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Designing technology promoting increased user body awareness

USING MICROSOFT KINECT V2

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Design av teknik för ökad kroppskännedom genom nyttjande av Kinect V2

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Godkänt 2015-06-15	Examinator Martin Törngren	Handledare Bengt Eriksson
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Sammanfattning

Detta examensarbete undersöker möjligheten att använda Microsoft Kinect V2 som sensor vid design av teknik med syfte att öka en användares kroppsförståelse. Då den digitala tekniken både fysiskt samt funktionellt kommer närmare användarens kropp har ett intresse väckts rörande hur dessa digitala apparater bör förhålla sig till användaren. Detta kräver nya perspektiv som tillåter att designen inkluderar en användares kropp och dennes förhållande till sin kropp.

Detta examensarbete utfördes vid Mobile Life, ett forskningscenter med fokus på människa-datorinteraktion. Mobile Life använder sig av ett nytt förhållningsätt baserat på Somaestetik för att möta utmaningen med kroppsnära teknik. Tidigare har prototyper konstruerats med syftet att förstärka Feldenkreis-övningar med syfte att dra slutsatser angående fundamentala riktlinjer vid design av kroppsnära teknik.

I detta examensarbete har även förhållningsättet hämtats från Somaestetik. Utgånsgpunkten för arbetet ligger dock i hur Kinect V2:s funktionalitet kan användas för att inkludera kroppen i design av teknik. Genom att använda metoderna ”Research through design” och ”double diamond model” utvecklades en rad prototyper med syfte att undersöka olika tillvägagångsätt. Inledningsvis utforskades Kinect V2 genom tre inriktningar. Dessa var andningscykeln, puls och små rörelser relaterade till balans. Med dessa tre utgångpunkter utvecklades fyra prototyper. De mest lovande versionerna av prototyperna utvärderades genom användartester där användarreflektion låg till grund för vidare utveckling under en iterationsbaserad prototypframtagningsprocess.

Resultatet av examensarbetet visar att Kinect V2 är en sensor väl anpassad för denna typ av design. Studien visar att Kinect V2 har förmågan att finna små rörelser som är relaterade till en användares andningscykel. Algoritmen som utvecklades för att mäta andningsförloppet bedömdes dock otillräcklig för vidare implementation på grund av sporadiskt beteende. Kinect V2 har god förmåga att mäta små balansrelaterade rörelser och implementerades som styrsignal för en av de utvecklade prototyperna.

Baserat på slutsatser från användartester genomförda under examensarbetet samt resultat från de prototyper som tidigare utvecklats av Mobile Life föreslås ett designkoncept för vidare utforskning. Detta koncept lyder: *”Ett system med mål att hjälpa en användare reflektera över en specifik del av sin kropp måste i sin interaktion med användaren framhäva eller förmedla en liknande förnimmelse som de användaren upplever.”*

KTH Industrial Engineering
and Management

Master of Science Thesis MMK 2015:75 MDA 527

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Approved 2015-06-15	Examiner Martin Törngren	Supervisor Bengt Eriksson
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Abstract

This master thesis investigates Kinect V2's ability to be used as a sensor when designing technology with the aim of increasing the body awareness of a user.

With a transition to an increasing number of different devices operating close to the user's body, an interest in this subject has increased alongside it. These technologies demand a new approach which includes the user's body into the design.

This thesis was conducted at Mobile Life, a research center focused on the field human-computer interaction. Mobile Life uses a new approach based on Somaesthetics to include the complexity of humans in the interaction, mainly by exploring the therapy form Feldenkrais. Building prototypes based on Feldenkrais exercises, integrating technology into them, Mobile Life explores new ideas for fundamental user design.

In this thesis the perspective of Somaesthetics is kept, but the functionality of Kinect V2 is used as a base point when investigating how to include the body in technology design. By utilizing research through design and the double diamond model, different prototypes were built to investigate various approaches. Initially three paths were chosen to investigate Kinect V2 from; the characteristics of breathing, heart rate and small movements related to balance. Based on this, four different prototypes were built. The most promising prototypes were then evaluated in user tests and the input was analyzed and used in the next prototype iteration.

The thesis concludes that Kinect V2 is a potent sensor when facing the challenge of including the body in the interaction. It has the ability to detect the small movements related to a user's respiratory cycle. However, the implemented algorithm was not capable of sufficiently mapping the breathing to an actuator with the requirements set up for the prototype.

Small movements related to balance were measured without issue and the noise present in the sampled signal was filtered successfully without any delay affecting the prototype performance.

Based on the knowledge gained during the master thesis, a new design concept is proposed for future investigation. This concept states that: *"To build a system that helps the user reflect on a specific part of their body, the system must highlight or provide a similar sensation as the one felt in the user's own body."*

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In this chapter the authors thank the people involved in the work performed during this thesis.

This thesis has broadened our perspective on what we have learnt during our time at KTH and it has given, for us, new and exciting views of what technology is and can be. We would like to thank for the great support and freedom provided to us by the researchers at Mobile Life during this thesis.

A special thanks goes to the members of the SOMA project for all their helpful ideas during the design meetings and their positive attitude towards two lost mechatronics students in the deep sea of human computer interaction design and the world of Somaesthetics.

Yet another special thanks goes to our supervisor at Mobile Life, Martin Jonsson, who at every turn of the project provided ideas and inspiration for our prototypes. We would also like to thank our KTH supervisor Bengt Eriksson for the much needed support with our final report.

Andreas Axtelius & Simon Asplund

Stockholm, June 2015

ABBREVIATIONS

In this chapter the abbreviations used in this master thesis are presented.

ARGB	Alpha Red Green Blue
BPM	Beats per Minute
CAD	Computer Aided Design
DOF	Degrees of Freedom
EVM	Eulerian Video Magnification
FPS	Frames per Second
HCI	Human-Computer Interaction
ID	Identifier
IDE	Integrated Development Environment
IR	Infrared
IIR	Infinite Impulse Response (digital signal filter)
LED	Light Emitting Diode
MIT	Massachusetts Institute of Technology
MIT CSAIL	MIT Computer Science and Artificial Intelligence Laboratory
MSB	Most Significant Bit
SDK	Software Development Kit
SICS	Swedish Institute of Computer Science
ToF	Time of Flight

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1. INTRODUCTION

This chapter contains a presentation of the background, the purpose of the thesis, the delimitations, and the methods used during the thesis. It also contains an overview of the work performed, an outline of the report, and a short description of how the work was divided during the master thesis.

1.1 Background

There is an ever growing quantity of sensors and actuators surrounding us in our everyday life. They are getting smaller, more affordable, and simultaneously transforming our devices into “smart” devices, e.g. smart phones, smart watches and smart homes. These “smart” devices, that are becoming intimately closer and closer to us, have the ability to share data sampled about ourselves and our bodies, in a way not previously seen before. As digital technology is approaching our bodies; a question takes shape of how this technology is to be used. How are designers of this new technology supposed to relate to humans and their bodies in a way that takes advantage of the possibilities the technology provides? In what way can this technology be used to increase the quality of life? These questions are expressed, among others, by The Mobile Life VINN Excellence Center and sought to be answered. By adapting new concepts of how to view the body, Mobile Life is investigating alternative ways of designing interaction between humans and the “smart devices”. Mobile Life, with together with other human-computer interaction (HCI) researchers, have put a special interest in an (initially) philosophical concept called Somaesthetics (Shusterman 2008); as it has been shown promise in delivering this new perspective for understanding the human body.

