how he was going to use the ears, and the costume designers had explained their needs. This communication corresponds to the first two steps of the iterative design process. This understanding of the context of use did not change during the project. That is why there are no more steps in this category for the rest of the process.

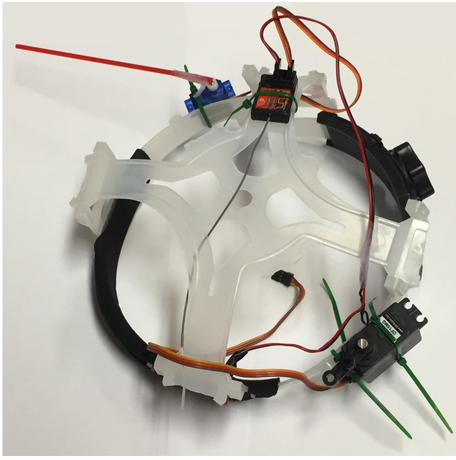


Figure 4.3: A picture of an early prototype using a remote control activate two servos.

4.3 Making a Simple Prototype

The next step in an iterative UCD process is to produce a solution. This process begun with my supervisor and me visiting Trond Are at IPD, he showed us around the workshop, and we discussed the project with him. He suggested that we use an already existing solution for fastening the ears to the head, something like the headband from a protective visor or the fastening mechanism from a hard hat. The first prototype used just that, the fastening mechanism from a hard hat, the prototype can be seen in Figure 4.3. This prototype had two servos strapped to the sides with strips. The servos were controlled with a radio remote control. The prototype gave the opportunity to make a fast and straightforward demonstration of the imagined functionality.

4.4 Show the First Prototype to the Costume Designers

The early prototype was shown to the sewing team. They agreed with the idea, and we discussed further development. Karoline, the person responsible for the elephant costume, suggested that we could fasten a metal hoop over the head to have a sturdy and stable place to fasten the servos and the ears.

During the meeting with the costume designers, we also discussed how the skeleton of the elephant ears should be constructed. Moreover, how the ears should be fastened to the helmet, this was important to get the position of the ears correct so that they would look good on stage.

4.5 Making a Second Prototype

In the next iteration, my supervisor and I worked for a couple of hours in the workshop at IPD to make the metal hoop or frame and fastening the servos to it. After a couple of tries, we arrived at a design that secured the servos sufficiently and also provided an acceptable level of comfort. The prototype can be seen in Figure 4.4.

After discussing with some students at IPD, my supervisor and I proceeded to create a hinge system to connect the ears to the helmet. The ears would be mounted on hinges; the hinges would then be attached to the servos. Hinges were used so that the servos would not have to carry the weight of the ears. The servos were connected to the hinges with flexible but strong metal wire from the steering mechanism of a radio-controlled model aeroplane. These wires do not deform when bent unless they are bent with considerable force. By using these wires any shock that might come from the ears being hit or shaken would not be transferred directly to the servos, but be partly absorbed by bending the wire. A simple illustration of the force transfer mechanism can be seen in Figure 4.5.

The structure that was chosen for the ears was a trapezium, where the long edge is hinged to the helmet and the angled edges form the

(a) From the side (b) From the front

Figure 4.4: Pictures of the first version of the metal hoop for securing the servos to the head.

length of the ears. This structure was chosen in order to provide strength and stability for the ears that would be fastened over the mechanic skeleton.

4.6 Show the Second Prototype to the Costume Designers

The new version was demonstrated to the costume designers and the actor. The actor complained of a piece of metal that protruded from the hoop and hurt his ear. This was his only negative remark. The control mechanism had not been completed yet, so he did not get to try to move the ears. The meeting was mainly for the costume designers to take measures and see if they could fit their test hood for the elephant head over the helmet.

4.7 Making the Final Version

In this iteration, the most important task was to complete the control mechanisms using bend sensors. The system consists of two modules, the sensor module and the servo module. The sensor module

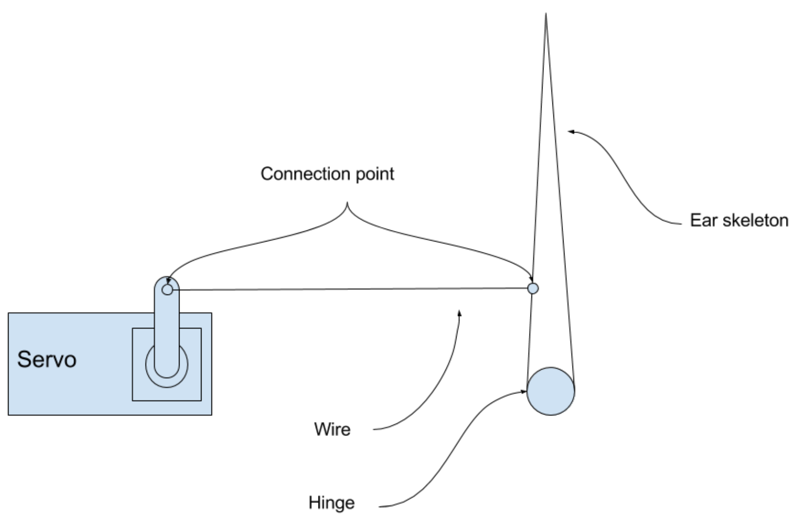
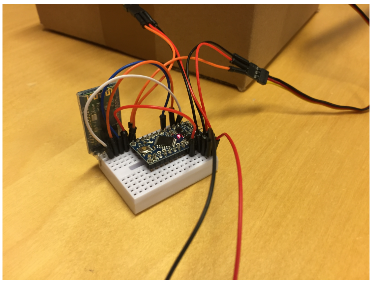
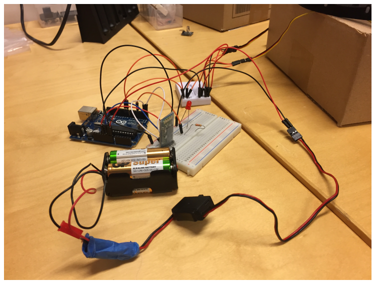


Figure 4.5: A diagram of the force transfer mechanism between servo and ear.



(a) The miniaturised version of the servo module.



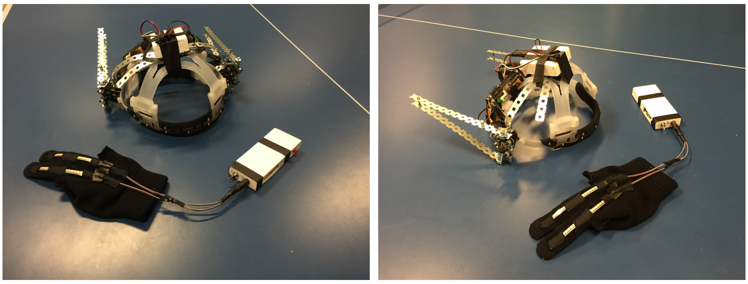
(b) The development board prototype of the servo module.

Figure 4.6: Illustrations showing the miniaturised and development board versions of the servo module.

records the values of the bend sensors, maps these values to degrees and send them to the servo module. The servo module is responsible for receiving sensor data from the sensor module and put these values on the servos. The communication between the modules is over Bluetooth. The technicalities of the different modules and the Bluetooth communication will be described in Section 4.8.

After having prototyped the design for the two modules using breadboards, jumper wires, and a pair of Arduino Unos, the design was miniaturised using Arduino Pros from SparkFun. These are much smaller than the Arduino Uno development board. The miniaturised versions were first assembled on small breadboards before the production versions were soldered. The difference between the two versions can be seen in Figure 4.6.

To protect the production versions of the modules my supervisor designed and printed cases to hold the electronics. The peripherals, sensors and servos, and power were connected through plugs to keep the design modular and maintainable. After some tweaking, the electronics fit within their enclosures and the first version of the ears were finished and ready for the dress rehearsal the next day. The finished version can be seen in Figure 4.7, without fabric and in Figure 4.8, when fitted with fabric.



(a) The finished version from the front.

(b) The finished version from the side.

Figure 4.7: The finished version of the ears with the sensor gloves.

Figure 4.8: The elephant ears being tried on for the first time.

4.8 Making the Ears Move

4.8.1 Thinking About Movement Mapping

As discussed in Section 2.3 it is important to think about how the user interaction with the final product will be. This is important to create a natural user experience so that the interaction do not feel forced or awkward. Operating the ears should feel natural. The mapping between the user's movement and the ears' movement should be seamless and be perceived as logical and natural.

To control the ears, the wearer uses his index and middle fingers on his left hand. The reasoning behind using the left hand for the interaction is that the actor's right arm functions as the elephant trunk. By using the fingers to control the ears, the hope was that the mapping would feel natural and that the actor would get used to the interaction quickly. The degree the finger is bent is directly mapped to the movement of the ears, providing a logical relationship between the controls and the movement of the ears. If the actor moves his fingers slowly, then the ears will move slowly.

The original idea of the design was to make it possible for the actor to move both ears independently. That is why two fingers are used for the interaction. The index finger controls the right ear and the middle finger the left. When the fingers are straight, the ears are folded back and when the fingers are bent the ears straighten out.

4.8.2 Arduino

Rationale for Using Arduino

The Arduino was chosen for this project because of its simplicity. It makes it easy to prototype fast and efficiently. The Arduino has multiple libraries available and is very easy to program and re-program. The development board makes setting up a prototype efficient and uncomplicated. It also makes it easy to miniaturise the prototype. The same program used to program the development board can be transferred to a multitude of small Arduino boards without having to do any changes to the program.

The Servo Module

This is the simplest module, as it only connects to two servos and the Bluetooth unit. The servo module was configured as the Bluetooth master; this means that it had the Bluetooth `HC-05` unit. This module used the standard serial Bluetooth configuration and library. The Bluetooth unit's `VCC` and `GRD` pins were connected to the corresponding pins on the Arduino. The `TXD` pin on the Bluetooth unit was connected to the `RX` port on the Arduino and the `RXD` port on the Bluetooth unit was connected to the `TX` pin. These are the serial pins for the units. They have to be connected to the opposite pin type to function. `TX` to `RX` and vice versa.

The servos were connected to ground and current on the power supply; this was because they needed more current than what the Arduino could provide.

The schematics for the servo module can be seen in Figure 4.9.

The Sensor Module

This module is the most complicated one as it has two sensors that are connected in a somewhat complex manner compared to the servos in the servo module. The Bluetooth is also connected differently. This module uses the Bluetooth serial library from the course: TDT4112 - Programming Lab for Computer Science[1]. This library works differently than the standard serial library. Instead of connecting the serial ports of the Bluetooth unit to the serial ports on the Arduino, the Bluetooth unit's serial ports were connected to digital `10` and `11` on the Arduino.

The bend sensors are a type of variable resistor. By bending the sensor, the particles in the sensor rearranges changing its resistance. When the sensor is completely straight, the resistance is 10Ω, if bent

[1]Course page: `http://www.ntnu.edu/studies/courses/TDT4112#tab=omEmnet`

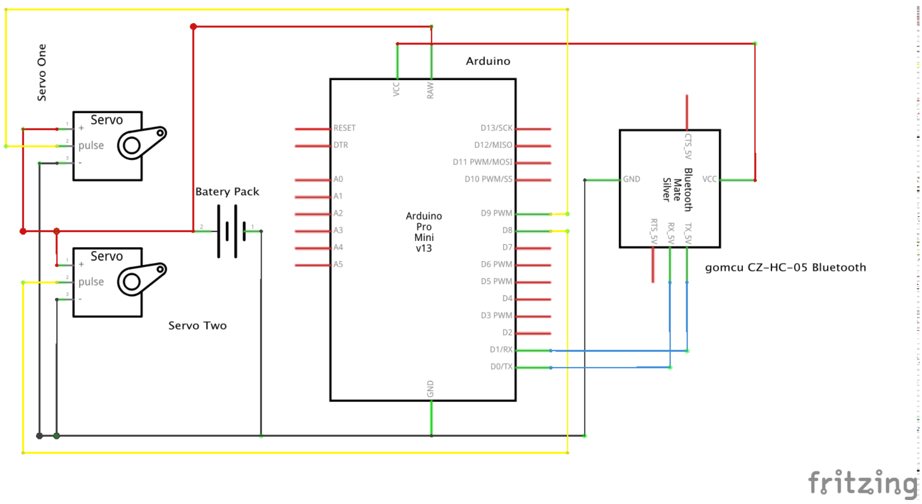


Figure 4.9: The schematics for the servo module. Made with Fritzing.

the resistance rises to $22k\Omega$. The sensors used in the project are described in the data sheet provided by the manufacturer (Spectra Symbol 2014). The sensors were connected to the `VCC` and `GRD` pins of the Arduino. The connection to ground was through a $22k\Omega$ resistor. When measuring the value of the bend sensor, what you are measuring is the total resistance. That is why a $22k\Omega$ resistor was placed between ground and the sensors ground pin, to provide a stable minimum resistance. The data wire for the first sensor went from analogue `0` to the sensor leg connected to ground. The other sensor used analogue pin `1`.

The sensor module also had a light to indicate Bluetooth communication. This LED was connected to digital pin `4` and to ground via a 220Ω resistor.

The schematics for the sensor module can be seen in Figure 4.10.

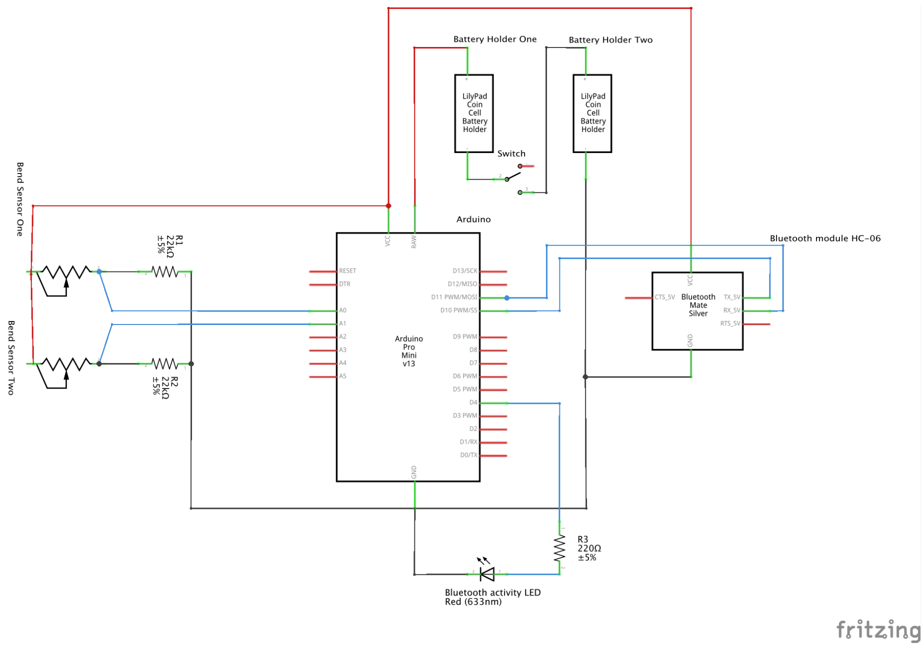


Figure 4.10: The schematics for the sensor module. Made with Fritzing.

4.8.3 Bluetooth

To handle the communication between the sensor and servo unit we, my supervisor and I chose to use Bluetooth. To keep the communication as simple as possible, the Bluetooth solution that we decided to use was an `HC-05` and an `HC-06` unit that were already paired. The units were set up in a master-slave relationship where the `HC-05` unit was the master, and the `HC-06` was the slave. For the programming of the Arduino, this does not have any practical importance. The two units have microcontrollers on them that automatically finds each other and establishes contact. This means that the programmer writing code for the Arduinos does not have to do any significant setup. The units provide a serial communication between each other; this means that on each Arduino the programmer can read and write to what is essentially the same serial stream. A library is needed to handle the serial communication. First, we tried using a custom library for serial communication over Bluetooth that had been made for the P-lab course. This solution worked for a while until we also sought to use the servo library. It turned out that there was a timer conflict between the servo library and the P-lab Serial library[2]. They both used the same timer in the processor. Which resulted in only one servo being able to operate at a time. To fix this, we changed the code for the servo module to use the standard Serial library in the servo module.

4.8.4 Implementation

The implementation of the logic for the Arduinos was done in the C-like language Sketch. Sketch is a language made specifically for the Arduino, but it is in effect the same as C. A point that makes Sketch different from regular C is that for a Sketch program to compile it is required that it contains the methods `void setup()` and `void loop()`. The setup method is executed when the Arduino starts up. Then the loop method is run again and again until the Arduino powers down. Compiling and importing libraries in Sketch is also made easy through the Arduino IDE.