Mobile Life investigates this by creating prototypes that explore interaction between body and “smart devices” based on inspiration from Somaesthetics. However, as these systems are prone to be complex and based on sensor actuator loops, it is becoming relevant to include mechatronics in the early design stages. This thesis is an early attempt to build prototypes using the new concept and investigate how students with a mechatronic background might contribute when designing prototypes with a Somaesthetic viewpoint. The work is performed by building prototypes, heavily based on Kinect, following the perspective and guidelines from the previous research carried out at Mobile Life - aiming to incorporate mechatronics.

1.2 Purpose of the Thesis

Most of the previous work conducted at Mobile Life regarding Somaesthetics and HCI has been focused on the practice of Feldenkrais, and the prototypes has been a reflection of that. It is in Mobile Life's interest to further explore the domain of the unification of HCI and Somaesthetics; but with a different focus. One of the common denominators of the previous prototypes has been the lack of adaptation to the user. It is also important that the sensors used are non-bodily intrusive, since this will allow for a somaesthetic experience were the focus is kept around the user's body experience. A sensor that enables non-bodily intrusive data collection is the Kinect V2. In order to explore the possibilities of the Kinect V2, an investigation of the performance of the sensor is to be done. By combining mechatronic system knowledge with HCI and Somaesthetics, the goal is to design a system that creates an interaction that promotes body awareness. The subject will be explored by mapping small movements to different types of feedback in order to create a pleasant experience. This study will supply Mobile Life with knowledge regarding the use of Kinect V2, so that it may be used in future projects regarding Somaesthetics and HCI. In other words the thesis will be split into three different parts:

- Investigating the limitations and possibilities of using the Kinect V2 as a sensor of small body movements.
- Constructing a prototype that explores the area of body awareness and HCI with the Kinect V2.
- Performing a mechatronic evaluation of the prototype and the Kinect V2's performance.

Ultimately, the goal of the thesis is to provide inspiration and ideas, captured in a prototype and its design process, together with the investigation of the Kinect V2. It is to be decided if the Kinect V2 has the potential to be used as a sensor in the field of Somaesthetics and HCI.

1.3 Delimitations

Since the master thesis is focused on the evaluation of Kinect V2's performance, it is also the main requirement of the project. The data gathering is performed using the Kinect V2 as the sensory input and the prototypes are to be built with the Kinect V2 as the main component. This means that the technical specifications of the Kinect V2 will limit the accuracy of the data collected, as well as the types of data that can be measured. Using the Kinect V2 also restricts the ability to construct a standalone system prototype. The Kinect V2 requires a lot of processing power which is not available, from an economical perspective, in other forms than a personal computer. It also requires power from a wall-based power socket. Furthermore, the mobility of the prototype will be slightly affected because of this.

It is Mobile Life's request that a type of haptic feedback in the form of servo motors or DC motors is used, since that feedback is somewhat unexplored as of yet. This means that the prototype preferably will contain a number of actuators which are used to communicate with the user.

For their previous projects based on Somaesthetics, Mobile Life has used an open-source programming interface/language called Processing 2. Beneficial for designers, Processing 2 has a lot of functionality for visual representation and image data handling. It is decided that Processing is going to be used when exploring the Kinect V2's features, mainly because there is an open-source Processing wrapper available for the Kinect V2 functionality. By using Processing, it is easier for Mobile Life to use the results in future research.

As the Kinect V2 in this case is bound to a PC, it is favourable to use an actuator control unit that supports a direct connection between the two. Phidgets is an array of sensors and actuator control units that are designed to act as a bridge between an actuator or sensor and a PC. At Mobile Life Phidgets are well used and has been implemented in their previous prototypes. Phidgets are further explained in 2.6 Hardware.

1.4 Method

Mobile Life and other HCI researchers utilize a way of doing research named “research through design”. When conducting research in this way, focus is placed on the knowledge gained while exploring the area of interest by designing prototypes for interaction in the same setting. This method is utilized in an effort to counteract that there are no complete human user models. Therefore, an interaction has to be created before it is studied and understood. In this case this is the use of Kinect V2 as a sensor for interaction aiming to give increased body awareness. The final prototype will be an additional way of exploring the subject and will not represent the entirety of the results. This implies that the focus of the master thesis will be exploring the area of increasing body awareness with the help of the Kinect V2, but also performing an evaluation of the limitations of the Kinect V2 sensor. In accordance with this, a design and development model called the “double diamond model” will be implemented as a part of the thesis. To be able to design and perform research for Mobile Life it is advantageous if their methods are used. As previously mentioned, when designing for interaction with humans, one of the greatest obstacles lies in the lack of a complete model of a human user. The double diamond model deals with this by building its foundation on user tests and reflections throughout the design process - from the understanding of the problem and the task to design for, to the finished solution and evaluation. By utilizing this way of working the design will be more adapted to human users and the process guided by their inputs.

When collecting data on the Kinect V2’s performance a quantitative approach is used. In other words, data is gathered in different settings and analyzed in aspects of noise, accuracy and others. By analysing this data, a number of conclusions will be drawn regarding the Kinect V2’s viability in this setting with respect to accuracy and performance. For the evaluation of the prototype a more qualitative approach will be adopted. Here the results of the user tests will be the deciding factor when determining if the prototypes succeeds in the task of increasing body awareness.

1.5 Overview of Master Thesis

This section is provided to give the reader an overview of the master thesis' design process.

Initially a literature study was performed to gain a fundamental understanding of the area of Somaesthetics and human-computer interaction as well as previous work conducted by Mobile Life. Using the Kinect V2 as a base, three different areas of interest were identified for further investigation. To explore these, a number of prototypes were constructed and user tests were performed for each of them. With the knowledge obtained throughout the design process a final prototype was constructed and evaluated with user tests. **Figure 1.1** shows an overview of the process based on the double diamond model, which is explained in 2.2 Double Diamond Model.