[2]Retrieved from the course's GitHub page: `https://github.com/idi-plab`

The program code for the sensor and servo modules can be found as an attachment to this paper, please see Appendix B.

Chapter 5

Evaluating the First Version of the Ears

5.1 Evaluation Criteria

As mentioned in Section 3.2, Oates (2006) calls for the definition of success criteria that can be used to judge the finished product. This project has been run using UCD; this means that the user has been central in establishing the requirements for the product. The evaluation method should reflect that the process used UCD, but it should still be in keeping with Oates (2006).

The UCD process lends itself to a thorough evaluation process through the iterations. In every iteration, one tries to establish requirements and make a solution achieve these requirements. After that, the solution is evaluated based on the requirements to gain insights for the next iteration. During the iterative process the requirements proposed by the main users, the actor and the costume designers, were recorded and formulated as success criteria. The criteria were not established through a direct discussion, but rather by extracting the ideas and requirements that the costume designers and the actor came up with while discussing the project. Some basic success criteria that the users did not explicitly ask for, but my supervisor and I as saw as fundamental goals that we wanted to achieve were also added.

The basic success criteria for the ears is of course that they move. That is after all the entire purpose of the project, to make moving ears. Then the success of the movement would be evaluated based on to what degree the actor wearing the ears could control them. The interaction needed to control the ears should also be as discreet as possible. Another general criterion is that the ears should be quite solid in construction. They are meant to be used in some performances, and there will be a certain amount of wear and tear.

The actor wished that the ears should fit snugly and securely to the head. He did not want the ears to move around or fall off during a performance. He also wanted the ears to be reasonably comfortable to wear. That means that comfort will be one of the success criteria, another criterion will be that the ears can be fastened to the wearer's head securely.

The costume designers needed the mechanical components of the ears to be compatible with their design for the elephant's head. That meant that it should be possible for them to sew a hood that would encase the head of the wearer and hide the mechanics of the ears. They also needed some skeleton to fasten the fabric ears to. The pattern that was used to design the elephant ears placed the elephant ears about the same place that the wearers ears were, maybe a bit higher. For the costume to look nice, they also wanted the mechanics and sensors to be as small and unobtrusive as possible, for them not to show through the costume. Table 5.1 lists all the success criteria. Where **C1** are the general criteria, **C2** are the actor criteria, and **C3** are the criteria set by the costume designers.

—***General Success Criteria***—

C1.1 The ears should move. Success will be measured based on to what degree the movement is controlled by the wearer.

C1.2 The interaction needed to control the ears should be as unobtrusive as possible.

C1.3 The ears should be reasonably solid.

—***Actor Success Criteria***—

C2.1 It should be possible to fasten the ears securely to the wearer's head, in order for them not to fall off or move around during performance.

C2.2 The ears should be comfortable to wear.

—***Costume Designer Success Criteria***—

C3.1 It should be possible to fit a hood over the head of the wearer. This hood should hide the mechanics of the ears.

C3.2 The mechanical ears should provide a skeleton to which the fabric could be fastened.

C3.3 The ears should be placed about the same place as the wearers ears.

C3.4 In general, the mechanics and electronics for the ears and sensors should be small and easy to hide under the costume.

Table 5.1: List of success criteria for the first version of the ears.

5.2 Interviews

5.2.1 About the Interviews

To let the interviewees reflect on the different questions and make it possible to explore new themes if they were brought up, the interviews were carried out as semi-structured, in accordance with the research design discussed in Section 3.6. The interview guides for the interviews with the actor and instructor can be found in Appendix C. Both interviews were done on the same day, 14. October 2015, almost two weeks after the premiere of the play. The timing was chosen to be late enough for the actor to familiarise himself with the ears, but also early enough that he would have the learning process fresh in his memory. The instructor also needed to have seen the play many times to have made an opinion of how the ears worked on stage, not just one of two times, but in general. Both interviews were done in Cafe-sito Stripa, at Gløshaugen. The location was chosen in order to keep the atmosphere informal and like a normal conversation in the hope that this would make the interviewees more prone to speak their mind.

5.2.2 The Actor

What's your experience of using the ears?
"They are great! When they work...". Already in the very start of the interview a problem was revealed. The actor did not feel confident that the ears would work every time. The biggest worry was the sensor module. Sometimes the bend sensors would become detached from the box with the Arduino and Bluetooth unit. Other times the bend sensors would get caught in the fabric in the gloves. This, he said, was the biggest problem. If the plug for the sensors fell out when he put on the costume, he could always try to plug it in again through the fabric. However, if the sensors got caught on the glove then there was nothing he could do, and he had to manage without being able to move the ears. However, when they do work, he said, the response from the audience has been phenomenal. The actor told about the premiere when he got an applause when he entered

as the elephant. He commented that he thought, "Wait a minute, it's not me, but the ears that are getting the applause".

Does it feel natural to operate them?
The actor was happy with the control mechanism for the ears; he felt it was natural to use his finger to control them.

How do you feel that the ears work on stage?
The ears was well received by the children in the audience. Some kids thought that he is a bit scary, some found him funny, and others tried to punch him.

Do you feel that they add something to the performance?
"Absolutely! They make the character more playful and interesting". The actor said that there was much interest in the ears and how they work. Many people approached him after the shows to ask how the ears work. He said that he felt that the ears add a lot to the performance and the character and that the character would not be the same if it were not for the ears. Moreover, he said that he enjoyed experimenting and using the ears in fun ways. The ears made the character and the acting more playful.

Have you grown in the way you use the ears?
The actor said that he was a bit unsure of how to use the ears at the start, but after a few shows, he began to get used to them and worked them into the character using them to emphasise emotion and make funny walks.

What are your thoughts on the control mechanism? Do you think it is a problem that one can see that the ears are controlled by the hand?
Because the costume was a bit tight, the actor was not able to use the fingers individually. Therefore, he could not move the ears individually; he said that he did not feel that this was a significant loss because it is important to keep the interaction uncomplicated. When he started using the ears, he was still a bit unsure of how to use them, sometimes he even forgot that he had them. However, after some performances, he got used to them and found fun ways to use them on stage. He said that he did not think that it was a problem that the audience could see that he used his hand to control the ears.

Can you think of any alternative methods for controlling the ears?
The actor had no ideas for alternative control mechanisms; he expressed that he liked using his hand.

Do you have any positive or negative feedback on the ears?
The actors main critiques of the ears were that the helmet holding the ears was a bit uncomfortable and that he felt that he could not trust that the ears would work all the time. However, thanks to the hard hat fastening mechanism the ears fit securely on the actors head.

5.2.3 The Instructor

Were you involved in the decision to make mechanical ears for the elephant?
She said that she had and that they had known quite early on that there was a possibility for cooperation with, as she put it, "The guy who did the tail for 'Peer!'[1]". So they had known that they could make something move, and they found out that the elephant's ears would have the biggest effect. The instructor said that they also chose to do the elephant ears because the elephant is such an important character in the play.

How did you imagine that the ears would work?
"The movement is exactly how I thought they would be, they are just a bit small compared to what I imagined"

What are your thoughts about using this kind of technology in theatre?
The instructor said that she thought that using this kind of technology in a theatre setting is crucial to living up to people expectations nowadays. She stated that because of the increased availability of movies and TV shows, people want to see something new and exciting. They want to see things that they can not do by themselves at home. This is, she said, especially important for children theatre.

[1] The play 'Peer!' is Knut Nærum's adaption of Henrik Ibsen's classic 'Peer Gynt'. The play was performed by 'Studentersamfundets Interne Teater', and was on from October to November 2014

Children are very used to being entertained by flashy and colourful children's shows. You need to work harder to keep their attention. While in a show for adults a good text might be enough, in a show for children the visual aspect is most important.

Can you tell me a bit about the lights on the octopus?
There was an octopus character in the play; he had lights on his costume that changed colour. The instructor said that the script had said that the octopus should change colour, and using lights on the costume was a nice way to do this. Originally the lights were supposed to be controlled by the actor who played the grandfather and the elephant. This plan turned out to be problematic because of range problems with the remote control for the lights. They decided to let the actor that played the octopus use the remote himself, and control the lights. He found it challenging to use the remote control inside the costume, but ultimately he had more control, and he learned how to operate the remote after a while.

What are your thoughts on the control mechanism? Do you think it is a problem that one can see that the ears are controlled by the hand?
The instructor did not feel that there was a problem with the way that the ears are operated. She commented that the control mechanism only made the character feel more alive.

Can you think of any alternative methods of controlling the ears?
She suggested using shoes with sensors in the soles to sense stomping. She thought that that might be a good way of controlling the ears because stomping is a natural behaviour for an elephant.

Do you have any positive or negative feedback on the ears?
To answer this question, the instructor recounted some feedback that she had gotten from the people involved with the play. Before the elephant got the mechanical ears, it did not get much attention, but after it got the moving ears people started saying that it became their favourite character. The response to the ears has been very positive.

5.3 The Ears in Use

Costumes get a lot of wear and tear; the technology has to be over-engineered to handle the stress that it is put through. At the start of the project, my supervisor and I were aware that the ears would have to be solid, but we seem to have underestimated how robust the construction would have to be. While the play was on, the ears had to be repaired or modified three times. First, there was some trouble with the sensor module, then the connection between the servos and the servo module, then there was a problem with the sensors again, and the ears had to be fixed because the structure holding the ears had been bent, and one of the servo arms had come loose. One should not underestimate how much physical stress a costume will see while a play is on.

5.4 Future Improvements

The main area of improvement that was identified in the interview process was the stability of the sensor module. The gloves need to be redesigned so that the bend sensors do not catch on the fabric. This improvement would let the actor relax more when he uses the ears, and it would make it possible for him to deliver consistent performances, with functioning ears every time. The most important improvement is still to make the ears and sensor module more robust. For further development, it would be a good idea to take inspiration from brands like GoPro, that makes action cameras. The enclosures have to be solid, and the number of movable pieces should be reduced as far as possible.

Chapter 6

Constructing Second Version of the Ears

6.1 Technology

6.1.1 Arduino

For the new version of the ears, similarly to the first version, Arduino microcontrollers will be used to handle communication, read sensor data, and control the mechanics. The Arduino that will be used is the same as before, the Arduino Pro Mini, a small Arduino design. However, it still has many pins for connecting all the components that will be needed for this project.

6.1.2 Bluetooth

The new version of the ears will still use Bluetooth, but to save battery Bluetooth Low Energy (BLE), also marketed as Bluetooth Smart modules will be used instead. The units that will be used for this project are called `HM-10` (hm2 2014), which are the BLE version of the `HC-05`/`HC-06` units that were used for the elephant ears. `HM-10` does not provide very advanced BLE features which mean that serial communication also will be used for the new ears the same way it was used for the elephant ears. A description of how Bluetooth was used in the elephant ears can be found in Section 4.8.3.

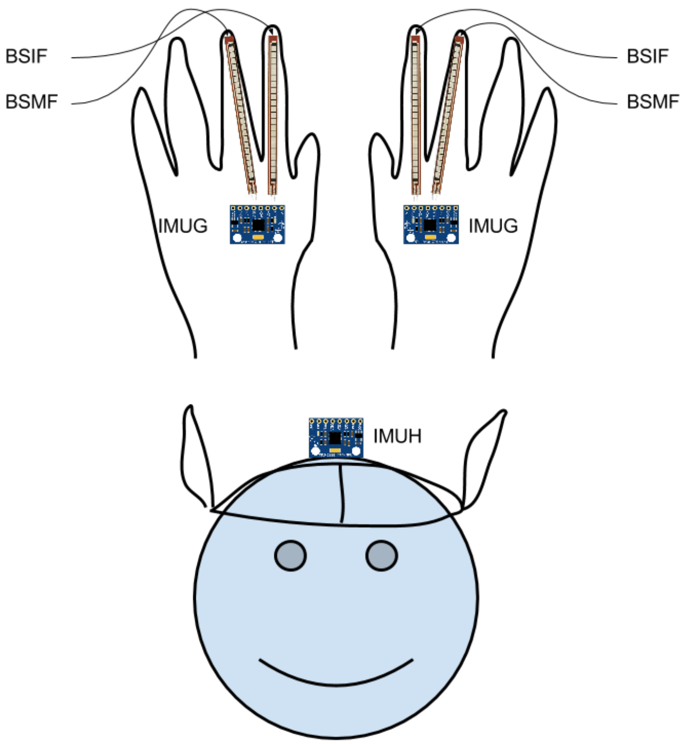
6.1.3 Sensors

To control the interaction with the ears the user will be wearing multiple sensors. The two sensor types that have been chosen are bend sensors and IMUs. The previous ear version only used bend sensors, but as the second version aims to explore more methods of interaction it has been decided to include IMUs. The IMU works by using an accelerometer, a gyroscope, and a magnetometer to calculate the yaw, pitch, and roll of the device. Figure 6.1 shows the different sensors and sensor placements.

6.2 Conceptual Design

6.2.1 Prototyping

This version of the ears was constructed through a rapid prototyping process, however since there were no customer or user to involve the process could not be run as a UCD process. This is both positive and negative for the development process. The positive side is that I was free to control the process and could decide exactly how and when I wanted to make the various parts. The downside of this is arguably bigger. By not having a customer or user to centre the process around it was much harder to know whether the project was on the right track. Because of the lack of user input, the lessons learnt from developing and testing the ears version one was very important for the development of the second version.



- Bend Sensor Index Finger (BSIF)
- Bend Sensor Middle Finger (BSMF)
- IMU Head (IMUH)
- IMU Glove (IMUG)

Figure 6.1: Figure illustrating the placements of the different sensors.

6.2.2 Ear Design

The ear design for the second version of the ears was very inspired by the experiences from designing and making the first version. However, the second version has a very different goal and will be used under different circumstances. While the first version needed to be solid to survive as a costume in a theatre piece, the second version will be used in a controlled test environment and will not need to especially sturdy. The first version had very specific requirements regarding interaction. The second version will have to incorporate many different modes of interaction, or mappings.

The second version of the ears will have two degrees of freedom per ear. This means that the ears will not only be able to rotate but will also be able to tilt the ear up and down. For an explanation of ear, movement names see Figure 6.2. This called for a specially designed servo holder system to attach the servos to the head and make them move as specified.

As in version one, the ears version two would be controlled using the hands, however for the second version both hands will be used. Bend sensors will be attached to the index and middle fingers on both hands, in addition an IMU unit would be connected to both hands and one IMU will be placed on the head. All these sensors will allow many different sensor combinations to control the ears.

6.2.3 Physical Design

The ears need to be fastened to the user's head; this was done similarly to how it was done for the first version of the ears. But because the elephant ears were much heavier than the ears would be in the second version it did not have to be just as solid. The same kind of hard hat fastening mechanism was used as in the first version, and the ears were fastened to a metal hoop. However, the metal hoop for the second version was made from a much softer metal alloy allowing it to be bent and manipulated manually, where the hoop for the first version needed tools to be manipulated.

The servo holders were designed using the Computer Aided Design

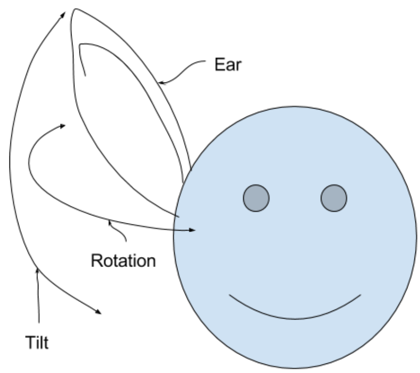


Figure 6.2: Illustration of the two ear movements, rotation and tilt.

(CAD) program FreeCAD and then 3D printed. The same was done for the box that would hold the electronics for the head unit. This design process needed several iterations before the 3D printed components came together and worked as they were supposed to. This was both because of malfunctions of the 3D printer, and errors on the 3D model. It proved to be very hard to make the 3D model correct on the first try, and multiple prototypes were needed before I learnt how to use both the DAC tool to make models that were intended for 3D printing. Pictures of the 3D models can be seen in Appendix A.

6.2.4 Electronic Design

The electronic design was driven by the need to communicate with two gloves instead of one. This meant that each glove would have its own BLE component as well as an IMU and bend sensors. The head unit needed to receive data from the glove units; this was not as easy as one might assume. The solution that was decided on had one BLE unit on the head for each glove to avoid pairing problems. To send data between two BLE units, they need to be paired. To do this pairing on the fly and switch between each glove as they transmitted data seemed like too much of a challenge. By having a designated BLE unit to handle communication with each glove unit the BLE units in the glove units can always be connected to their respective head BLE unit. This decision introduced problems regarding how to implement the communication in the microcontroller firmware; this will be discussed in Section 6.4.

The head unit needed to incorporate a button to switch between different mappings and a way to connect the servos and batteries to the head unit. For the initial design, it was decided to use a VGA input and cable to handle this connection.

Aside from the decision to use two BLE units in the head module the design was quite straight forwards, connecting the different components to the Arduino and trying to fit them in the box. The glove units did not get boxes as that would have made them too bulky, also it was decided that the boxes were not strictly needed for a test environment.

6.3 Construction

6.3.1 Head Unit

The main components in the head unit have two BLE units, one IMU, and the Arduino Pro Mini. The head unit also has a power switch and a mapping switch button. The power switch controls the power connection between the batteries and the Arduino raw power pin, and the button sends a HIGH signal to the Arduino when pushed.

The feature of the head unit that needed the most work was the connection between the head unit, and the battery and servos. The initial design used a VGA cable and input for this. That proved unreliable and clunky, almost doubling the weight of the unit. The VGA connection on the head unit was removed and replaced by header pins that made it possible to connect the jumper wires from the batteries and servos directly to the head unit. This saved weight and made the connection much more reliable.

The biggest problems with the head unit design are that the power switch does not control the power to the servos, this means that while the batteries and servos are connected to the head unit, the servos will draw power from the batteries. To mitigate this, the power had to be disconnected from the head unit while the ears were not in use. Also, the design of the entire head piece was not very comfortable to wear. This problem was not addressed because the discomfort was not that high and the headpiece would not be worn for very extended periods of time.

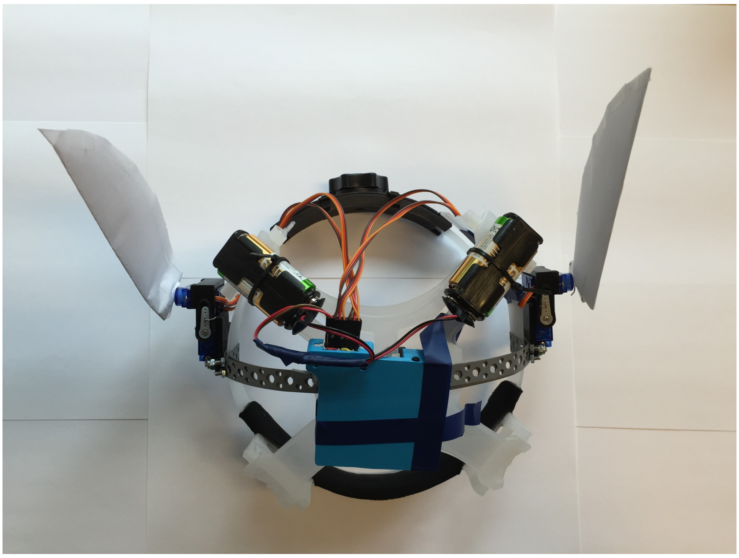


Figure 6.3: The head unit from above

6.3.2 Glove Unit

The glove units were designed and constructed by the project supervisor while I concentrated on getting the head unit completed to start the user tests.

The glove units' main components are the Arduino pro mini, a BLE unit, an IMU, and a pair of bend sensors. The sensors are not connected directly to the Arduino; they are joined as a separate part that connects to the Arduino via jumper wires. This allows the user to wear the sensors on a glove on the hand, while the Arduino, BLE unit and batteries are strapped to the user's wrist with a Velcro band for stability. The glove unit design is quite simple and utilitarian, but the solution is elegant and reliable.

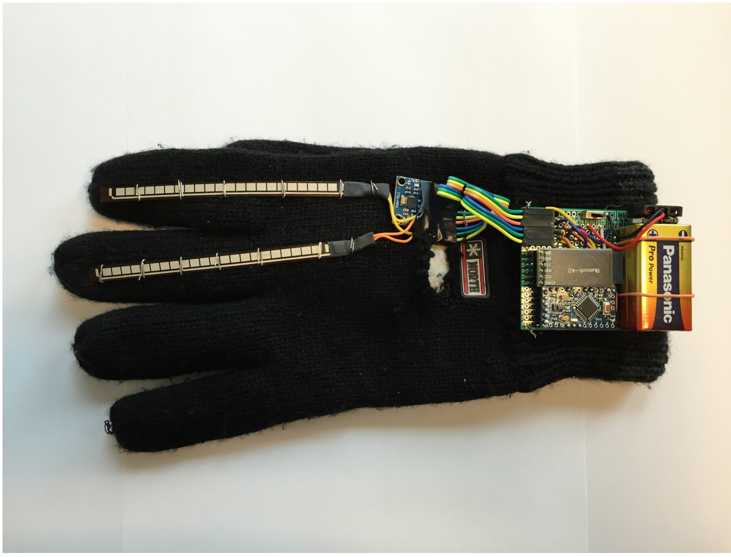


Figure 6.4: The glove unit

6.4 Coding and Mapping Design

6.4.1 Microcontroller Firmware

The head unit polls data from each glove unit, for each loop it polls one glove unit and writes the sensor values to the servos that the glove control. The next loop it does the same for the other glove. The loop is the piece of code that the Arduino executes. In the head units case this loop consists of reading from a glove unit and

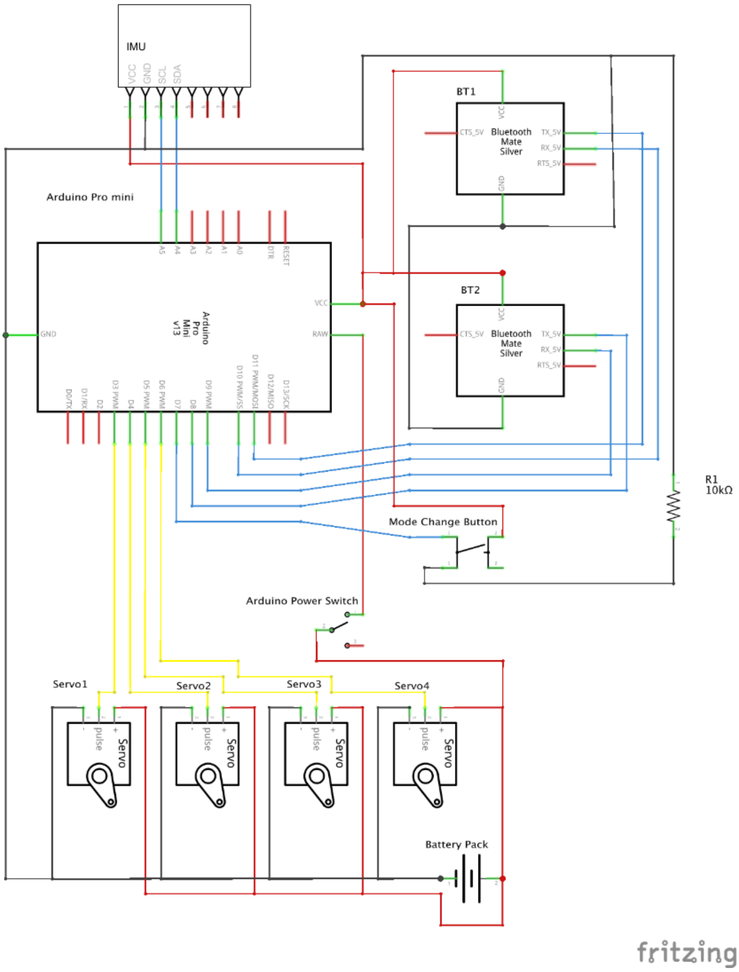


Figure 6.5: The schematics for the head. Made with Fritzing.

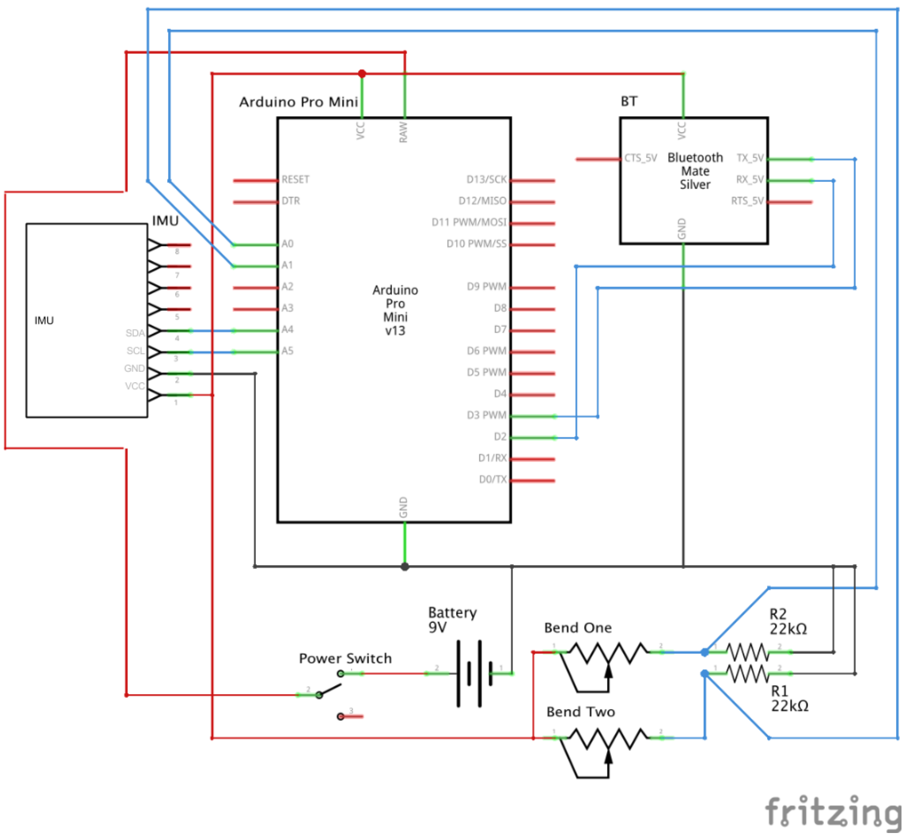


Figure 6.6: The schematics for the glove module. Made with Fritzing.

then updating the servos based on the reading and what mapping is chosen. The glove unit reads from its sensors and transmits the readings to the head unit. The program code for the head and glove units can be found in Appendix B.

6.4.2 Challenges

When it was decided to use two BLE units in the head unit in order to communicate with two glove units, this introduced a problem for the implementation of the head unit. Because of a limitation in the SoftwareSerial library for the Arduino it is impossible to read from two bluetooth units at the same time, this is because the BLE units are read from and written to using this library. This is why the solution described in Section 6.4.1 was chosen. To read from both BLE units the Arduino needs to specify which SoftwareSerial connection is active and readable. This effectively halves the speed at which it is possible to read from the glove-units because each glove can only be read every other loop. In addition there was a timer conflict between the PlabBTSerial library that was used to handle the bluetooth communication and the Servo library. This conflict meant that the servos had to be logically detached from the Arduino when any Bluetooth communication was performed and then reattached to be written. This lead to some mild servo jitter.

6.4.3 Mapping Design

There are very many possible sensors combinations that can be used to control the ears. From each hand there are five outputs, bend sensors on index and middle fingers and yaw, pitch, and roll from the IMU. Also, there are three outputs from the head mounted IMU. To lower the complexity, and because it makes more sense from a usability perspective, both ears will always be controlled by the same sensor value from the glove corresponding to the side of the ear. This decision means that if the index finger on the right hand controls the rotation of the right ear, then the index finger on the left hand will control the rotation of the left ear. In other words, it will not be possible to have a mapping where the index finger controls rotation for one ear and pitch for the other. Given these decisions, there are $\binom{8}{2} = 28$ possible distinct combinations of two inputs. Since each value in every combination can control both ear rotation and pitch, each combination of values is used twice, resulting in a doubling to 56 possible ways of controlling the ears. By reversing the mapping of the sensor values the number of combinations is quadrupled to 224 possible combinations. That is an infeasible amount of combinations to test, especially when used in a user test where the user is supposed to evaluate each input method. Moreover, many of these combinations will not be very user-friendly or usable. It might for example not make much sense for the user if their movements are inverted. For example, if hand pitch is used to control the pitch of the ears it will be quite unintuitive to lift the hand to lower the ears.

To test different input methods or mappings, used to control the ears some testing mappings have been defined. To make these mappings names for movements and parts needs to be established. The servos are mounted as displayed in Figure 6.7. The servos 1 and 3 are closest to the head, and their job is to rotate the ear. The servos 3 and 4 hold the ears themselves, and their job is to tilt the ears. If not specified in the mappings, the sensor values from the left hand control the left ear and vice versa for the right side. When describing the movements of the hands while using IMU data, if the hand is tilted out when the thumb is pointing upward, and the palm of the hand is pointing toward the body, rather than away from it. To make the table more concise abbreviations are used, these are IMUG, IMUH, BSIF and BSMF.

6.4.4 Mappings

The following six mappings were chosen to be implemented for the usability test of the ears. They represent all the different sensors. The mappings that have been chosen should not be too hard for the users to learn and understand. Table 6.1 shows which sensors are used to control which ear movement.

- `M1` Bend sensors on hands are used to control the ears. The sensor on the index finger controls rotation and the sensor on the mid-

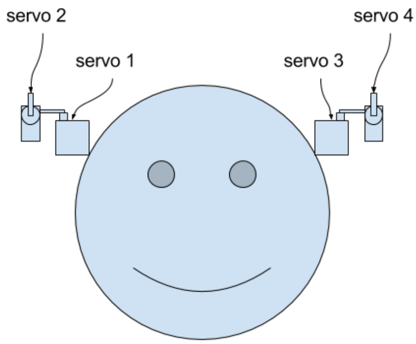


Figure 6.7: Illustration of servo positions.

dle finger controls tilt. The ears tilt upwards and are rotated against the head when the fingers are straight.

M2 The hand IMU's pitch and roll are used to control the ears. The rotation of the ears are controlled by the roll and the tilt is controlled by the pitch value. The ears tilt upwards and are rotated against the head when the hand points upwards and is tilted out.

M3 The ears are controlled by a combination of IMU and bend sensors. Rotation is controlled by the roll value of the IMU and the tilt is controlled by the bend sensor on the index finger. The ears tilt upwards and are rotated against the head when the index finger is straight the hand is is tilted out.

M4 The ears are controlled by a combination of IMU and bend sensors. Rotation is controlled by the index finger and the tilt is controlled by the pitch value of the IMU. The ears tilt upwards and are rotated against the head when the hands point upwards and the index finger is straight.

M5 The ears are controlled by the head IMU and the bend sensors on the hands. The rotation is controlled by the pitch value from the IMU and the tilt is controlled by the bend sensor on the index finger. The ears tilt upwards and are rotated against the head when the index finger is straight and the head is bent forward.

`M6` The ears are controlled by the head and hand IMUs. The rotation is controlled by the pitch value from the head and the tilt is controlled by the pitch from the hands. The ears tilt upwards and are rotated against the head when the hands point upwards and the head is bent forward.

	Sensors	**Rotation**	**Tilt**	**Zero Position**[1]
`M1`	Bend Sensors (BSs)	BSIF	BSMF	Fingers straight
`M2`	IMUG	Roll	Pitch	Hands points upwards and tilted out
`M3`	IMUG & BSs	Roll	BSIF	Index fingers straight and hands tilted out
`M4`	IMUG & BSs	BSIF	Pitch	Hands point upwards and index fingers straight
`M5`	IMUG & BSs	Pitch	BSIF	Index fingers straight and head bent forward
`M6`	IMUG and IMUH	Head pitch	Hand pitch	Hands point upwards and head bent forward

Table 6.1: Mappings for mechanical ears.

In order to set the different mappings the following list of criteria was used:

- The mapping should be 'natural' and feel intuitive.
- All sensors should be represented in the final list of mappings.
- The mappings should represent a broad selection of sensor combinations.

Based on the above list of criteria I picked the six mappings that would be used. I chose to include `M1` because I thought it might be interesting to try only the bend sensors. This mapping is the closest to the mapping used for the first version of the ears. `M2` was chosen seeing as `M1` used only the bend sensors, I thought it would

[1] Ears tilt upwards and are rotated against the head

be interesting to use only the IMUs. `M3` and `M4` were selected to try the combination of bend sensors and IMUs, one mapping where IMU is used for roll and bend sensors are used for tilt and one where the mapping is the other way. I chose not to use yaw because it was hard to get solid sensor values without moving the arms to uncomfortable positions. The two last mapping, `M5` and `M6`, were included to test the head IMU. I decided only to use the pitch of the head because that was the easiest and most logical mapping to use, the ears would follow the movement of the wearers body. An overview of which sensors are mapped to which ear movements is showed in Table 6.1

Figure 6.8: Collage of different ear positions. The x-axis goes from minimum to maximum rotation, and the y-axis goes from minimum to maximum tilt.