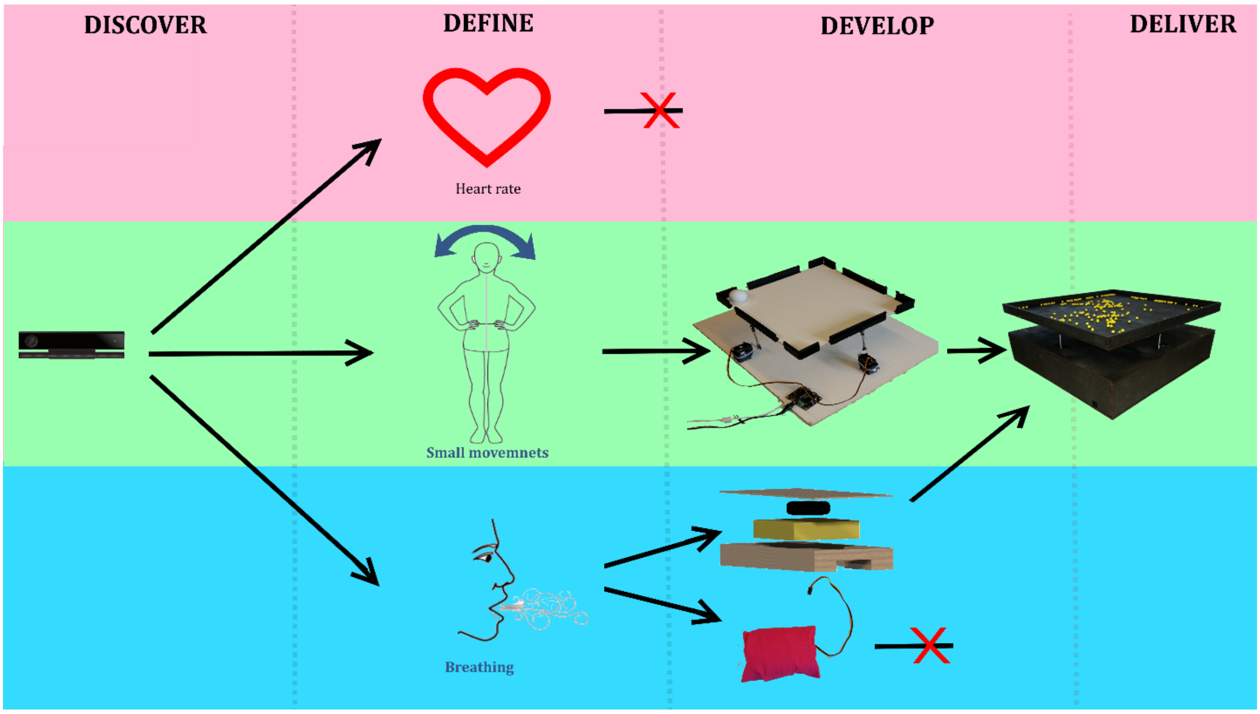


Figure 1.1. Overview of the master thesis' design process.

1.6 Outline of Report

The **frame of reference** contains information regarding methods used in the project and various concepts important to Mobile Life's research, derived from human-computer interaction design theory. It also contains information regarding the software development environment used in the thesis as well as technical information on the hardware used – the Kinect V2 and Phidgets. Additionally, the frame of reference contains information regarding previous research conducted at Mobile Life relevant to the master thesis, which has been used to identify the problem solved during the thesis.

Built on the identified problem, the **design process** describes the "define" and "develop" phases. These, just as the "discover" phase presented in the **frame of reference**, are based on the double diamond model and form the framework used during the thesis. In **design process** the work performed during the thesis is presented in chronological order with the initial investigation of the Kinect V2's capabilities, the three different design paths explored as well as the iterations of the various prototypes.

In **results** the final prototype iterations are presented along with the user test results. The section also contains the results from the investigation of the Kinect V2 as a sensor for human-computer interaction.

Finally, in **discussion and conclusion** the thesis results and the methods used are examined. The questions stated during the initial chapter of the thesis are discussed in reference to the final results. Furthermore, recommendations for future work and problem approaches are presented in **recommendations**.

1.6.1 Work allocation

During the master thesis the steps taken and decisions made has been discussed between Asplund and Axtelius and both has been equally involved in the design of the prototypes. With this said, Axtelius has conducted the overall work of understanding the Kinect V2 software library utilized during the thesis and has written the software application frameworks implemented in the prototypes. Asplund has been responsible for CAD-models and 3D-printing various objects, as well as the work conducted in MATLAB.

1.7 Contributions

This thesis provides an investigation of the Kinect V2's usability when designing interactions and technology with the aim of increasing a user's body awareness. The technical limitations of the Kinect V2 are explored and a base for further work with the Kinect V2 as the sensory is built.

Furthermore, the user tests performed during the thesis lay the foundation in the form of tendencies of a concept. The concept is seen as a potential strong concept to be utilized when designing technology which includes the body into the interaction.

2. FRAME OF REFERENCE

This chapter presents the theoretical reference frame that is necessary for the performed research. It also contains information regarding the hardware and software used during the development of the prototypes presented in this thesis.

2.1 Designing for Human-Computer Interaction

In Human-Computer Interaction, “designer” is a profession not very well defined. One of the main reasons for this is that the definition of Human-Computer Interaction has changed a lot during the previous years. In the beginning of HCI focus was on usability and design was a very specific concept: *“…the idea of design in HCI was taken for granted and [was] not a point of concern or discussion….”* A previous definition was: *“[design] meant the process of modeling users and systems and specifying system behavior such that it fitted the users’ tasks, was efficient, easy to use and easy to learn.“*(Wright, Blythe, and McCarthy 2006). In recent years HCI has expanded and the meaning of the word “design” in HCI has changed alongside it. In a conference proceeding from CHI 2007, *Research Through Design as a Method for Interaction Design Research in HCI,* it is written that it is very common in the HCI community to use the term design to mean HCI practice and the term designer for a HCI practitioner. In this example that could mean *“…interaction designers, usability engineers, software architects, software developers, etc…”*(Evensson, Forlizzi, and Shelly 2007). In the same proceeding the view on design and development in HCI is discussed in interviews with nine leading academic HCI researchers accompanied by one of their graduate students and six leading interaction designers. They provide a view of the HCI community during the early years and how it has developed. Most notably is the mention of the transition where trained designers began working with software developers, providing skills in areas such as visual hierarchy, color and typography. These are skills that they had developed while working with other design projects.

Previously designers were brought in during the later stages of the project and were asked to make the final visual touches of the interaction. This meant that they were excluded from the process and could not be a part of the design of the interaction. Improvements to the design were disregarded because of the late stage in the development process. Furthermore, the interviews presented three ‘main themes’ that discuss the value design brings to HCI.

The first theme regarded under-constrained problems and how interaction designers provided an approach to solving these problems that usually proved to be a problem for traditional engineering practice. Secondly the designers provide a solution to integrating ideas from other disciplines, such as art, design and science, to create aesthetical features to interfaces. The third theme the designers brought was the empathy for the users and the needs from an “external observer’s” perspective; thus creating interfaces that have the users in mind. It is with these three main themes that design in HCI has changed into what it is today. As is written in the paper *User Experience and the Idea of Design in HCI* by Wright, Blythe, and McCarthy: *“…various technological developments have led to a questioning of this idea of design in HCI. The confluence of information and communications technologies, and the reconceptualization of interactive systems as a new media brings a much broader set of ideas about what it means to design an interactive system….”*

The HCI community can be split into two different areas, where one is HCI research and the other is HCI practice. Mainly what separates these two areas is the goal of the projects. As shown in **Figure 2.1** the HCI researchers create research artifacts which are then used for inspiration and ideas by the HCI practitioners when they are designing products for commercialization. Artifacts generated by the research community will most likely not even cross the research/practice barrier seen in **Figure 2.1** and the process from idea or research question to commercialized product is often takes a lot of time.

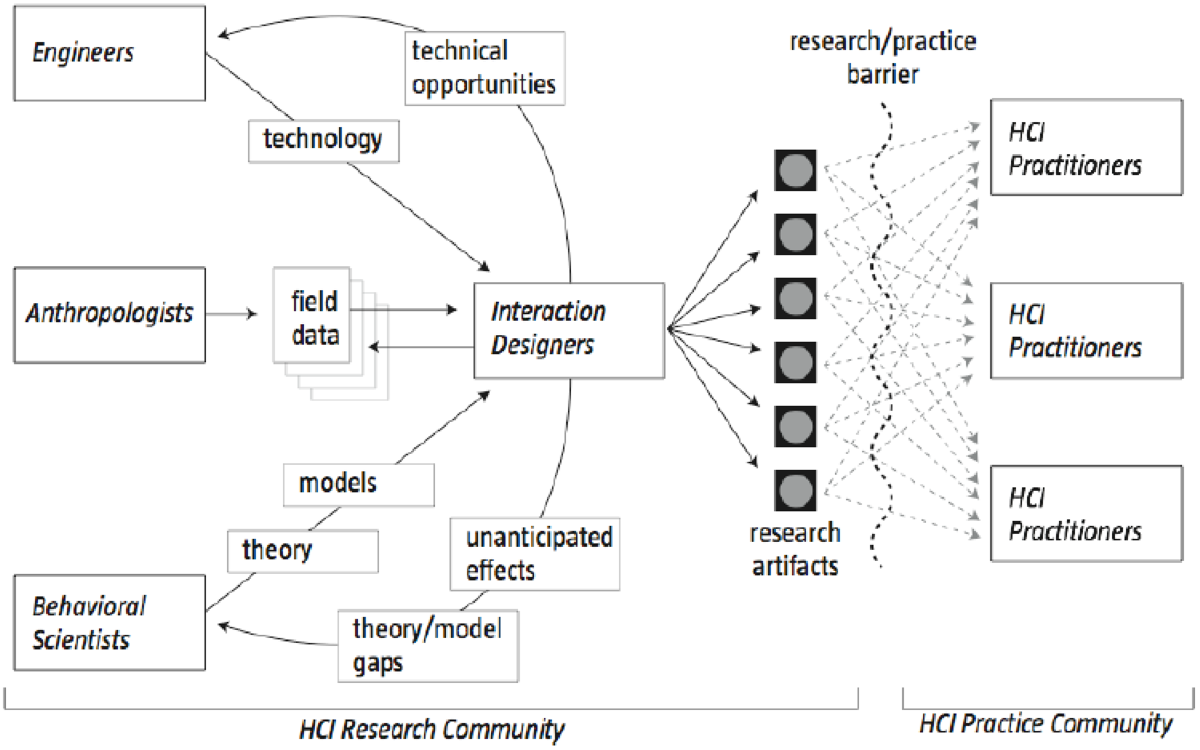


Figure 2.1. An illustration of the pathways and deliverables between and among Interaction Design Researchers and other HCI researchers. (source: (Wright, Blythe, and McCarthy 2006))

To help categorize design processes in HCI a researcher named Daniel Fallman has split the field into two large categories, or approaches, which is presented in his paper *Design-oriented Research versus Research-oriented Design*. Fallman has named the two different development methods *Design-oriented Research* and *Research-oriented Design.* In the paper Fallman also writes that *"It is hence possible to find projects which are situated in between design-oriented research and research-oriented design, seeking to contribute with both knowledge and products."* and continues with the statement that it is in the interest of HCI projects to focus on one of the approaches. Fallman's idea is that using these two distinctions it is possible to pinpoint the position of current HCI projects. Although it might be possible for a project to be positioned in between these two distinctions, ending up there would be very non-beneficial for the outcome of the project. What separate the two approaches are the way prototypes, or artifacts, play a part in the purpose and goal of the projects.

2.1.1 Design-oriented Research

Just as the name implies, design-oriented research is research based on design. It also goes under the name *research through design*. While practicing research through design the focus of the project, and of the expected results, lies on the knowledge gained at the end of the process. This means that the artifact, or prototype, is often created through more than one iteration throughout the project and is *designed* to explore the *area* where the knowledge gain is needed. A number of iterations imply that more than one prototype is created throughout the process, as all of them provide knowledge gain that contributes to the aim of the project – exploring the possibilities of the area.

Traditional engineering practice often base projects on a number of requirements and limitations that is taken into account when a prototype is developed. While this sets a clear goal for the project, the limitations may restrict some of the intended features. When designing for research on the other hand, especially in HCI, it is vital that the scope of the research is not limited by requirements or specifications. This means that the scope is not narrowed down until the later stages of the project. By narrowing the scope one of the iterations of prototypes may be chosen to be further developed or a particular area within the field may be studied in-depth. Allowing for this, the field or subject itself is studied. Using the information gained during the research project it is possible to either perform further research on the results or use the knowledge in constructing a commercial product - by transferring the artifact across the “research/practice barrier” seen in **Figure 2.1** and allowing the HCI practitioners use the knowledge to their advantage.

2.1.2 Research-oriented Design

Contrary to design-oriented research, research-oriented design is an HCI approach very similar to “traditional” engineering practice. In this case, the aim of a project is to create an artifact that is based on a number of requirements and restrictions. Often there is a third party involved in the project and there is an expected outcome of the project, defined by the initial requirements. The resulting artifacts differ from design-oriented research such as they may be finished products instead of prototypes or concepts. While this approach also produces knowledge, just as design-oriented research is focused on, it is not seen as the primary outcome. Instead the artifact is the result of the effort spent in the project. What separates this approach and the “traditional” engineering approach is the fact that it is still an HCI practice. This implies that the user is still one of the main factors when designing the artifacts since it is interfaces between systems and users that are designed. (Fallman 2004)

2.2 Double Diamond Model

The Design Council is a British organization established by Winston Churchill in 1944. During 2005 the organization created the Double Diamond Model, a design development model that aims to group up a multitude of other design models used in the industry. With this it is possible to create a visual representation of a design process and name the different phases of the development process. The visual representation of the model created by the Design Council, with explanatory text added, can be seen in **Figure 2.2**, where the major “gates” are seen above the red double diamond and the four different phases are seen below it. The gates represent go/no go stages in the process, similar to the gates of the Stage-Gate® project management technique in the sense that the work performed during the previous phase is reviewed and it is decided whether to proceed with the project or modify the current result (Cooper 2008).

Each of the four phases contains different activities and methods that define them. While the Double Diamond model explains the development process step-by-step it is important to note that it is a way of gathering multiple models used in the design industry under one name. In other words, every company has their own version of the Double Diamond model. This may include various definitions of the different phases or strategies to employ during the development. Despite this it is possible to explain these steps in general using the Double Diamond model definitions and names.

As the visualization of the double diamond model shows, understanding the problem is just as important as finding a solution. When designing for users; a good understanding of why the problem exists is crucial to solving it. As with design processes in general, it is important to not limit the project by adding requirements or restrictions. To find a need it is vital to keep all options available and make sure that the scope is widened. When research on the area is finished a point of focus is decided and the scope of the project is narrowed down. In the Double Diamond model this occurs at two points in the project. Once for the background research and once for the development of the artifact (Council 2015a, b).

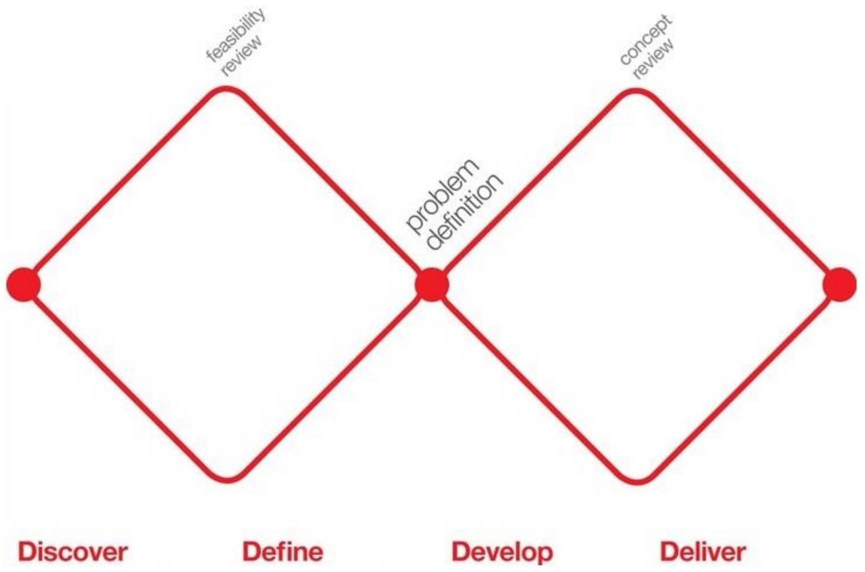


Figure 2.2. A visual representation of the double diamond model (source: (Council 2015a)).