Chapter 7

Evaluating Second Version of the Ears

7.1 Evaluation Criteria

Unlike the development process of the first version of the ears, the development of the second version has not been iterative. In Section 5.1 a set of evaluation criteria were defined. The choice to use evaluation criteria was motivated by Oates (2006). In the description of the design and creation strategy, Oates (2006) recommended the use of evaluation criteria to assess the product of the process. The strategy for this project is experiments, which means that evaluation criteria not necessarily are needed. Because of the positive experiences of using evaluation criteria for a prototyping process lead to the decision also to use them in this project.

There are no users or customers that can help define evaluation criteria for this version of the ears. However, the development process for the second version of the ears would benefit from a formalised goal-oriented set of criteria to drive the process during development and to evaluate the final product. The criteria were defined in co-operation with the project supervisor; they are also inspired by the

C1	The ears should have two degrees of freedom.
C2	The movement of the ears should be smooth and follow the user input naturally.
C3	The ears should be responsive; there should not be much lag between the user signals a movement and the ears move.
C4	The ears should be able to use multiple sensor inputs to control their movement.

Table 7.1: List of success criteria for the second version of the ears.

criteria for the first version of the ears and the lessons learnt from the development of the first ears.

7.2 About the User Tests

7.2.1 Trying the Mappings

In Section 6.4.4 a set of six mappings were introduced as a selection of sensor servo mappings that were deemed interesting and potentially viable interaction alternatives for the ears. These mapping were programmed onto the ears and during the user tests, the test person got to try all six of them.

The user test starts with the test person trying the six different mappings. The number of mappings might be a bit overwhelming for the test person. For the test person to be able to get the most balanced impression of each mapping, each test person was asked to express four emotions for each mapping. These emotions were sadness, happiness, fear, and curiosity. These emotions were chosen without any psychological motivation, but rather as a way of motivating the test persons to use the ears. The test persons will also be told that they can play around and experiment with each mapping as much as they feel like to get used to it. The idea behind using the emotions is that it will be a good exercise that makes the test persons aware of how they use the ears, and it will make them explore each mapping. If the test persons were simply told to try each mapping as they liked, they might not spend much time in mappings that they thought was hard or uninteresting, but by making them try each mapping with an assignment, they have to experience each mapping. This also gives the test persons a similar experience for each mapping for them to judge each mapping on an equal basis.

7.2.2 Card Ranking

To obtain some quantitative data regarding the usability of the various mappings introduced in Table 6.1 in Section 6.4.4, each test person performed a card ranking exercise after having tried all the mappings. The cards used in the card ranking exercise are shown in Figure 7.1 where the card with the letter A corresponds to mapping 1 in Table 6.1, and B corresponds to 2, and so on. The card ranking also provides much qualitative data from asking the test person about why the different cards were placed in the specific order chosen by the test person. This technique is also a nice tool to encourage the test persons to reflect over what they liked and did not like about the different mappings.

7.2.3 Semi-Structured Interviews

Similarly to the evaluation of the ears v1, semi-structured interviews were conducted to gather qualitative information. After having tried the ears and performed the card ranking exercise each test person was asked a few questions designed to make them reflect on their experience with the ears. The questions are listed in Appendix C.3. Because this is a semi-structured interview, some of the test persons were also asked follow-up questions, in that case, the follow-up question is listed in that test person's interview summary.

7.2.4 Performing the User Tests

The user tests started with a short introduction explaining the sensors on the gloves and head unit. Then the test person was told that first they would try six different mappings using various combinations of the sensors to control the ears. Moreover, for each mapping they should try to show the four emotions discussed in Section 7.2.1: sadness, happiness, fear, and curiosity. During the testing, the users were explained each mapping as they got to them. They were also told to ask questions if they did not understand something about the interaction.

After the test persons have tried, all the mappings they will be asked if they feel like they were able to experience all of the mappings and are ready to continue to the next step in the user test. If they want to continue, they will be assisted in removing the gloves and ears and asked to sit at a table where they will perform the card ranking exercise. On the other hand, if the test person wants to try a mapping again they will get the opportunity to do this before continuing. After the card ranking exercise is done the test persons will be subject to a short semi-structured interview. Both the card ranking and semi-structured interview will be recorded at the test person's approval.

All the tests were performed in an office room at the IT Building at Gløshaugen. There was a mirror in the room so that the test persons were able to look at themselves while trying the ears. The door to the room was closed during the tests for the test persons to feel like they could relax and not feel that other people were watching them during the tests. The tests were performed in the period between 5 May and 11 May 2016. The plan for the user tests can be found in Appendix D.

7.2.5 Testing the Elephant Actor Separately

The elephant actor is the only person who has previous experience of using similar technology. This factor sets his user test apart from any other user test. Because of his previous experience with the elephant ears, he will be able to compare the experience of using the ears version one with version two. He also has experience from theatre which will influence the way he judges the ears. Because of this, the user test with the elephant actor will not be evaluated together with the other user tests, but rather be evaluated by a comparison between the old and the new version of the ears.

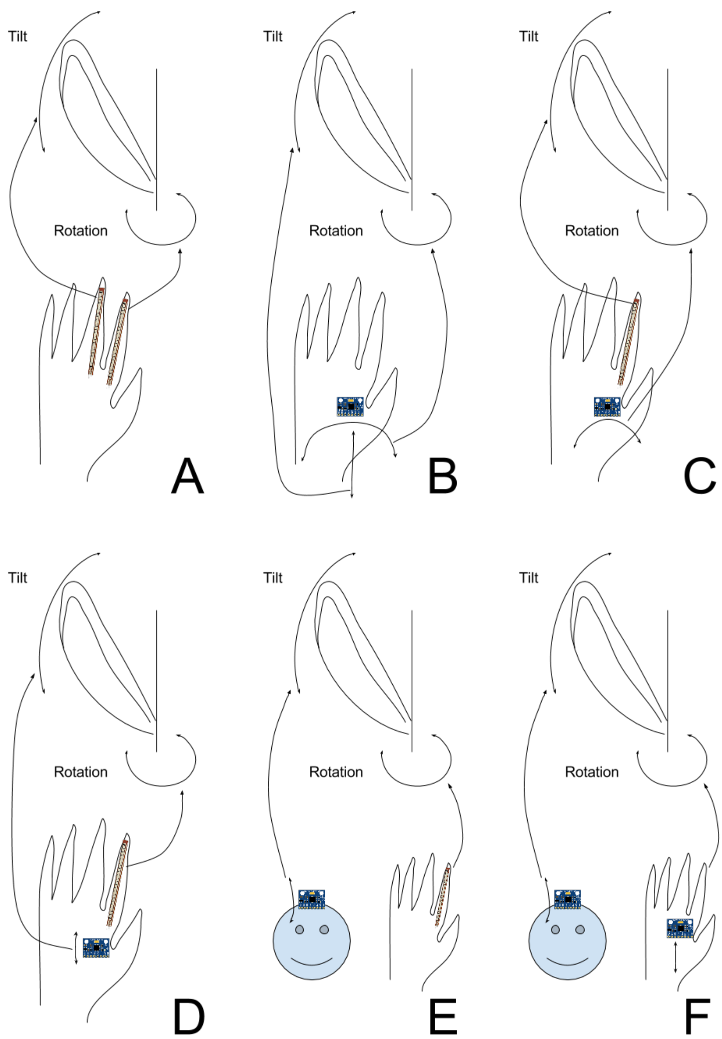


Figure 7.1: The cards used in the card ranking exercise

7.3 User Test with Elephant Actor

Sadness	Ears down at an angle
Happiness	Ears up and wiggling
Fear	Ears up
Curiosity	Ears out and wiggling

Table 7.2: The elephant actor's emotions

Card Ranking

Score: D, C, B, E, A, F

I think D felt most natural; it worked better with the body language which is important if I would use them on stage. The controls give more room for acting, than the others. This mapping is also very subtle, it is hard to see precisely how I control the ears, that makes it more exciting to watch. It is nice that it uses one finger. That makes the interaction more precise. The reason I like this mapping could also be that I got used to using my finger to control the rotation when I used the previous version of the ears. I also think that it felt natural to use the finger for the rotation and the pitch for ear tilt, the movements correspond well to each other, it feels natural. The mapping is also quite easy to use which is important for me when I am on stage. I do not want to think about how to do what I want to do.

Mapping C felt right, but it was not as good as D. Even though C had different gestures if felt quite similar to D, only not quite as good. Using hand gestures felt very natural, but mapping B made it to easy to lose control. It was nice to have one finger together with the hand gestures like in C and D. It was fun to use the hand gestures, but there are some problems. I could not do all the movements I wanted with only the IMUs on the hands, and you lose some opportunities when you cannot use the hands for other things than moving the ears.

I did not like using the head to control the ears; I felt it took too much freedom away, and it did not leave the same room for expression. I also did not like A; I thought it was hard to use the middle finger to control the ears. The mapping was not particularly exciting or interesting to use. The only plus was that it gave added control, but I did not think that was enough to make the mapping good. Mapping F was much the same as E; it did not give any interesting opportunities for expression. Also, it took away too much control; I like to have more control on stage.

Semi-structured Interview

Do you have any acting experience, or rather, can you tell me about your acting experience?
I mostly have experience with theatre and revue; I also study drama at NTNU. I am active in SIT[1]and use much of my free time on theatre.

Can you describe your experience of using the ears?
It was fun! I could have stood there for a long time, just playing with the different mappings. I had expected something new from the elephant ears when you asked me to come and try the new version, and it was something new. It was cool, a real improvement. I liked having two gloves; that worked a lot better than having just one like the elephant ears had.

How would you compare these ears to the elephant ears?
These new ears have much more possibilities because they have the opportunity to make more complex movements. The more complex movements add extra dimension to the movements. These ears also give more opportunity for interaction between body language and ear movements. I liked the subtle interactions that made it easier to obscure how the ears are controlled to make it seem a bit magical for an audience.

How did the interaction feel?
I felt that I had control, but some mappings gave better control than others. I was frustrated when I could not make the ears move like I

[1]Studentersamfundets Interne Teater (SIT), is a theatre troupe at Studentersamfundet i Trondhjem.

wanted, especially when I could not coordinate the ears because the sensors moved them differently.

Can you think of any alternative ways of controlling the ears?
I liked to use the IMUs on the hands. The head movement might be better if it is used with both pitch and roll from the hands and the head is most for some extra flavour. Maybe the ears go from side to side when you tilt your head from side to side, but you can still move them with the hands.

Do you have any positive or negative feedback on the ears?
Yes, you did a good job. Using the ears is fascinating. I think that they are user-friendly, and you explained how they worked in a good way. I just think that it is very cool.

7.4 User Tests with Test Subjects

7.4.1 Evaluating the User Tests

To be able to use the data collected from the user tests, data analysis and evaluation is needed. The data gathered is both qualitative and quantitative, this means that both quantitative and qualitative data evaluation methods need to be employed. To see the full notes from the user tests see Appendix E. The following sections will use the results from the user tests' three main data sources and present an analysis of them.

Section 7.4.2 card evaluation will show the different pros and cons that the test subjects mentioned during the card ranking questions. All the remarks will have a note that shows what test subjects had the same experience.

Section 7.4.3 will be a collection of common themes from the semi-structured interviews. The themes will be marked with which of the test subject had the same opinion or made a similar remark.

Finally, Section 7.4.4 will contain a statistical analysis of the quantitative data gathered from the rating cards tests.

Figure 7.2: A test person during testing

By using all of these different sources to discover insight about the way the test persons used the ears the final conclusions that can be drawn from the experiments will be more sound. Through triangulating the different results of the user tests, the results from the different data generation methods can be used to support or supplement each other.

7.4.2 Card Ranking Evaluation

Mapping A

Pros: Best for precision control of the ears (1, 3). Not very visible (1).

Cons: Fiddly to use both index and middle fingers at the same time (1, 2, 5). Did not remember what finger did what, no natural mapping (4, 5, 7). The interaction movements influenced each other (7).

Mapping B

Pros: Works like you would expect, natural, logical (2, 6, 7). Makes it easy to control each ear individually (3).

Cons: It was hard to use (1, 4, 6). The movements needed to control the ears were too big (1, 2). The movements used to control the ears were too similar, I got them mixed up (4, 6). The hands ended up in awkward positions (5). The interaction movements influenced each other (7).

Mapping C

Pros: Makes sense logically (1). Individual control of the ears (3). The combination of roll and bend sensor worked well (6).

Cons: Interaction takes too much space (1). Interaction dictates body movements, limits other actions (1). Too much to think about, that feels unnatural (2). Using roll was a bit unnatural (4). Used bend for the biggest movement, feels more natural to control the smallest ear movement with a small control movement and the big ear movement with a big control movement (5).

Mapping D

Pros: Split the functions onto more body parts, separated the interaction (4, 7). Felt natural (4, 5, 7). Use big movements to control the big movements of the ears, and small movements for the small (5). The interaction made it easy to distinguish the movements from each other (7).

Cons: Feels silly flipping the arms up and down to control the ears (1). The hands ended up in awkward positions (1). Too much to think about, that feels unnatural (2). Difficult to combine using bend sensors and tilt (3).

Mapping E

Pros: It was positive to be able to use the head, not just the hands (1, 6). Gives more freedom to express yourself because the hands are free (1). Using the bend sensors was good because it did not show (1, 2, 4, 5, 6). Uses more of the body is not so static (1). Natural in relation to body movement (2). The functions were split between different body parts (4).

Cons: Using the bend sensors was bad (3) Did not like to bend the head (4, 7). Lost movement freedom (4). Hated it (7).

Mapping F

Pros: It was positive to be able to use the head, not just the hands (1). Gives more freedom to express yourself because the hands are free (1). Uses more of the body is not so static (1). Makes it easier to express emotions (3). Using the IMU was good (3, 7).

Cons: Using the IMU was bad (1, 2, 4, 5). The movements needed to control the ears were too big (1). Limited how I could move (1). No individual control of the tilt of the ears (3). Did not like to bend the head (4, 7). Lost movement freedom (4). Hated it (7).

7.4.3 Semi-Structured Interviews Evaluation

> It was fun!
>
> *(1, 2, 3, 5, 6, 7)*

> It was easy to understand and learn how to use the ears.
>
> *(1, 2, 5, 6, 7)*

> It was sometimes hard to make specific movements when there was some delay, unevenness, slowness, or inaccuracy in the movement of the ears. That made it hard to move the ears to specific positions.
>
> *(1, 2, 3, 4, 6)*

> For some of the mappings, the interaction felt natural and intuitive, at least after some time when I started to understand how the ears worked.
>
> *(2, 3, 4, 5, 6)*

> The most natural way of using the ears was by using the head, mapping E or F.
>
> *(1, 3, 6)*

> It was hard in the start, needed some time to learn how to use the ears, to get used to them.
>
> *(3, 5, 7)*

The interaction felt responsive; I felt that I was able to do what I wanted.

(2, 6)

I needed the mirror.

(4, 5)

For some of the mappings, I got the controls a bit mixed up, it was not obvious what movement did what.

(4, 6)

I was too conscious of my hands when using the IMU; the fingers were better because then I did not have to think so much about my movements.

(1)

Some mappings felt weird, and the movements felt awkward. It was sometimes hard to know which movement would do what.

(1)

The ears worked as expected.

(4)

Which mapping is the best is dependant on in what context the ears will be used.

(5)

I think that all the mappings were nice, but I think that using the bend sensors was like pushing a button to make the ears move, it was more like a remote control.

(6)

It was hard to imagine how the ears would use before I tried them.

(7)

It felt a bit pointless.

(7)

7.4.4 Statistical Analysis of Card Ranking Results

To have some quantitive data card rating was used to let the persons participating in the user tests rank the interaction modes from their favourite to the mode, they liked the least. It was fascinating to see how the different test persons ranked the modes based on their previous experience and their experience with the ears. In Table 7.3 all the ratings from each participant are listed. The mode on position 1 is the participant's favourite mode and the mode on position six their least favourite. A detailed explanation from each participant as to why they chose that ranking can be read in Appendix E. The way the modes are ranked means that the more times the mode has been highly ranked that is a position with a low number, the more populate that mapping was with the test persons. However, for the data to be used with the chosen statistical analysis method, the data had to be reorganised in Table 7.4. In the second table, the data is scored from worst (1) to best (6). The elephant actors results has also been removed as the data collected from his user tests is not relatable to the other data, as discussed in Section 7.2.5.