2.2.1 Discover

Marking the start of the project, the *"discover"* phase begins with an initial idea. Here the user needs are identified and possible areas of interest are discussed. During this phase information regarding the target area or subject is collected using various techniques, e.g. market research, user research, design research groups and brainstorming. The characteristic trait of the design process, which is the basis for the double diamond model, is that the user need are researched before the problem is stated and the problem solving has begun.

The *"discover"* phase varies a lot depending on what type of design project it is, but the general idea is collecting information from various sources. By analyzing users and their behavior it is possible to study how current products are used and how different areas may provide opportunities for improvements, innovation, or services that addresses certain user needs. The user studies often include "immersion" in the customer/user experience for the designers to understand what they are designing for and what they are trying to solve. Written in the Design Council's instructional paper on the Double Diamond model is: *"Starbucks sends their designers to work as baristas in their stores for up to a month to fully immerse them in the coffee and user experience that the Starbucks brand embodies."* Market research provides a good view on possible future trends and user behavior/preferences in relation to current products or services. In all cases the *"discover"* phase is a lot about trying to broaden the view and getting as much information as possible from as many sources as possible.

2.2.2 Define

During the second phase, the *"define"* phase, the collected data and user needs are used to state and specify a problem or need that the users have. Depending on the project type, this phase may also be seen as defining what the customer is looking for based on what has been studied in the *"discover"* phase. It is during the *"define"* phase that the first "reduction of the scope" is performed. During this phase it is also important to gain an understanding of why the problem exists in the first place and where the problem is located. Here the designers have to communicate with individuals from other disciplines to obtain a multidisciplinary view on the problem. Information provided by "non-design" disciplines, such as engineering and research & development, is used to assist the designer and input information into the design process; steering it toward the right direction.

2.2.3 Develop

Continuing the previous planning and theoretical work the "*develop"* phase consists mainly of practical work where the construction of the prototype(s) is performed. Together with this the multidisciplinary work between designers and developers is initiated. One of the strengths of this type of work lies in the ability to create cross-disciplinary teams and utilize the multitude of skills available. Working close together also reduces time for communication between the different areas of expertise. It is also possible to identify potential bottlenecks in the development since every part of the team will be communicating regularly.

Visual planning is still a big part of the development process and is utilized throughout this phase as well. CAD models, Excel spreadsheets and project roadmaps are just three examples of implementations of the visual planning.

The aim of the *"develop"* phase might differ depending on the project type. In industrial projects the reason for the project is most likely a new product. Through various iterations of this process, depending on how many is necessary, the aim is to reach a result that is as close to the final product as possible. Here the *"develop"* name of the phase serves it justice since ideally all of the development is performed during this phase. In projects not directly focused on a finished product, the *"develop"* phase is more focused on narrowing down the scope of the final deliverable. In projects based on research through design, the *"develop"* phase results in one or more prototypes that in some sense represent the knowledge gained during the project.

2.2.4 Deliver

The final phase, *"deliver"*, represents finalization of the project. During this phase the deliverable is completed and final testing is performed. Remaining constraints or problems are identified before the product is manufactured and shipped. The product is also checked against various standards and regulations to ensure that everything is in order.

While the development is finished and the product is launched the *"deliver"* phase is not finished. Making sure that the successful parts of the project are kept in future product developments, it is vital that the process is well documented. An evaluation of the development process is performed and the results are kept for future reference. To steer the company in the right direction, customer feedback is collected and analyzed for future projects. The feedback collected post-launch is then used to steer the *"discover"* phase of the next design project.

2.3 Strong Concepts

The categorization of projects in human-computer interaction written by Daniel Fallman speaks of design-oriented research. As mentioned in chapter 2.1, the idea of this type of research is to create knowledge based on designs. In the journal article *Strong Concepts: Intermediate-Level Knowledge in Interaction Design Research* Kristina Höök and Jonas Löwgren introduces a notion they refer to as "Strong concepts". Built around the design-oriented research way of creating knowledge, the idea addresses knowledge on a so called "intermediate" level of abstraction (Höök and Löwgren 2012).

Figure 2.3. Strong concepts' level of knowledge (source: (Höök and Löwgren 2012)).

When creating knowledge, the results take on a certain level of abstraction. High-level knowledge is defined by Höök and Löwgren as generally applicable and is named **theories**. On the opposite side of the spectrum is **instances**. These are applicable for certain instances of design and are scenario specific. A visualization of the abstraction levels can be seen in **Figure 2.3**, where the term "Strong concepts" is positioned in the middle ground between theories and instances. To put strong concepts in reference with other concepts in design the notion of "design patterns" is introduced.

In design and development the idea of using "patterns" when designing is not uncommon. These "patterns" provide a sort of template that is applicable to a certain type of recurring problem. The practice is used in software design as well and the 23 established design patterns presented in *Design Patterns* by Christopher Lasater was created to improve performance and make it easier to maintain and port the code (Lasater 2010).

In general design, a more abstract way of seeing patterns has emerged. Löwgren proposes the concept of "inspirational patterns" (i-patterns) in his journal article *Inspirational Patterns for Embodied Interaction* and explains them with: *"Unlike [how] most current patterns work, we do not require an i-pattern to be based on successfully deployed solutions to recurring design problems. Our intention is to broaden the repertoire of the design community…rather than to provide tools for problem solving."* Despite this, the idea of i-patterns is to provide a sort of template containing a core idea that is recurring of a certain type of problem – just as "regular" design patterns (Löwgren 2007).

When looking at level of abstraction, patterns and strong concepts place themselves on approximately the same level. Coming back to the notion of strong concepts, it is important to note that, as Höök and Löwgren writes, *"Strong concepts are design elements abstracted beyond* *particular instances which have the potential to be appropriated by designers and researchers to extend their repertoires and enable new particular instantiations."* Patterns bring a solution that is abstract enough to be applicable in a certain type of environment, but not abstract enough to be generally applicable. This is where strong concepts fill a gap of sorts. Höök and Löwgren seem to promote the idea that *"…the notion of patterns have matured, and perhaps even frozen, over the years into a widely known construct that mainly addresses best practice in professional design, with overtones of standardization and rationalization…"*, which strengthens the notion of strong concepts as a unique entity in intermediate-level design abstraction.

Strong concepts are meant to be created as a guideline for general design and to be applicable on more than one scenario. Rather than telling designers how to solve a problem, they are supposed to guide the designer on the path towards a solution to the design problem. Despite belonging to the same "intermediate" level of abstraction as many other concepts in design, strong concepts allow for design elements such as a certain way of thinking or approaching a problem. A strong concept does not tell a designer how to solve a problem or how the concept itself is applied. Since the field of research is ever changing, Höök and Löwgren clarifies that *"Sometimes [strong concepts] last only for a short time period, following the fashion of the designers at that time."* When the field changes and values and goals change with it, the previously relevant strong concepts will be replaced.

2.4 Microsoft Kinect V2

One of the primary features of the Kinect V2 is its ability to track users and their bodies' position relative to the camera. It has the possibility to give exact location of joints of six people simultaneously and for each user the Kinect V2 can keep track of 25 joints. The device uses a color camera and an infrared emitter with an infrared camera to calculate where objects are located in its field of view.