To evaluate if the quantitative data gathered from the rating card test can be used to say that there is a statistically significant difference between any of the mappings, a Friedman test will be done. The first thing that has to be done before performing the test is to rank each *treatment* (mapping) for each *block* (response). This set-up is shown in Table 7.4; it can then be used to calculate the test statistic, Q. For the values in Table 7.4, that score is $Q = 1.204$. Because the card ranking test had more than four cards to be ranked the probability distribution of Q can be approximated as a chi-squared distribution. With 5 degrees of freedom and using a cumulative chi-squared distribution, this gives a significance of 0.944 that means that the null hypothesis should be retained. In other words, the rankings are statistically similar. The quantitative results of the user tests can therefore not be used to argue that any of the mappings have different acceptance. The analysis done using Microsoft Excel can be found in Appendix F.

	1	2	3	4	5	6
Subject 1	E	F	A	D	C	B
Subject 2	E	F	A	B	D	C
Subject 3	A	B	F	C	D	E
Subject 4	D	C	E	F	B	A
Subject 5	D	B	C	E	F	A
Subject 6	E	F	B	C	A	D
Subject 7	D	B	C	A	F	E

Table 7.3: The scoring card results from the different test persons

	A	B	C	D	E	F
Subject 1	4	1	2	3	6	5
Subject 2	4	3	1	2	6	5
Subject 3	6	5	3	2	1	4
Subject 4	1	2	5	6	4	3
Subject 5	1	5	4	6	3	2
Subject 6	2	4	3	1	6	5
Subject 7	3	5	4	6	1	2

Table 7.4: Ranking of the different mappings prepared for the Friedman test.

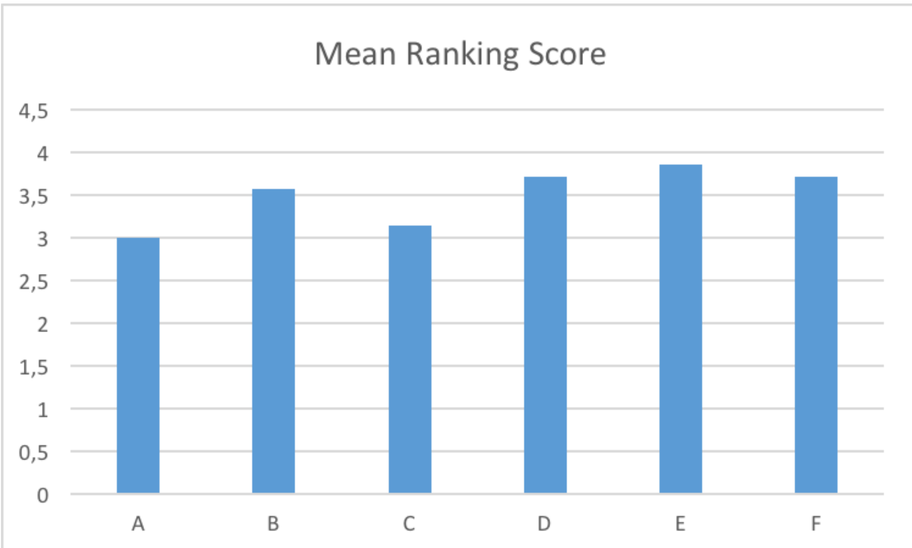


Figure 7.3: The mean ranking of each mapping

Chapter 8

Discussion

8.1 The First Version of the Ears

8.1.1 The Development Process

The development process was as mentioned in Section 4.1, an iterative UCD process. This approach proved to be very useful to get feedback from the stakeholders and the final user, the actor. This feedback proved valuable in developing smart solutions, like the hoop that was discussed in the first prototype presentation. The close collaboration turned out to be important to gain an understanding of how the ears would be used and to make them perform the way both the actor and the costume designers needed.

Because of a very tight schedule, the development process needed to be quite swift. When the project was introduced to my supervisor and me, there were only a few weeks until the ears had to be finished. However, the process of gathering information from the costume designers and also gathering materials and finding a place to work took time. When the iterative process started there was only one week to go before the costume had to be finished. This can be seen in the Gantt diagram for the project in Figure 4.2 on page 45. This meant that we, my supervisor and I, were under a bit of a time pressure to get the ears finished and at the same time run a tidy process. The time pressure meant that we had to spend some late nights finishing the final version of the ears.

After the ears had been handed over, there were still some problems that we had to figure out. In effect, there were more iterations in the UCD process after the ears had been handed over in that we had to repair and fix some design flaws. If there had been, more time these problems might have been fixed in a final iteration. On the other hand, the problems might not have become apparent before the ears were used in the play. It was fortunate that my supervisor and I was ready to do the repairs as they were needed. Having the opportunity to test the ears in actual real life use also made us able to see what parts of the design needed to be more solid and provided us with insight into how the ears might be improved. Both how they might be enhanced in the future, and how we could make them more solid for the succeeding performances.

8.1.2 Interviews

The feedback from the interviews in Section 5.2 is largely positive, both from the instructor and the actor. The negative feedback comes mainly from the actor who had some stability issues with the ears. Some of these issues were addressed during maintenance and repairs later, although never completely fixed. The issues were mainly regarding the construction quality of the ears which, of course, is an important aspect of usability, but it should not weigh too heavily when considering that this product is not a finished product.

A more important aspect of this discussion is the actors experience of the interaction with the ears; whether they had indeed become as a part of him. In reviewing this, it is interesting to remark that the actor could not think of any other way of interacting with the ears, see Section 5.2.2. This observation is interesting as it indicates that he feels that the way he interacts with the ears is the only logical way. In contrast, the instructor, when asked the same question, quickly came up with a suggestion for another interaction method. This could of course just be because the actor had learnt to use the interaction method and had difficulties imagining other ways of interaction because he had grown accustomed to it. Also, he said that he had liked the interaction method from the start and felt that it was natural. He also stated that it took him some time to get used to having this extension to his body. It is only natural that it takes some time, and as pointed out in Höök (2010) the focus of design is too often to make it simpler. It is important to focus not only on function but also on bodily experience. The goal of this project was after all to experiment with designing for the body, and the acquisition of skill can be said to be an important part of assimilating a body extension. When adding a new body part one would expect the body to need some time to get used to the addition. The actor also expressed that he had enjoyed experimenting with ear choreographies and ways to use the ears on stage.

In addition to creating a natural interaction between the body and the ears, an important goal of the project was to make a product that would add something to the play. The actor said that he thought that the ears did that. In his experience, the ears add some additional playfulness to the play. This opinion was shared with the instructor. The instructor thought that the ears added an important dimension to the play, which was underlined by her thoughts on using this kind of technology in theatre. She had some interesting views on using technology to create a unique and fascinating experience, which as she put it could "compete with television and movies". This effect is an intriguing aspect of the project that I had not considered. The instructor noted that to keep people, especially children, interested they have to be shown something that they do not feel that they could do in their living room. Regular costumes can make a character interesting, but adding movement amplifies this. The actor talked about how people would come up to him after the show to ask about how the ears work. They spark an interest in the audience and a sense of wonder. In other words, they seem to have achieved what the instructor hoped they would. The instructor has also received a lot of positive feedback and comments on the ears. She stated that some people who said that they previously did not pay that much attention to the elephant now says that the elephant is their favourite character of the play. This change of mind suggests that the ears had a major impact on the character, and how the character is perceived by the audience. This might, as the instructor explained, be an effect of having this bit of technology adding another aspect to the character. At the very least it sets the elephant apart from the rest of the characters.

8.1.3 Evaluation Criteria v1

The evaluation criteria are listed in Table 5.1. Here I will go through all the criteria and evaluate to what degree the criterion was met. Each criterion will either be completely fulfilled, partly fulfilled, or not fulfilled.

C1.1: The ears do move, and the wearer has individual control of the angle of each ear. The criterion is therefore judged to be **completely fulfilled**.

C1.2: The interaction with the ears requires the wearer to move their hand. This movement is quite pronounced, but the actor and instructor do not think that it has a negative impact on the acting. Nevertheless, the criterion is only judged to be **partly fulfilled** as the movement is visible even if it has no negative impact.

C1.3: The ears were constructed with wear and tare in mind, but they were put together in a hurry, and not all of the plugs and connections were solid enough. The ears and sensor module have both needed repairs and modification during the development process. Even after this the ears and sensor module are not robust enough to handle the stress of being used in theatre to a sufficient degree. The criterion is evaluated to being **partly fulfilled**, as the product can be seen as a prototype the requirement for reasonable solidity is not that high.

C2.1: To make the ears fit securely on the wearers head the fastening mechanism of a hard hat was used, this provided the opportunity to tighten the fit of the head piece so that it would fit snugly on the wearers head. The actor said that the ears fit securely on his head. Based on this the criterion is judged to be **completely fulfilled**.

C2.2: As the actor mentioned in the interview, the fastening mechanism for the head is not very comfortable even after having been modified to improve comfort. He did not, however, say that the ears are painful to wear, so the criterion is judged to be **partly fulfilled**.

C3.1: This was an important criterion since the ears would not have been usable if they could not be dressed in fabric so that the electronics and mechanics were hidden. It was a bit hard to do it, but by cutting the back of the fabric when fitting it and sewing it back together when the fabric was in place worked nicely. This criterion is **completely fulfilled**.

C3.2: By hingeing some metal pieces on the hard hat headband and securing them up with screws, it was possible to provide a quite robust and practical skeleton for the costume designers to sew the ears onto. This criterion is evaluated to be **completely fulfilled**.

C3.3: By using the hinges it was possible to place the mechanical ears where the costume designers wanted, the criterion is **completely fulfilled**.

C3.4: This is partly true, the logic unit for the ears was placed on the top of the head, this meant that the upper part of the elephant head was a bit higher than planned, and a bit square. The sensor box was also a bit thicker than what would have been ideal. The costume was also a bit tighter than planned, which made the size of the unit even more critical. Despite this, the mechanics and electronics for both the sensor unit and the ears were small enough not to be noticeable through the costume. This criterion is evaluated to be **completely fulfilled**

Based on this evaluation the ears were very successful. There are twice as meany completely fulfilled criteria as there are partly fulfilled, and no criterion was evaluated to be not fulfilled.

8.2 The Second Version of the Ears

8.2.1 The Development Process

When developing this version of the ears there was no client or user that could be involved in the process. This has been reflected in the choice of development methodology. In stead of an iterative process, the development of this version of the ears was conducted as a final construction step in the iterative process used to develop the first version of the ears. However, the product was no longer to be delivered to the costume designers and actor, but rather evaluated by a group of test persons. The elephant actor was able to participate in the same test, but not in the role as elephant actor as the play is no longer running. However, he judged the second version of the ears as an actor and with his experience of using the first version of the ears in mind.

Because this development process had neither a client, or user or user group, the chosen development methodology was a prototype oriented approach. This worked tolerably well, but proved to be much more time consuming than both my supervisor and I had assumed at the start of the process. I assumed that the experiences I had made when developing the first version of the ears would help me conduct a swift and efficient development process. This was not entirely the case. For this version of the ears I decided to teach myself 3D modelling, to then teach myself how to 3D print so that I could be able to 3D print joints for the ear servos and containers for the electronics. I learnt a lot, but I also used a lot of time. The product of spending much more time than expected is however a product finished to a high standard.

8.2.2 Evaluation Criteria v2

The evaluation criteria are listed in Table 7.1. Here I will go through all the criteria and evaluate to what degree the criterion was met. Each criterion will either be completely fulfilled, partly fulfilled, or not fulfilled.

C1: The ears do have two degrees of freedom. This criterion is therefore **completely fulfilled**.

C2: The movement of the ears is somewhat smooth and follow the user input quite naturally. However, as it is possible to see from the user tests in Section 7.4, the test persons were not completely satisfied. This criterion is therefor judged to be **partly fulfilled**.

C3: The ears are responsive. The feedback recorded in Section 7.4 confirms this, this means that the criterion is **completely fulfilled**.

C4: The ears are able to use multiple sensor inputs to control their movement, rendering this criterion **completely fulfilled**.

All criteria were fulfilled to some degree. Just one was only partly fulfilled. These results gives cause for claiming that the ears were developed and constructed in conformance with the pre-set criteria.

8.2.3 Usability Tests

The usability tests produced three sets of data; a quantitative set of rankings of the mappings, a qualitative set of comments on the mappings, and finally a qualitative set of comments on the system as a whole. These three inputs will be seen in relation to each other and help secure the validity of the final conclusions by triangulating the results of the usability tests.

The ranking card tests provided rankings of the different mappings; the results can be seen in Table 7.3. However, even though it is possible to see that some of the mappings have received slightly higher ratings the Friedman test described in Section 7.4.4 shows that there is no statistical basis for claiming that any mappings were better than the others. The conclusion based solely on the statistics must, therefore, be that a person's preferred mapping is highly individual. Because of this, all mappings will get the same score.

The rating card test was in addition to being a quantitative data source, also the basis for a discussion with the test person about what mappings they preferred. This process yielded the results shown in Section 7.4.2. These results give an overview of what the different test persons thought about the different mappings, giving a much more nuanced impression of the qualities that the test persons saw in the different mappings.

Similarly to the statistical data, the qualitative data generated from the rating card discussion does not show any strong leaning towards any particular mapping. If anything, there might be a slight preference to mapping E. However, mapping E has in addition to receiving many positive comments, also received many negative comments.

From the results of the rating card exercise, all but one of the test subjects fall into one of two groups. By looking at Table 7.3 one can see that there is one group, consisting of subject 1, 2, and 6 that prefer mapping E and F. The other group, comprised of subject 4, 5, and 7 prefer mapping D and do not like E or F that much. The last person is the only one to prefer mapping A. This contrast shows that even though one group of people or one individual might have strong preferences, this does not mean that it is possible to generalise and say that everyone would prefer one particular mapping. These observations seem to be in keeping with the results of the Friedman test.

From the analysis of the semi-structured interviews, it is not very easy to say much about specific mappings. It is better applied to assess the system as a whole, which means that the data can not be used efficiently in a triangulation of the results. However, some of the findings might help strengthen any conclusion made on a basis of the rating card data. The one thing the interview data can say definitively is that all test participants enjoyed the experience of trying the ears. The only feedback that was the same for all the participants was "It was fun!"

The problem with the quantitative data gathered from the card ranking exercise was that by using a simple 1234 ranking of the mappings, it was not possible to collect any nuanced data about the acceptance of the different mappings. However, by applying a Likert scale and asking the test persons to score each mapping from 0 to 10, the data might have been able to reveal some differences between the mappings. The method was chosen mainly as a tool to make the test persons reflect on their experience. The quantitative data was seen as a bonus that might help to uncover some interesting findings. The test also did not have very many participants. Only seven ratings do not give a very solid statistical basis. On the other hand, even with better data and more participants the results might have been the same. It seems that which mapping a person prefers is very individual, as well as being situational.

All the data sources point toward the same result. The choice of mapping is highly individual and situational. Both the test persons and elephant actor also pointed this out during the user tests. The actor said that he thought that it would be important to make a mapping that was purpose made for the situation where it would be used. Experiences with the first version of the ears also underpin this finding. The chosen solution was not necessarily the best possible mapping. However, it was the mapping that was best suited to the situation, and preferred by the actor.

8.3 Designing for the Body

1. Designing spaces for mutual wordless understanding between human and machine
2. Letting bodily learning take time and be a pleasure in itself
3. Putting more emphasis on the aesthetic pleasures of rhythm when designing for bodily interaction
4. Finding ways of describing experiences of bodily interactions that can serve as inspiration to design

Table 8.1: Experience-oriented qualities of horsback riding that are transferable to design (Höök 2010)

In this project, the bodily experience of interacting with a body extension has had a particular focus. The points in Table 2.3 (the list is reprinted in Table 8.1 for convenience) from Höök (2010) have been important in influencing the design approach and how I have viewed the interaction. Point one is a bit hard to grasp, but the way I understand it is how I saw it when conducting the usability tests for the second version of the ears. The test persons were trying the ears and by using the ears they learnt how to use them. By wearing the ears and experimenting with the different mappings, the users got an understanding of how to interact with and manipulate the ears.

Point two from the list is especially interesting and has been discussed in both Section 8.1.2 and Section 8.2.3. It is important not to underestimate the body's ability to attain new skills and the joy associated with that experience. The most frequent feedback from the interviews during the user-test of the second version of the ears was that it was fun. Point four is also significant, especially for the theatre setting, where the extraordinary experience of acting needs to be reflected in the design solution.

Point three is not that easy to transfer to this project, not directly. But the actor has to move the ears with his movement. Thus, he has to be able to accent his body rhythm with the ears. On stage he used the ears this way, moving them in sync with his movements. This point is also an argument that strengthens the instructor's idea for a possible alternative mode of interaction, by having sensors on the actors feet. This would, of course, make the interaction less direct and maybe more confusing, but it would possibly have made the movement more a part of the actors movement. By making the ears respond to the movements of the actors body, the actor would not have to translate the movements that he wanted to do. Instead, they would be a kind of natural response to how he moved his body as a whole.

8.4 Mapping

The mapping that was chosen for controlling both versions of the ears was successful, at least if the measure is whether or not the actor and test persons were happy with it. An important reason for this success was that the mapping that was chosen relies on a natural understanding of how the interaction should work. The mapping between the hand movement and ear movement is direct, degree by degree as discussed in Section 4.8.1. The interaction is comparable to the computer mouse, scroll wheel example from Section 2.5. Both interactions rely on a direct mapping where manipulating the controls result in a reaction that relates directly to the interaction with the controls. For the scroll wheel, this is to move the finger, resulting in the view of the content on screen moving accordingly. For the ears, this is flexing the fingers while the ears follow the movement.

When choosing a mapping for the ears, it was quite hard to identify one that could be said to be natural. Humans do not have ears that move, we have no understanding of this experience beyond thought experiments, which is why the hand was chosen to control the ears in version one. Humans are used to controlling and manipulating objects with their hands. By taking advantage of this and people's innate understanding of direct mappings, it was possible to make an interaction pattern that felt natural and was easy to master. In version two of the ears, the hands were still the preferred input method for the same reason. Moreover, the requirements for the second version of the ears allowed the use of both hands. By adding an IMU to the head unit of the second version of the ears, the head could also be used as an input. This addition made it possible to map ear movement to body posture. The test persons provided both negative and positive feedback to bending the head to control the ears. Some felt that it was uncomfortable to bend the head, or they were afraid that the ears would fall off their head. Others thought that it was fun to involve the entire body in the interaction.

8.5 Interactive Costumes

Section 2.8, in the background chapter, describes the research presented by Honauer and Hornecker (2015). This paper is new, and because of the process that was run with the children's theatre in the development of the first version of the ears, it was not possible to do a thorough enough literature analysis to find the paper in time before the start of the project. The paper was however found later and has therefore been used in the evaluation and discussion of the results of the project. Honauer and Hornecker (2015) describes two interactive costume projects. One of these projects were a collaboration with a theatre house; this collaboration made the researchers aware of many challenges related to interactive costume design. In the conclusion of the paper, the authors made the following suggestion for further research:

> *"One of our suggestions for future research is to involve actors early-on in iterative design. However, how would we go about this? For a fully user-centered or participatory process they should be involved already during ideation."*

This suggestion is fascinating as it describes the exact approach that were used in the development for the first version of the ears, the elephant ears. The process was fully user-centred and involved the actor from the start of the project. The choice of this process was not motivated by the above mentioned paper however, as I did not find it until after the development of the elephant ears was done. The motivation for applying a user-centred approach was partly my supervisors experience from trying to implement interactive costumes in a another student theatre play. The choice was also motivated by the fact that I knew little of what the actor would require of the ears and needed his input to help me design and construct the ears that he needed.

In the paper, Honauer and Hornecker (2015) also describe how the organisational structure of the theatre was a hinderance in regards to creating the interdisciplinary cooperation necessary to make interactive costumes. The actors also showed reluctance and were sceptical of using the new costumes. This was not so much the case in the development of the elephant ears. The costume designers were very helpful and always ready to help me make the ears work and look the way they should. This difference in attitude might be because the elephant ear project was done in collaboration with a student theatre where no one has become too set in his or her role and people might be more open to trying new things. However, the fact that the costume designers and actor was so closely involved in the project they were able to get a feeling of ownership to the project. The way the process was run, the costume designers performed as the customer and the actor as the user of the product. This gave them all a close involvement and made them invested in the project. I think this was the key to the success of the interactive costume.

Although the organisational structure of theatres is not the subject of this paper, I found it interesting to make some reflections on this subject.

8.6 The Third Version of the Ears

If a third version of the ears were to be developed, the most significant improvement that would be needed is to the construction. The gloves should support the bend sensors better so that they do not move or bend in any other way than the fingers move. The IMUs and other electronic components should be better concealed and secured inside fabric pockets. The technology would be the same, only more refined and elegantly constructed. The same goes for the ears. Instead of a piece of paper on a metal wire; the ears themselves should be better constructed. The mechanical principles of the servo holders for the ears could be preserved, but by using smaller servos and holders finished in metal the ears would look more elegant and less like the prototype that the second version of the ears was. The way the ears are fastened to the head would also need refinement so that it is not uncomfortable for the wearer. The ears should also not fall off the wearer's head easily. Some tightenable headband made of fabric might work well.

The most important feature of a third version of the ears would be a method to modify the mapping easily on the go. A mobile application on a smartphone device, communicating with the ears, could handle this modification by letting the user could draw lines between the different ear movement and body movements he wanted to create his or her preferred mapping. The finding that the mapping should be modifiable and tailored to the specific user of the ears motivated this choice.

8.7 Threats to Validity

The two main factors to the threats to the validity either version of the ears are the selection of participants and history. Something might have happened with the elephant actor in the time between him using the first version of the ears and testing the second version. However, how this historical factor might adversely impact the elephant actors perception of the second version ears is not clear. The threat from historical factors, therefore, seem minuscule. The selection of participants for the test of the first version of the ears, however, could possibly impact the results. All of the participants were students of technical subjects at NTNU and therefore well equipped to understand the technical aspects of the ears better than any randomly selected test person. The effect of better technological understanding should however not influence the test person's behaviour. There might still be other factor concerning the selection that escaped my awareness.

The external validity of this research project is not very high. The findings can not be generalised beyond its application to the theatre. The findings concerning mapping between the body and a mechanical body extension are relatable to similar problems, but mainly the research can not be generalised to areas outside interactive costume design.

The first version of the ears was used in theatre, and the process was run in collaboration with the theatre. Because of this the testing environment, in fact, was the same environment as the ears were intended to be used. It should, therefore, be secure to say that the ecological validity was preserved.

The second version of the ears was tested in a laboratory environment, where the ears were far removed and abstracted from any 'real world' context of use. However, the second version of the ears was intended as a tool to test different mappings; it is a research experiment. Because the second research question is not concerned with any specific context the project is not vulnerable to problems concerning ecological validity.

Construct validity is a problem for the evaluation of both the first and second version of the ears. The evaluation is highly dependant on qualitative data that is challenging to correlate with other results. However, an effort has been made for the evaluation of the second version of the ears, where multiple data sources were used. The results were triangulated to the highest degree permitted by the collected data. The rating card exercise was also used to make the test persons focus on the mappings, and they were encouraged to rate the mappings according to what they liked best to use.

Chapter 9

Conclusion

9.1 Research Question One

In Section 1.3 the research questions for this project were defined. The first question is:

> *What are important aspects to consider when developing mechanical body extensions for use in a theatre setting?*

Using the iterative UCD process for the development and construction of the first version of the ears proved to be successful. It was useful in order to maintain a close collaboration with the project's main stakeholders; the actor and the costume designers. The costume designers helped with the development of ideas for the design and construction of the ears. By involving and working closely with the actor it was possible to get continuous feedback on the design and also familiarise him with them before the dress rehearsal. That way the ears and the interaction would not be completely new to him when he started using them on stage. The close collaboration also made it possible to learn what the actor thought about how he imagined using the ears. When developing for the body it is important to include the body that is being developed for. Using human centred design has been instrumental in the success of the process.

Involving the actor and the costume designers from the start of the process was crucial for the success of the development, just as it was suggested in Honauer and Hornecker (2015).

When involving the actor in the development process and letting him try the ears during the development, it was possible for him to influence the evolution of the ears. The development of a new iteration of the ears gave the actor new possibilities of use which in turn generated new requirements for the ears. This principle is called the 'task-artifact cycle' by Carroll (1991).

The interaction has been the core theme through the process, and how the controls and movement of the ears should be mapped. The goal has always been to make an intuitive and natural interaction. By using the hand, the control became very visible, but neither the actor nor the instructor felt that this was a problem for the performance. The actor said that he felt that it was very natural to use his hands to control the ears. He pointed out that it was important to keep the interaction simple. This is true for all interaction, but maybe especially for interaction with something that is supposed to be like a part of the wearers body.

When the elephant actor tried the second version of the ears he observed that by making it possible the use multiple mappings, it would be easier to customise the body extension for use on the stage.

Through the process of making the ears in collaboration with the costume designers and the actor I have made some experiences of developing mechanical body extensions for theatre. The answer to research question one is comprised of three main findings.

- **Process:** It is important to work closely with the stakeholders for the process and especially the potential user(s) and involve them in the process early on. The process has to be dynamic to let the user(s) influence the process,
- **Use:** The body extension must be easy for the actor to use and customised for the specific theatre play, like any other costume.
- **Mechanics:** When designing a product for use in theatre, ruggedness is an important concern. The product has to be able to take a beating.

To answer the first research question experiences both from the development of the ears, discussions with the main stakeholders, and the evaluation of the product and process has to be taken into consideration. The most important aspect for a mechanical body extension in theatre is that is should work on stage. In order to achieve this, we had to work closely with the stake holders. The body extension also has to work for the actor. It should not obstruct the acting, and only add to the performance not hamper it. Ease of use was one of the criteria that the actor who used the ears emphasised as important for him to have such a positive experience from using the ears as he did. The last thing that was experienced in this project is that body extensions for theatre has to be durable and tough. Even if this was something that my supervisor and I were aware of at the start of the project we still underestimated how strong the ears needed to be, as a result we had to do multiple repairs and improvements.

9.2 Research Question Two

The second question described in Section 1.3 is:

> *How should a mechanical body extension be controlled to make the interaction feel natural?*

A theme that has carried substantial weight in this project is interaction. How should this be done in order to create a user experience that is natural and make the mechanical body extension feel as a part of the user's body? This question has not been easy to answer and will still need future work. In the context of theatre, the main aspects that have been identified as important in order to achieve a good interaction pattern are; ease of use, and a direct mapping between the controls and the mechanical body extension. These aspects will surely prove important for the general case also. The direct mapping might be the most important aspect as it makes the translation of the movement easier to interpret for the mind of the user. However, the choice of what movement should be mapped to the ears, the usability tests of the second version of the ears found that the preferred mapping is highly individual.

The complexity and detail level of the controls would depend on the situation and the users preference. The actor said that he liked the simple controls for the first version of the ears because he found that he needed to use most of his concentration on acting. He did not have enough time or energy to internalise a complex interaction pattern. A complex pattern could still be positive in another context. As discussed in Höök (2010), learning a skill is a positive experience for the mind and body. This insight is very important to consider when developing interaction with complex body extensions. It was also confirmed both by the actor for both versions of the ears, and by the test persons when trying the second version.

To sum up, there are three parts to the answer to research question two, these are:

1. It is important to make a mapping that is easy for the user's body to internalise. That is, the mapping should be 'natural', non-complex, and direct.

2. The interaction has to be made specific to the context of use, that is the play and the actor that will be using the body extension.

3. Mapping preference is individual and has to be modified for the person using the body extension. The mapping has to be tailored for the person that will use it and role that it will be used in.

In the description of what a third version of the ears would be like in Section 8.6 the importance of modifiability for the mappings is discussed. It is the findings listed above that motivated this view on how to make a third version of the ears. By providing the user direct control of the manipulation of the mappings he or she can themselves experiment and find the mapping that best fits them and the role they will play.