The distance between the camera and the user, which according to Microsoft is preferably in the interval of 0.5-4.5m, is measured using a time of flight (ToF) method. Infrared light is emitted and simultaneously the pixels in the camera are "split" so that half of a pixel is absorbing and the other half is rejecting infrared light. When the light stops being emitted the pixel halves change their roles. By comparing how big quantity of the emitted light that was absorbed by the two different pixel halves, the distance can be calculated. When the IR light is emitted from the source, it takes a certain amount of time for the light to return to the sensors. With information about the states of the pixel halves as well as the time it takes for the light to return, it is possible to calculate the time of flight. Furthermore, alternating between longer and shorter emitting times enables a combination of rough distance estimation and a more precise measurement. Since the precise measure has to be placed at the correct distance to produce usable values, an initial measure is performed using the more crude estimation. This ensures that the more exact measurement is positioned at the appropriate distance. **Figure 2.4** is an illustration of the ToF method employed in the Kinect V2 that explains the phase switching of the pixel halves. If the pixels are overexposed by incoming light when measuring the distance, the software is able to counteract this – during the process – to prevent external lights from creating noise or disrupting the input signal (Lau 2013).

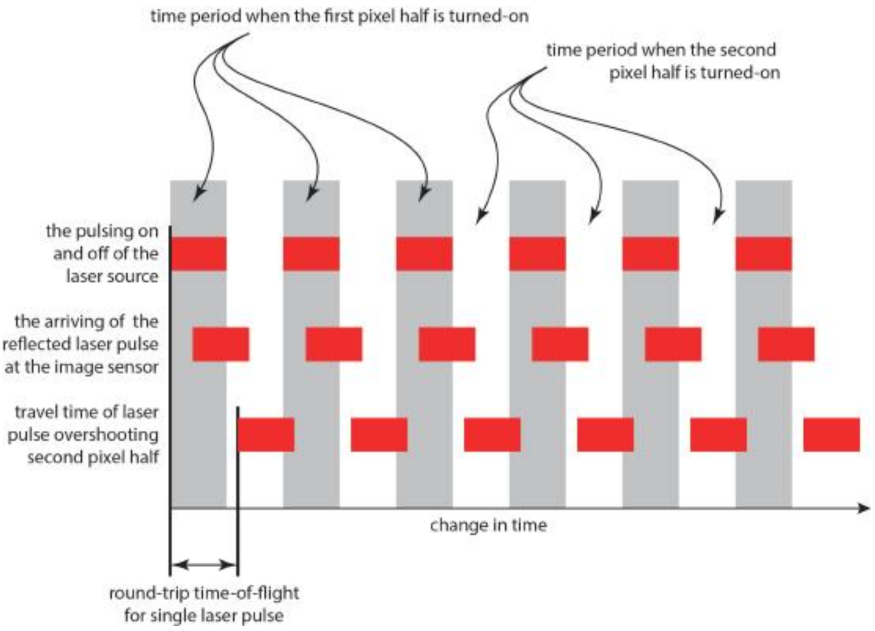


Figure 2.4. Illustration of Kinect V2's time-of-flight implementation (source: (Lau 2013)).

With this method every pixel gets its own distance and combined with the color image the location of what is represented in every pixel can therefore be obtained. This is an advantage to methods where the distance is obtained with light pattern, as the previous Kinect V2 used, because the light pattern method cannot provide an accurate position that corresponds to each pixel.

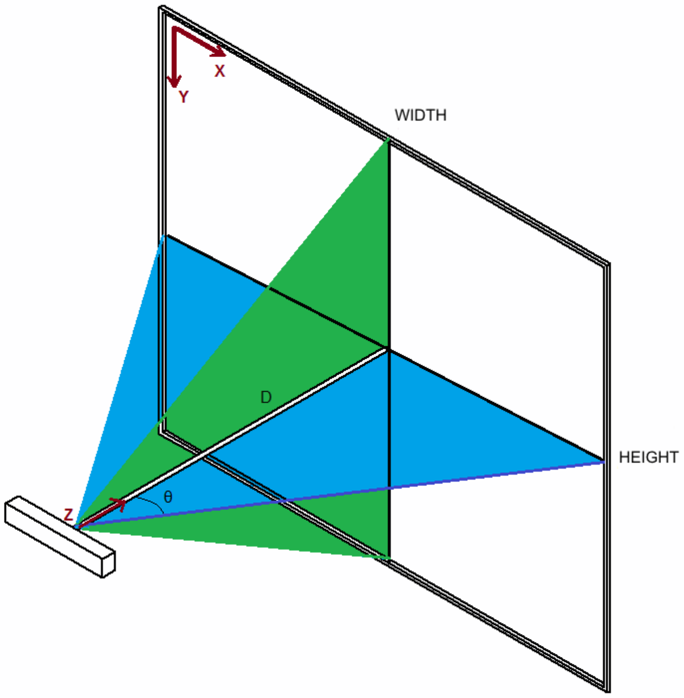


Figure 2.5. The Kinect V2's field of view and the direction of the coordinate system implemented in the KinectPV2 library.

The resolution of the Kinect V2's coordinate system is dependent on the distance between the object measured and the camera. To calculate the distance each pixel represents, the following equation is used:

$$\frac{2 \cdot \tan(\theta) \cdot D[mm]}{1920[pixels]} = x\frac{[mm]}{[pixel]}, \tag{1}$$

where x is millimeters per pixel, D is the distance in millimeters from the user to the camera and θ is half the maximum field of view for the depth camera of that angle; $35°$ for width and $30°$ for height. In other words, the distance in x/y-coordinates is dependent on the position of the measured object. Being positioned further away increases the amount of distance represented by each pixel and thus reduces the pixel resolution. A representation of the Kinect V2's field of view as well as the direction of its coordinate system can be seen in **Figure 2.5**.

2.5 Processing Development Environment

Developed to be a software that allows designers to create visual representations and teach computer programming fundamentals within a visual context, Processing has grown into a professional tool used by a major part of the design industry. Processing is both a programming language and an IDE (Integrated Development Environment) and has a large community behind it. The programming language is objective-oriented and is based on Java. It is also open source, available for multiple platforms and has support for OpenGL as well as 2D, 3D or PDF output. As a result of the large community, the programming language is well documented and there are a multitude of guides and books available – making it well fit for individuals that have little previous programming experience (Reas and Fry 2014).

2.5.1 Kinect Library for Processing

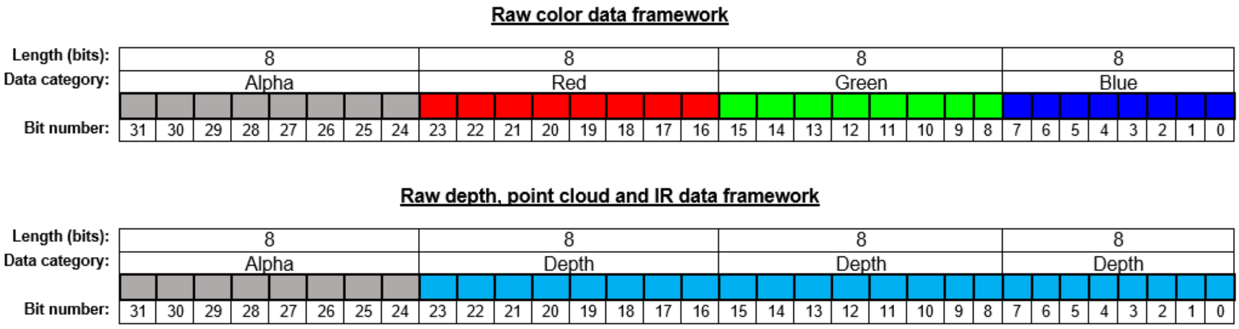
To be able to access the functionality of Kinect V2 in Processing it is necessary to employ a wrapper. Since Processing is based on Java, it is also possible to access Java libraries and functionality. This enables the use of the Java Native Interface, JNI, which is a Java wrapper. The JNI is a programming framework and allows for the construction of a virtual Java machine. Using JNI enables access of the code implemented on the Kinect V2, which is written in C++, using Java-based methods and functions (Liang 1999). Thomas Sanchez Lengeling has created an open source Kinect V2 library for Processing called KinectPV2 (Sanchez Lengeling 2014b). This library allows for access to most of the functionality offered by the Kinect V2 while using Processing. Lengeling also has a number of example scripts that show off the different functionalities that are implementable using his library, along with documentation on the methods and classes that are included in the library. Further simplifying the Kinect V2 functionality access, Processing has a number of built-in methods that allow for easy image processing and an easy way of subscribing to Kinect V2's image streams.

2.5.2 KinectPV2 functionality

Provided by the Kinect V2 is a stream of data that contains information about each frame captured and processed by the hardware built into the Kinect V2 camera. The library, KinectPV2, is constructed so that in order to get data, certain "streams" are subscribed to. This means that for each frame the main class performs an update of the current frame values extracted from the data stream. Instead of processing all the data all the time, which can be time consuming, it is possible to choose what kind of information is important. This may include color data for each pixel (to display the current camera image captured) or data regarding people that have been identified by the software and are being tracked.

Color, depth, IR and point cloud depth data is accessible in raw format and when extracted provides information for each pixel of the frame the camera has captured. This data can be used by first storing it in an array where each element in the array is a value that corresponds to the pixel data.

The pixel color data is stored according to the ARGB (Alpha, red, green, blue) standard (Microsoft 2015a) and contains a string of 32 bits, where each color is represented by 8 bits with the 8 MSBs (most significant bits) as the alpha value – opacity. Since the depth and IR camera does not contain colors the corresponding value is stored in all of the color slots of 8 bits, while the alpha value still represented by the 8 MSBs. This means that it is possible to access the depth and IR value using the least significant 8 bits, the second least significant 8 bits as well as the third least significant 8 bits. The point cloud data has the same container framework as the depth and IR values. The data containers for each of the streams can be seen in **Figure 2.6**.



Raw color data framework

Length (bits):	8	8	8	8
Data category:	Alpha	Red	Green	Blue
Bit number:	31 30 29 28 27 26 25 24	23 22 21 20 19 18 17 16	15 14 13 12 11 10 9 8	7 6 5 4 3 2 1 0

Raw depth, point cloud and IR data framework

Length (bits):	8	8	8	8
Data category:	Alpha	Depth	Depth	Depth
Bit number:	31 30 29 28 27 26 25 24	23 22 21 20 19 18 17 16	15 14 13 12 11 10 9 8	7 6 5 4 3 2 1 0

Figure 2.6. Framework for the containers of raw data.

It is possible to read depth measurement from two different streams – depth and point cloud. What separates the two is the ability to control the interval of which the point cloud stream splits its available values. Since the measurements have a resolution of 16 bits the maximum available numbers of values are 256. The Kinect V2 has the ability to measure objects at a distance of at least 0.5 meters from the camera. At this point the depth value is zero. Moving further away, this value increases until it reaches 255. Here it resets to zero since the 8-bit value is overflowed. In other words, there is a set distance until the value overflows and is reset. For the point cloud stream, this distance can be changed by the user, allowing for measurements over greater distances. This also decreases the accuracy of the measurement, since the resolution will always stay the same.

To handle the user tracking a skeleton class object is created. Each skeleton class has a number of attributes and methods. One of the main functionalities is the list of joints that each skeleton has stored. The joints represent the limb connection points of the user and are a part of the skeleton tracking system. A skeleton object contains x- and y-coordinates for each of the tracked joints. Via the methods implemented in the skeleton class it is also possible to access the current state for each hand. Kinect V2 has the ability to differentiate between three different hand states: open, closed and “lasso”. If the state is vague it is set to “unknown”. This hand state access is useful when implementing command gestures into the program. More information regarding skeletons can be found in the KinectPV2 documentation (Sanchez Lengeling 2014b).

For each of the slots available in the list of skeleton class objects, a placeholder skeleton is created when the Kinect V2 is initiated. When a user is successfully tracked, the skeleton of that person is put in the array of skeletons. To make sure that only active skeletons with actual values are processed there is a Boolean sanity check attribute called “isTracked” (see appendix A) that is set to true when the skeleton is identified as a user. This ensures that it is possible to ignore the skeletons with null pointers as attributes. For each processing draw cycle the array is updated but the skeletons keep their position in the array (the array index) until the user leaves the camera field of view - in other words when the Kinect V2 loses track of the skeleton.

The Kinect V2 also has the ability to track skeletons in 3D. For each skeleton an additional coordinate system is created, one that is relative to the person being tracked. Using this information it is possible to determine how the line between each joint, the skeletal bone, is rotated in reference to the camera's coordinate system. This data is accessible using the KinectPV2 library.

2.6 Hardware

Hardware used for prototype construction during the thesis has been adapted according to what was available in-house. The decisions made regarding hardware were also affected by the use of Kinect V2 as the main component in the prototypes.

2.6.1 Phidgets

For the various hardware implementations control boards and sensors from Phidgets Inc. were used (Phidgets 2012). The Phidgets (circuit boards) are modular and communicate via USB 2.0. Used as an interface between the actuators and the PC, it is possible to control them fully using a Processing library – which also made them compatible with the Kinect code. There were a range of different Phidgets available in-house, which were used during the construction of the prototypes.

2.6.2 Computers Used

During the thesis two different computers were used to retrieve and process information from the Kinect V2 and to run the Processing code. The main specifications of the computers can be seen in **Table 1**. Using the Kinect V2 required a USB 3.0 port to be able to transfer the data successfully. The full list of minimal requirements is available on Microsoft's web page for the Kinect V2 (Microsoft 2015d).

Table 1. Technical specifications of the computers used.

Computer	**DELL (main computer)**	**Acer Aspire | V**
Processor	Intel® Core™ i7-4712HQ	Intel® Core™ i7-4500U
RAM	16Gb	8Gb
Graphics card	NVIDIA GeForce GT 750M	NVIDIA GeForce GT 750M
OS	Windows 8.1	Windows 8.1

2.7 Video Magnification

There are a number of methods currently employed when trying to detect small, subtle changes that are invisible to the naked human eye. Part of the research field of image processing and computer vision, the practice of video magnification can be utilized to find information that would otherwise be hidden. In general, the concept of video magnification is based on identifying small changes in and amplifying them to make it visible for the human eye.

2.7.1 Eulerian Video Magnification

Eulerian Video Magnification was created by a team of researchers at The Massachusetts Institute of Technology’s Computer Science and Artificial Intelligence Laboratory - MIT CSAIL. The method was presented during the 2012 SIGGRAPH conference (Wu et al. 2012).

EVM allows for investigation of changes in facial skin color and movements with very low amplitude. In contrast to the Lagrangian approach (which is explained in the following section) to video magnification, Eulerian video magnification does not explicitly track motions, allowing for an investigation of both color and motion. Using this feature it is possible to measure the heart rate of a human being by either color variations or vibrations and movements caused by the heart pumping blood through the body. A similar technique of measuring heart rate has been used by Philips in a mobile application by the name “Philips Vital Signs Camera” (Koninklijke Philips 2014).