Appendix A

3D Models

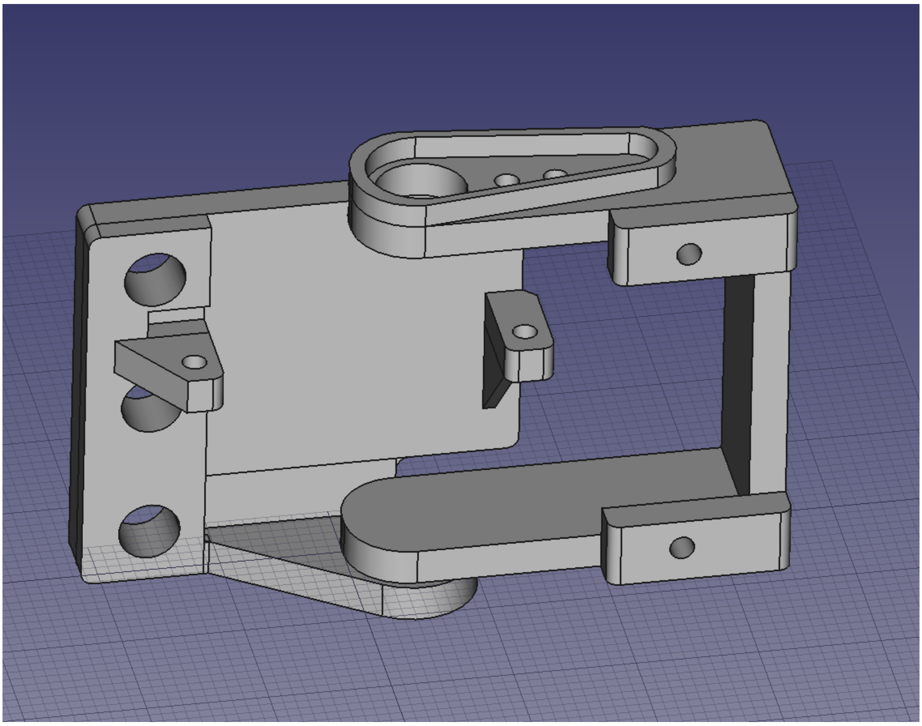


Figure A.1: 3D model of servo holder

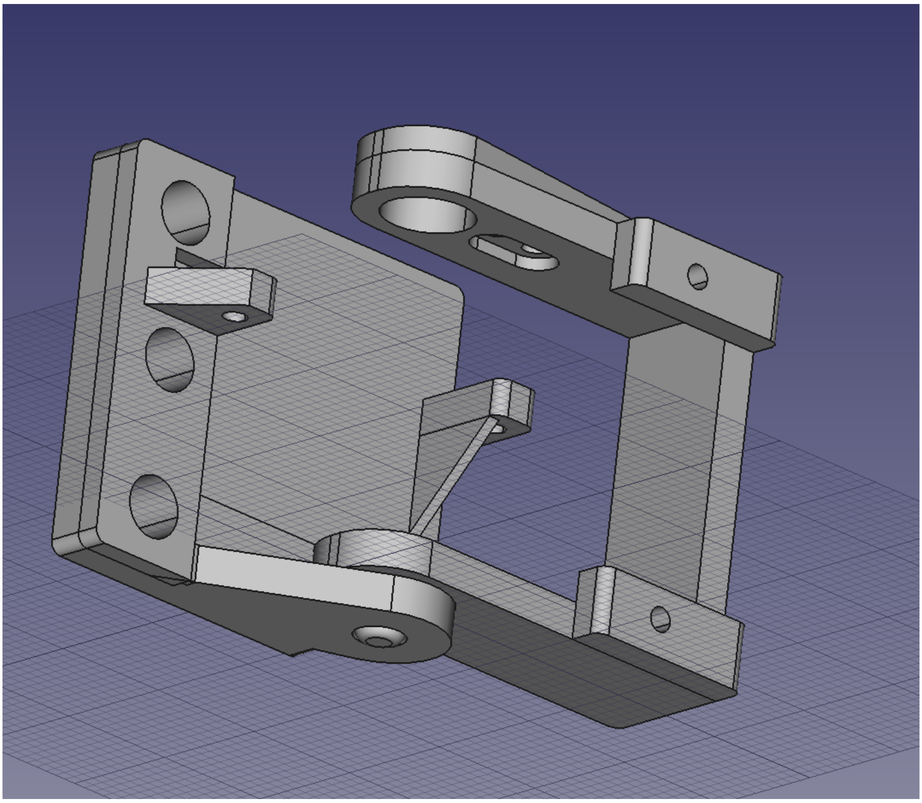


Figure A.2: 3D model of servo holder

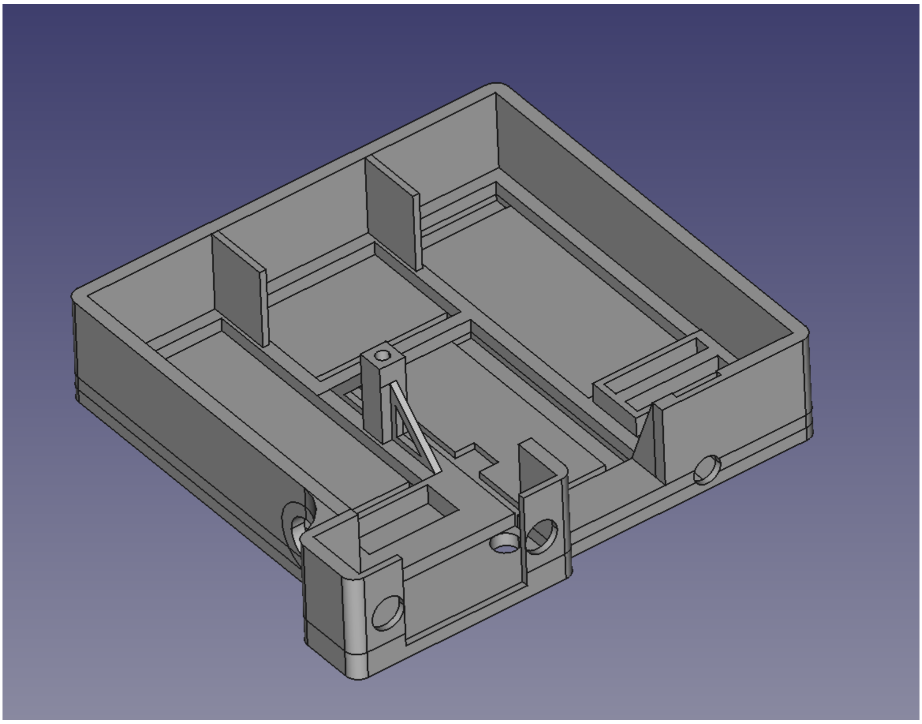


Figure A.3: 3D model of head box

Appendix B

Program Code

B.1 Code for Elephant Sensor Module

```
// Including library to do serial communication with bluetooth
#include <SoftwareSerial.h>
#include <PLabBTSerial.h>

// Define I/O ports used for transmit (TX) and receive (RX)
const int BT_RX = 10;
const int BT_TX = 11;


// Which output we have the lights connected to
const int LIGHT_OUT = 4;

int dataValueOne = 0;
int dataValueTwo = 0;

// Define the serial port for communication with bluetooth
PLabBTSerial btSerial (BT_TX, BT_RX);

// Set up the unit and start advertising with BLE
void setup(void)
{
  // Start communication throuhg console
```

```
  Serial.begin (9600);

  // Set the output for our light
  pinMode (LIGHT_OUT, OUTPUT);
  digitalWrite (LIGHT_OUT, LOW);

  // Start communication with bluetooth unit
  btSerial.begin (9600);
}

void loop()
{
  // Read data from the bend sensor
  int sensor_one, degrees_one, sensor_two, degrees_two;

  sensor_one = analogRead(0);
  sensor_two = analogRead(1);

  degrees_one = map(sensor_one, 683, 454, 0, 90);
  degrees_two = map(sensor_two, 700, 502, 0, 90);

  dataValueOne = degrees_one;
  dataValueTwo = degrees_two;

  // See if we have received a new character

  int availableCount = btSerial.available();
  if (availableCount > 0) {
    char text[availableCount];
    btSerial.read(text, availableCount);
    readCommand(text);
  }
}

void readCommand (char *text) {
  if (0 == strcmp ("bend1", text)) {
    digitalWrite (LIGHT_OUT, HIGH);
    btSerial.println(dataValueOne);
    digitalWrite (LIGHT_OUT, LOW);
  }
  else if (0 == strcmp("bend2", text)) {
    digitalWrite(LIGHT_OUT, HIGH);
    btSerial.println(dataValueTwo);
    digitalWrite(LIGHT_OUT, LOW);
  } else {
    // This should not happen, so we can tell that it did
    digitalWrite (LIGHT_OUT, LOW);
  }
```

```
}
```

Listing B.1: Slave code for elephant ears

B.2 Code for Elephant Servo Module

```
// Including library to do serial communication with
    bluetooth

#include <Servo.h>

// Define I/O ports used for transmit (TX) and receive (
    RX)
const int BT_RX = 1;
const int BT_TX = 0;

// Create servo objects
Servo servo_one;
Servo servo_two;

// Define servo pins
const int servo_one_pin = 9;
const int servo_two_pin = 8;

// Set up the unit and start advertising with BLE
void setup(void)
{
  servo_one.attach(servo_one_pin);
  servo_two.attach(servo_two_pin);
  // Start communication with bluetooth
  Serial.begin (9600);
}

void loop()
{
  int degrees_one, degrees_two;
  Serial.write("bend1\r\n"); // All commands should end
    with \r\n
  char c = Serial.read();
  String s = Serial.readStringUntil('\r');
  c = Serial.read();
  degrees_one = s.toInt();
  servo_one.write(-degrees_one + 180);

  Serial.write("bend2\r\n"); // All commands should end
    with \r\n
  c = Serial.read();
  s = Serial.readStringUntil('\r');
  c = Serial.read();
  degrees_two = s.toInt();
  servo_two.write(degrees_two);
```

```
}
```

Listing B.2: Master code for elephant ears

B.3 Code for Ear Version Two Gloves

```
#include "FreeIMU.h"

#include <SoftwareSerial.h>
#include <PLabBTSerial.h>

float ypr[3]; // yaw pitch roll
// The FreeIMU object
FreeIMU my3IMU;


#define rxPin 2   // Connect this to pin RXD on the BT unit.
#define txPin 3   // Connect this to pin TXD on the BT unit.
PLabBTSerial btSerial(txPin, rxPin);

const int LEDpin = 13;
unsigned long millisecs;

void setup() {
  my3IMU = FreeIMU();
  btSerial.begin(38400);
  my3IMU.init(false); // the parameter enable or disable fast mode
  for(int i=0; i<40; i++) { my3IMU.getYawPitchRoll(ypr); };
  pinMode(LEDpin,OUTPUT);
  millisecs = millis();
}

void sendData() {
    int sensor1 = analogRead (A0);
    int sensor2 = analogRead (A1);
    sensor1 = constrain(map(sensor1,608,816,0,100),0,100);  // Right glove
    sensor2 = constrain(map(sensor2,545,770,0,100),0,100);  //

    // sensor1 = constrain(map(sensor1,545,700,0,100),0,100);  // Left glove
    // sensor2 = constrain(map(sensor2,545,770,0,100),0,100);  //

    my3IMU.getYawPitchRoll(ypr);
    float yaw = ypr[0];
    int intyaw = (int) yaw;
```

```
    float pitch = ypr[1];
    int intpitch = (int) pitch;
    float roll = ypr[2];
    int introll = (int) roll;
    btSerial.print(sensor1); btSerial.print(",");
    btSerial.print(sensor2); btSerial.print(",");
    btSerial.print(intyaw); btSerial.print(",");
    btSerial.print(intpitch); btSerial.print(",");
    btSerial.print(introll); btSerial.print("\r\n");
}


void loop() {
  int availableCount = btSerial.available();
  if (availableCount > 0) {
    digitalWrite(LEDpin,HIGH);
    char text[availableCount];
    btSerial.read(text, availableCount);
    sendData();
    digitalWrite(LEDpin,LOW);
    millisecs = millis();
  } else {
    if ((millis() - millisecs) > 1000) {
        digitalWrite(LEDpin,HIGH);
        delay(100);
        digitalWrite(LEDpin,LOW);
        millisecs = millis();
    }
  }
}
```

Listing B.3: Glove code for new ears

B.4 Code for Ear Version Two Ears

```
#include <SoftwareSerial.h>
#include <PLabBTSerial.h>
#include <Servo.h>
#include <FreeIMU.h>

// Bluetooth unit settup
const unsigned long baudRate = 38400;

const int btUnitOneTxPin = 11;
const int btUnitOneRxPin = 10;
const int btUnitTwoTxPin = 8;
const int btUnitTwoRxPin = 9;

PLabBTSerial btOne(btUnitOneTxPin, btUnitOneRxPin);
PLabBTSerial btTwo(btUnitTwoTxPin, btUnitTwoRxPin);

int gloveNumber = 0;
int availableCount;
const int timeout = 100;

// Servo settup
const int servoPins[4] = {3, 4, 5, 6};

Servo servoLeftOne, servoLeftTwo, servoRightOne,
    servoRightTwo;
Servo servos[4] = {servoLeftOne, servoLeftTwo,
    servoRightOne, servoRightTwo};

int servoValues[4] = {90, 90, 90, 90};
int prevServo[4] = {90, 90, 90, 90};

// IMU settup
float ypr[3];
FreeIMU my3IMU;

// Button settup
int wasPressed = 0;
const int buttonPin = 7;
int operationMode = 0;

// Data
int gloveValues[2][5];


// Functions, in order used
void detectButtonPress() {
```

```
  int buttonState = digitalRead(buttonPin);
  if (buttonState == HIGH) {
    wasPressed = 1;
  } else {
    if (wasPressed == 1) {
      operationMode += 1;
      operationMode %= 6;
      Serial.print("Mode: ");
      Serial.println(operationMode);
    }
    wasPressed = 0;
  }
}

void pollGlove() {
  if (gloveNumber == 0) {
    btOne.listen();
    btOne.print(".\r\n");
  } else {
    btTwo.listen();
    btTwo.print(".\r\n");
  }
}

void parseComma(char str[], int returnArray[], int maxLength) {
  char *pt;
  pt = strtok (str, ",");
  int i = 0;
  while (pt != NULL) {
    int a = atoi(pt);
    if (i < maxLength) {
      returnArray[i] = a;
      i++;
    }
    pt = strtok (NULL, ",");
  }
}

void servoWriteAll(int waitTime) {
  for (int i = 0; i < 4; ++i) {
    servos[i].attach(servoPins[i]);
  }
  for (int i = 0; i < 4; ++i) {
    servos[i].write(servoValues[i]);
  }
  delay(waitTime);
  for (int i = 0; i < 4; ++i) {
    servos[i].detach();
```

```
  }
}

void waitForConnection(unsigned long timeOut) {
  while (millis() < timeOut) {
    availableCount = getAvailableCountFromGlove();
    if (availableCount > 0) {
      break;
    }
  }
}

void readFromGlove() {
  availableCount = getAvailableCountFromGlove();
  if (availableCount > 0) {
    char text[availableCount];
    if (gloveNumber == 0) {
      btOne.read(text, availableCount);
    } else {
      btTwo.read(text, availableCount);
    }
    parseComma(text, gloveValues[gloveNumber], 5);
  }
}

void mapGloveValuesToServos() {
  int rotation;
  switch (operationMode) {
    case 0: // Bend sensors
      mapToServoOne(getIndexBend(0), 0, 100);
      mapToServoTwo(getMiddleBend(0), 0, 100);
      mapToServoThree(getIndexBend(1), 0, 100);
      mapToServoFour(getMiddleBend(1), 0, 100);
      break;
    case 1: // IMUs
      mapToServoOne(getRoll(0), 0, -90);
      mapToServoTwo(getPitch(0), 90, -90);
      mapToServoThree(getRoll(1), 0, 90);
      mapToServoFour(getPitch(1), 90, -90);
      break;
    case 2: // IMUs + bend
      mapToServoOne(getRoll(0), 0, -90);
      mapToServoTwo(getIndexBend(0), 0, 100);
      mapToServoThree(getRoll(1), 0, 90);
      mapToServoFour(getIndexBend(1), 0, 100);
      break;
    case 3: //IMUs + bend
      mapToServoOne(getIndexBend(0), 100, 0);
      mapToServoTwo(getPitch(0), 90, -90);
```

```
      mapToServoThree(getIndexBend(1), 100, 0);
      mapToServoFour(getPitch(1), 90, -90);
      break;
    case 4: // head + bend
      my3IMU.getYawPitchRoll(ypr);
      rotation = (int)ypr[1];
      mapToServoOne(getIndexBend(0), 0, 100);
      mapToServoTwo(constrain(rotation, -90, 0), 0, -90);
      mapToServoThree(getIndexBend(1), 0, 100);
      mapToServoFour(constrain(rotation, -90, 0), 0, -90)
    ;
      break;
    case 5: //head + hand IMU
      my3IMU.getYawPitchRoll(ypr);
      rotation = (int)ypr[1];
      mapToServoOne(getPitch(0), 90, -90);
      mapToServoTwo(constrain(rotation, -90, 0), 0, -90);
      mapToServoThree(getPitch(1), 90, -90);
      mapToServoFour(constrain(rotation, -90, 0), 0, -90)
    ;
      break;
  }
}

void setup() {
  btOne.listen();
  btOne.begin(baudRate);
  btTwo.listen();
  btTwo.begin(baudRate);

  Serial.begin(9600);
  Serial.println("Begin");

  pinMode(buttonPin, INPUT);

  my3IMU = FreeIMU();
  my3IMU.init(false);
}

void loop() {
  detectButtonPress();
  pollGlove();

  delay(2);

  servoWriteAll(50);

  unsigned long timeOutTime = millis() + timeout;
  waitForConnection(timeOutTime);
```

```

  if (availableCount > 0) {
    readFromGlove();
    mapGloveValuesToServos();
  }

  gloveNumber = !gloveNumber;
}


// Helper functions for main functions:
int getAvailableCountFromGlove() {
  int count;
  if (gloveNumber == 0) {
    count = btOne.available();
  } else {
    count = btTwo.available();
  }

  return count;
}

// Helper functions for setting the servos with the
    correct mapping:
void mapToServoOne(int value, int from, int to) {
  servoValues[0] =  map(value, from, to, 120, 30);
}

void mapToServoTwo(int value, int from, int to) {
  servoValues[1] =  map(value, from, to, 180, 30);
}

void mapToServoThree(int value, int from, int to) {
  servoValues[2] =   map(value, from, to, 30, 120);
}

void mapToServoFour(int value, int from, int to) {
  servoValues[3] =   map(value, from, to, 0, 180);
}

// Helper functions for getting sensor data from list:
int getIndexBend(int gloveNum) {
  return gloveValues[gloveNum][0];
}

int getMiddleBend(int gloveNum) {
  return gloveValues[gloveNum][1];
}

```

```
int getYaw(int gloveNum) {
  return gloveValues[gloveNum][2];
}

int getPitch(int gloveNum) {
  return gloveValues[gloveNum][3];
}

int getRoll(int gloveNum) {
  return gloveValues[gloveNum][4];
}
```

Listing B.4: Ear code for new ears

Appendix C

Interviews

C.1 Questions for the Actor

- Whats your experience of using the ears?
- Does it feel natural to operate them?
- How do you feel that the ears work on stage?
- Do you feel that they add something to the performance?
- Have you grown in the way you use the ears?
- What are your thoughts on the control mechanism? Do you think it is a problem that one can see that the ears are controlled by the hand?
- Can you think of any alternative methods for controlling the ears?
- Do you have any positive or negative feedback on the ears?

C.2 Questions for the Instructor

- Were you involved in the decision to make mechanical ears for the elephant?
- How did you imagine that the ears would work?
- Now when you have seen them, how does the final product compare to what you imagined?
- What are your thoughts about using this kind of technology in theatre?
- Can you tell me a bit about the lights on the octopus?
- What are your thoughts on the control mechanism? Do you think it is a problem that one can see that the ears are controlled by the hand?
- Can you think of any alternative methods for controlling the ears?
- Do you have any positive or negative feedback on the ears?

C.3 Questions for User Tests

- Do you have any acting experience?
- Can you describe your experience of using the ears?
- How did the interaction feel?
- Can you think of any alternative ways of controlling the ears?
- Do you have any positive or negative feedback on the ears?

Appendix D

Test Plan

Before the test begins:

1. Connect power cables and turn the gloves and ears on.
2. Control that the ears work.

Plan for the test:

1. Introduce myself, and thank the person for participating.
2. Explain the ears and controls in short.
3. Explain that this is a test of the ears, not of the test person and that if for some reason they want to stop the test, they can do that at any time.
4. Explain what is going to happen during the test.
    - Go through six different input modes.
    - Card ranking.
    - Semi-structured interview.
5. Ask if the test person is comfortable with the session being audio recorded.

6. Ask the user to explain what she/he is thinking and trying to do during the test.
7. Help the test person put on the gloves.
8. Put the ears on the test person and ask her/him to fasten it comfortably.
9. Tell the participant that for each mode they should try to express the following four emotions using the ears: Happiness, sadness, curiosity, and fear.
10. Press the button to cycle through the six modes.
11. Help the user take of the equipment and turn it off.
12. Introduce the card ranking exercise.
13. Perform the card ranking and ask the user why they ranked the different interactions as they did.
14. Perform the semi-structured interview.
15. Thank the user for the participation, ask if they have any questions or anything more they would like to say.

Appendix E

User Tests

The texts are summaries of what the test persons said during the card ranking exercise and interviews. They are for the most part transcribed directly from what was said, but only the most essential parts of what was said have been written down. In some places the text is a somewhat modified version of what was said in order to make long statements shorter, while keeping the same content. All the conversations with the test persons were in Norwegian this means that all of the interviews and card ranking reflections are translated to english.

E.1 Subject 1

Sadness	Ears down
Happiness	Ears up and forwards
Fear	Ears backwards and straight out
Curiosity	One ear up

Table E.1: Subject 1 emotions

E.1.1 Card Ranking

Score: E, F, A, D, C, B

Rated B lowest because it was the hardest, the hands came in the way and the movements needed to control the ears were to big. E was best closely followed by F, this was because it was possible to use the head, not just the hands. You could use more of you body to express yourself and control the ears. It was also a good thing that one was less dependant on using the hands as much, giving more freedom to using the hands in order to express oneself. Using the bend sensors was best, because that did not show as much. When using the IMUs the movements had to be bigger, and that was more limiting for how one could move in general. A is best for precision control of the ears, it is not so visible, but it's less fun when the head is not used. The test person also found it weird to use both index and middle fingers at the same time. The test person felt that it was too fiddly. For D the test person felt that it was a bit silly to use the pitch of the hands to control the tilt of the ears. They felt silly flipping their hands up and down. The hands just ended up in awkward positions, except for the neutral position. The test person felt that C made sense logically, to rotate with IMU roll and tilt with index finger, but the hands take too much space and the interaction dictates too much where the hands should be. Which leaves little room for using them to express feelings or do other tasks. It also feels a bit unnatural. E and F uses more of the body and is not as static, you have to use your body in order to express yourself. The test subject said that: "I did not think about how I used my body for the other mappings, not until I tried this [referring to mapping E and F]."

E.1.2 Semi-structured Interview

Do you have any acting experience?
No, not acting but I am an active dancer. I have some drama experience from folk high school.

Can you describe your experience of using the ears?
Fun! But it was a bit hard to get used to. It was fun to play with

it and experiment with the ears, but it was hard to make specific movements and angle the ears just right.

How did the interaction feel?
It depended on the mapping, some mappings felt rely weird and the movements felt awkward. It was sometimes hard to know which movement would do what. I was too conscious of my hands when using the IMUs, the fingers were better, because then I did not have to think so much about my movements. You have more precision control over your fingers. The most natural way of using the ears was by using the head.

Were there too many things to think about?
No, it was ok, in the middle of the test if was a bit much to take in, but it was better when had used the ears for a while and had gotten more used to moving the ears on my head. But there could not have been more mappings, that would have been too much. It was nice to try different mappings though.

Can you think of any alternative ways of controlling the ears?
It's important to use natural movements, it has to be easy to control like when I used the fingers, that was good.

Do you have any positive or negative feedback on the ears?
I understood quickly what movements did what, even though the ear movements could be a bit uneven and slow. It was irritating when the ears got stuck or did not move the way they should, I did not know what to do about it and ended up just trying to wave my hands in order to get them to move again.

E.2 Subject 2

Sadness	Ears down
Happiness	Ears up
Fear	Ears backwards
Curiosity	Moving one ear up and down

Table E.2: Subject 2 emotions

E.2.1 Card Ranking

Score: E, F, A, B, D, C

E was the most natural mapping in relation to body movement. The ears follow the body when you bend your head the ears follow. If feels better than F because you can use your fingers [the bend sensors] to control the ears in stead of the hand [IMU]. F is much the same as E, but using the IMU was a bit unnatural.The fingers are more precise, but apart from that E and F where very alike. A was fine when I got used to it, but not as natural as E and F, you have to fiddle a lot to get the expressions want. B works as one would expect, but the hands are to actively used, it feels weird to involve the hands that much. D and C are also much of the same as B, there is just too much to think about, that feels unnatural.

E.2.2 Semi-structured Interview

Do you have any acting experience?
No, only school plays.

Can you describe your experience of using the ears?
It was fun! But it was annoying to use the wool gloves, and the screw on top of the head hurt.

How did the interaction feel?
Good, natural and responsive. But I did not always feel like the ears followed my movements.

Can you think of any alternative ways of controlling the ears?
Use more sensors to look at the body posture, for example on the shoulders, back, and legs. You could use both bend sensors to control the same ear movement. That that way an actor could switch what finger is used to control the movement depending on the situation, and in order to not make the mapping between the finger movement and the ear movement to obvious. Also, I did not like that the ears followed the hand rotation, it was better to use pitch. I use my hands a lot when I talk, so that makes it a bit weird when I am talking to move the ears just because I made a random gesture while talking.

Do you have any positive or negative feedback on the ears?
Very cool!

E.3 Subject 3

Sadness	Ears hanging
Happiness	Up and out
Fear	All directions
Curiosity	One ear back and one out

Table E.3: Subject 3 emotions

E.3.1 Card Ranking

Score: A, B, F, C, D, E

Mapping A made it easy to move the ears in different ways, it gave the best control. B also made it easy to control the ears individually. F made it easy to express emotions because one had to use the head. I did not like that I did not have individual control over the ears. C was ok, it made it possible to show what I wanted and I had individual control, but it was nothing special. It was hard to combine fingers and tilt in mapping D, I also lost some sensor values, so the movement was a bit of. E made it hard to move the ears were I wanted when I had to use the fingers. I think that it was most natural to use rotation in the movement, the way it was done in E.

E.3.2 Semi-structured Interview

Do you have any acting experience?
No.

Can you describe your experience of using the ears?
It was fun and new. It was a bit awkward in the start but I got used to the controls after a while. It's a fun concept.

How did the interaction feel?
It was ok, but you need some training to get the hang of it. Mapping F was most natural, but A gave best control. I got used to the controls after a while, and it felt more natural after a while when I got more used to the concept of controlling a pair of ears on my head.

Can you think of any alternative ways of controlling the ears?
You could move the IMU to the arm so that the hands had more freedom to move.

Do you have any positive or negative feedback on the ears?
The ears worked nicely, there was some delay. The hat has to be improved it is uncomfortable.

E.4 Subject 4

Sadness	Ears down
Happiness	Ears a bit up
Fear	Moving the ears around
Curiosity	Moving the ears up and down

Table E.4: Subject 4 emotions

E.4.1 Card Ranking

Score: D, C, E, F, B, A

I liked D because it split the functions on more body parts. The movements felt natural. C was a bit like D, but I felt that roll was a bit more unnatural. E was nice because the functions were split, like in D and C, but I did not like to bend the head I was nervous about the ears falling of and I could not see myself in the mirror. I also felt that by locking the ear movement to the body posture led to a loss of movement freedom. F was a bit like E, but pitch was not as good a control mechanism as bend. The movements used in

B was a bit to similar, it was easy to get them wrong because they both used the same joint in the hand. Maybe with some practice. A was just too much coordination for me, I had to concentrate a lot to get it right. Also, there is no natural mapping between for example the index finger and rotating the ear.

E.4.2 Semi-structured Interview

Do you have any acting experience?
I danced some hip hop when I was a kid. I also do a lot of dancing on the town.

Can you describe your experience of using the ears?
It was good, they worked as I had expected. I do not feel like there is anything missing movement wise. They were a bit uncomfortable to ware though. Also, I do not think that the movement is smooth enough.

How did the interaction feel?
It felt good. Most of the mappings felt intuitive to use. I did not like that the inputs were so close in mapping A, I needed the mirror in order to understand how the ears moved. Generally I felt that I needed the mirror for most of the mappings, but for the two mappings I rated highest, D and C, I probably could have managed without the mirror.

Can you think of any alternative ways of controlling the ears?
You could use brain activity. If it is possible you could try to use the wearers actual ears, if the wearer can move their ears. You could also use cameras and face recognition.

Do you have any positive or negative feedback on the ears?
The ears worked well. For the negative, I did not like that, when using roll to control the ears, if you rolled the hand to far, the ears would behave weirdly. The woollen gloves was a bit of a minus.

E.5 Subject 5

The head IMU did not work properly during subject 5's user test.

Sadness	Ears up
Happiness	Ear down
Fear	All possible directions
Curiosity	Ears out

Table E.5: Subject 5 emotions

E.5.1 Card Ranking

Score: D, B, C, E, F, A

I liked D the best, it felt most natural. B was also quite good, but I felt that the sensor combination was better for D. In mapping B I also ended up with the hands in some weird angles and that made the ears act a bit strange. I felt that the ears performed like I wanted. In mapping C I did not like that I used the finger for the biggest movement, and the hand for the small movement. I felt that it was most natural to use the arm for big movements, and the fingers for smaller movement. That is also one of the reasons why I liked D best. I did not really feel comfortable with mapping E and F because the ears kept falling of, also there was the thing where the ears did not seem to work. But here, like before, I preferred the mapping that used the finger for the small movement and not the hand. Lastly for mapping A the biggest problem was that I did not remember what finger did what, there is no real natural mapping between the fingers and the different ear movements.

E.5.2 Semi-structured Interview

Do you have any acting experience?
Not acting directly, but I have danced. I did theatre dance and ballet.

Can you describe your experience of using the ears?
It was nice and fun. And in the mappings that I liked it was easy.

How did the interaction feel?
It felt natural when I started to understand or comprehend that I was controlling something on may head with my hands. I guess that it kind of depend on the context the ears are used in, what is easiest. I felt I had a lot of control with my hands even though I felt a bit removed from the movement. The mirror was helpful I used it to correct the ears movement.

Can you think of any alternative ways of controlling the ears?
I don't know, maybe you could shake your bottom to shake the ears.

Do you have any positive or negative feedback on the ears?
I think it was a shame that the head [referring to the IMU unit on the head] did not work properly. Also I think it might have been useful to see the cards beforehand or during the test, in order to make it easier to remember the different movements.

E.6 Subject 6

Sadness	Ears down and back
Happiness	Ears forwards, moving up and down
Fear	Ears up and forwards
Curiosity	Ears forwards and up, moving one and one down and up

Table E.6: Subject 6 emotions

E.6.1 Card Ranking

Score: E, F, B, C, A, D

I liked E because I could use my head to control the ears, that felt natural. Using the bend sensors on the fingers also felt subtle, I did not have to wave my hands around and could keep my arms straight down at my sides. As for F I liked to use pitch and roll I thought it was more fun, but it did not work as well as the bend sensors did in mapping E. Using the bend sensors was more efficient. B felt natural, but it was harder to use only pitch and roll. I got the movements mixed up and had to think a lot. It was more fun than efficient. I liked mapping C because I felt that the combination of roll and bend sensor worked well, it made it easier not to get the movements mixed up. Still I don not think that it was quite as good as the others. I liked A and D almost as much, but I felt that using both bend sensors was a better combination than using the bend sensor with pitch.

E.6.2 Semi-structured Interview

Do you have any acting experience?
No not really, just some school plays when I was a kid.

Can you describe your experience of using the ears?
It was better than I expected. Some of the mappings felt really natural It did not feel like I was using a remote control, I don't know how to describe it, it was kind of like virtual reality.

How did the interaction feel?
I felt that I managed to do what I wanted, the ears were a bit inaccurate at times. I think that all the mappings were nice, but I think that using the bend sensors was like pushing a button to make the ears move, it was more like a remote control. Using the head was least like using a remote control, maybe because the ears are on the head. For some of the mappings I got the controls a bit mixed up, it was not obvious what movement did what.

Can you think of any alternative ways of controlling the ears?
I don't know, I guess it's best if you use the arms, if you used the legs for example it would be hard to move around.

Do you have any positive or negative feedback on the ears?
As I said the ears was a bit inaccurate in some mappings. Some of the sensors did not have the same range of movement as others. Other than that I felt that it worked well, it was responsive and the ears were very movable, more than I thought from just looking at

them. I don't think it was hard, it should be easy to learn how to use the ears. Also it was fun.

E.7 Subject 7

Sadness	Down and back
Happiness	Ears up and wiggling
Fear	Ears backwards
Curiosity	One ear up, the other out

Table E.7: Subject 7 emotions

E.7.1 Card Ranking

Score: D, B, C, A, F, E

I felt that D was the most intuitive mapping. The combination of hand gesture and finger movement made it easier to distinguish the movements from each other. In the mappings where you use both fingers or both pitch and roll on the hand moving one control often influences the other. For example with the fingers, I have small hands so the gloves did not fit very well so when I moved one finger the gloves moved a bit and bent the other sensor. In mapping D this was not a problem, because the interaction methods were separated. I also felt that the controls were logical. Mapping B was also logical, I felt that it was natural that hand roll rotated the ears and that pitch controlled tilt. Mapping C also mapped hand roll to ear rotation, but I did not feel that the finger was able to use the full movement spectrum of the tilt.

As I mentioned earlier the gloves were too big for me, that made the movements less precise and especially for mapping A made the two different movements influence each other. If I moved the index finger while keeping the middle finger still, the glove would tug at the other sensor and make the ear move. Also I felt that the mapping between the fingers and the ear movements were not very intuitive.

I did not like mapping E and F. It felt degrading to use the head to control the ears, and it was boring that I could not see myself in the mirror while tilting the ears down. No, I absolutely did not like it, it was not a good experience. I liked F better than E because I liked using the bigger movements, but I still did not like any of them compared to the rest.

E.7.2 Semi-structured Interview

Do you have any acting experience?
Well I made and acted in musicals with my friends in primary school. Except from that, not really, no.

Can you describe your experience of using the ears?
It was fun to try the ears, but it felt a bit pointless. I don't really understand what they are for. Also it took a while before I understood how to use the ears, but when I did, I liked it. I understood how to use the ears when i got to try them, it was hard to imagine how they worked before that. Using the ears was cool and exciting. It was easy to identify what mappings and aspects of the ears that I liked and what I did not like.

How did the interaction feel?
It felt unnatural, I think this kind of stuff is better for persons who are more artistic and creative than me. It was fun, but but it felt silly. It felt like I had some foreign object on my head. It might have been cool if you had used the same interaction to control something else, for example a computer game. That might have been more useful.

Can you think of any alternative ways of controlling the ears?
I think the finger controls would have worked better if the gloves had been a better fit.

Do you have any positive or negative feedback on the ears?
I liked it, but I think you could have explained the ears better before I tried them on. I did not really understand what I was going to do before I tried.

Appendix F

The Friedman Test

Friedman Test for Card Rating Results

Subjects	A	B	C	D	E	F
1	4	1	2	3	6	5
2	4	3	1	2	6	5
3	6	5	3	2	1	4
4	1	2	5	6	4	3
5	1	5	4	6	3	2
6	2	4	3	1	6	5
7	3	5	4	6	1	2
rj	3	3,571	3,143	3,714	3,857	3,714
(rj-r)^2	0,250	0,005	0,128	0,046	0,128	0,046
(rij-r)^2	0,250	6,250	2,250	0,250	6,250	2,250
	0,250	0,250	6,250	2,250	6,250	2,250
	6,250	2,250	0,250	2,250	6,250	0,250
	6,250	2,250	2,250	6,250	0,250	0,250
	6,250	2,250	0,250	6,250	0,250	2,250
	2,250	0,250	0,250	6,250	6,250	2,250
	0,250	2,250	0,250	6,250	6,250	2,250

n	7
k	6
r	3,500
SSt	4,214
SSe	3,500
Q	1,204

Degrees of fr	5
Chi	0,056
Sig.	0,944

Keep the Null hypothosis

Figure F.1: The Friedman test analysis from Excel

List of Abbreviations

BLE	Bluetooth Low Energy.
BS	Bend Sensor.
BSIF	Bend Sensor Index Finger.
BSMF	Bend Sensor Middle Finger.
CAD	Computer Aided Design.
DDR	Dance Dance Revolution.
IMU	Inertial Measurement Unit.
IMUG	IMU Glove.
IMUH	IMU Head.
UCD	User Centred Design.
UX	User Experience.

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