Implemented in MATLAB, the constructed Eulerian Video Magnification framework allow for detection of both motions and color changes in the input video stream in real time. EVM utilizes both spatial and temporal processing to find the changes. The name and its implementation is inspired by the Euclidian perspective where properties of a voxel of fluid, such as pressure and velocity, evolve over time. The path from input video stream to processed output can be seen in **Figure 2.7** and represents the framework of the implemented method.

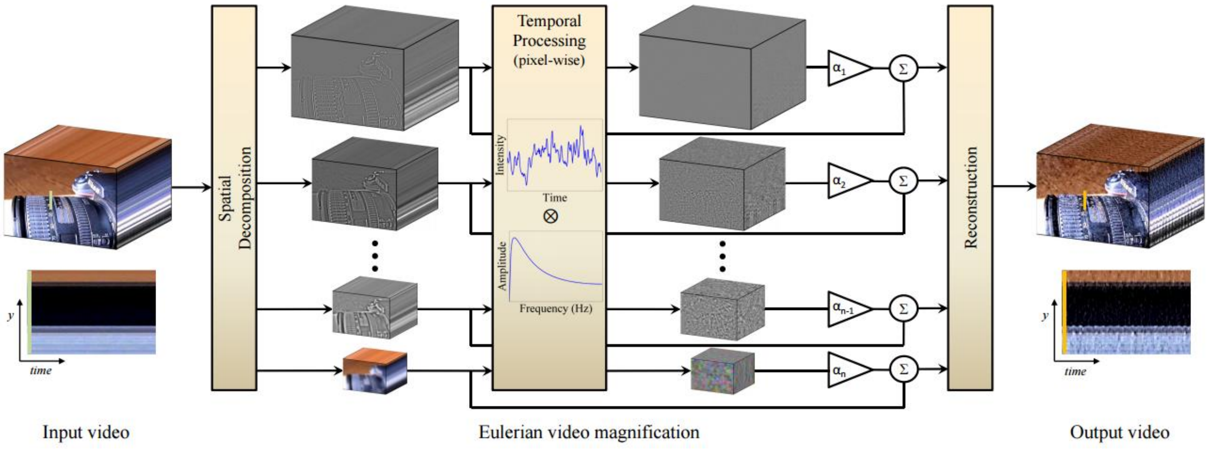
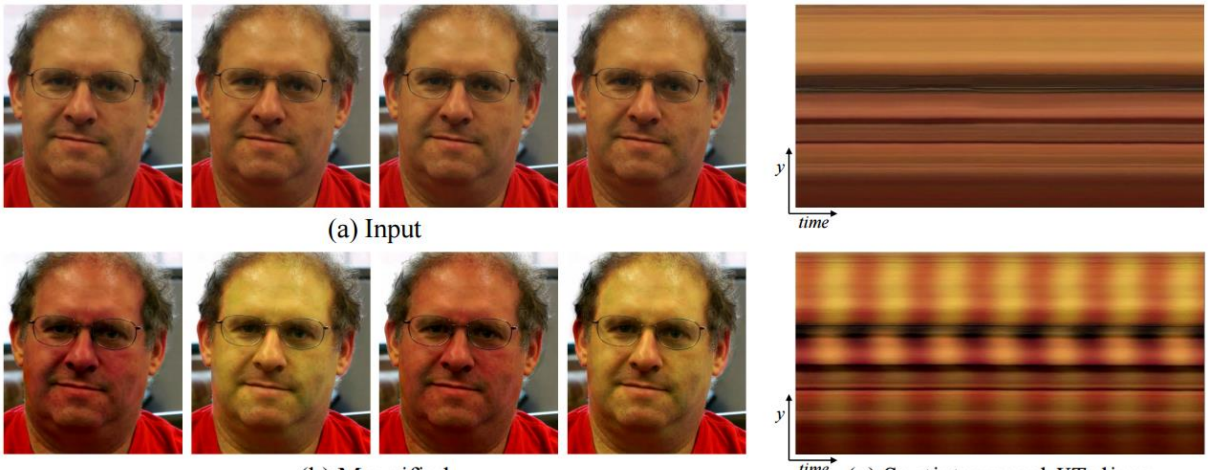


Figure 2.7. Framework of the Eulerian Video Magnification implementation (source: (Wu et al. 2012)).

By dividing the incoming data into different spatial frequency bands it is possible to amplify them independently of each other. This allows for magnification depending on different signal-to-noise ratios, which could pose a problem. Furthermore, it is possible to prevent magnification to exceed the boundaries set for the linear approximation used for the motion magnification.

To extract the information necessary to identify the sought after frequency band (heart rate, for example), the values of each pixel is considered. As **Figure 2.7** shows, temporal processing is performed on each of the extracted spatial bands. For each of the frequency band a bandpass filter corresponding to the sought frequency band is applied. When searching for heart rate a bandpass frequency of 0.5 – 2 Hz could be assumed to be a sufficient interval. This represents 30 – 120 BPM, which could be seen as a good approximation of an individual’s resting heart rate. When found, the extracted frequency band signal is magnified by a factor α, which can be specified by a user. Furthermore, there are guidelines implemented in the framework that may attenuate the factor if necessary.

To create the final output the amplified signal is added to the initial signal. The “pyramid” consisting of all the spatial levels is collapsed and the different spatial levels are brought back together. A comparison between input and output along with a spatiotemporal plot of the video can be seen in **Figure 2.8**, where the two upper pictures show the input video (a) and the lower ones show output/magnified (b and c). The two pictures to the left are four frames from the input video while the two pictures to the right show the change in color over time.



(a) Input

(b) Magnified

(c) Spatiotemporal *YT* slices

Figure 2.8. Example of input versus output of the EVM implementation (source: (Wu et al. 2012)).

Commonly, the amplitude of the noise present in the video is higher than the signal of interest. It might be possible to filter the signal, but that is not always the case. By introducing a spatial filter, it is possible to increase the signal-to-noise ratio. In this implementation a Laplacean pyramid is used as a spatial filter (Burt and Adelson 1983). It is mentioned that if the spatial filter is not large enough, it might not be able to reveal the signal of interest, but by implementing a filter it is possible to reduce the variance of the noise and enhance the subtle signals enough to process them.

To ensure that it is possible to identify the signals and motions to be amplified, it is possible to implement a temporal filter. When magnifying motions, it is preferred to use a filter with a broad passband – i.e. a Butterworth filter. While amplifying color caused by blood flow on the other hand, a narrower passband is preferred. This produces a more noise-free result. In the EVM implementation an ideal bandpass filter is used for the color amplification. For the real-time application a second-order infinite impulse response (IIR) filter has been used instead. The bandpass IIR filter was created using two first-order lowpass IIR filters with one higher and one lower cutoff frequency.

2.7.2 Motion Magnification

Motion Magnification, or Lagrangian Magnification, is the original method developed by the MIT CSAIL and the predecessor to Eulerian Magnification. Just as the name implies, the purpose of the method is to find motions that are invisible to the human eye and magnify them. Groups of pixels are formed depending on their similarities in characteristics such as position, intensity, and motion – seen in **Figure 2.9** as picture (b). The groupings are also based on the trajectories of the pixels over time and not just the motion's instantaneous velocity. When grouping pixels and magnifying the motion, holes appear in the image. These are filled using texture synthesis methods (Efros and Leung 1999).

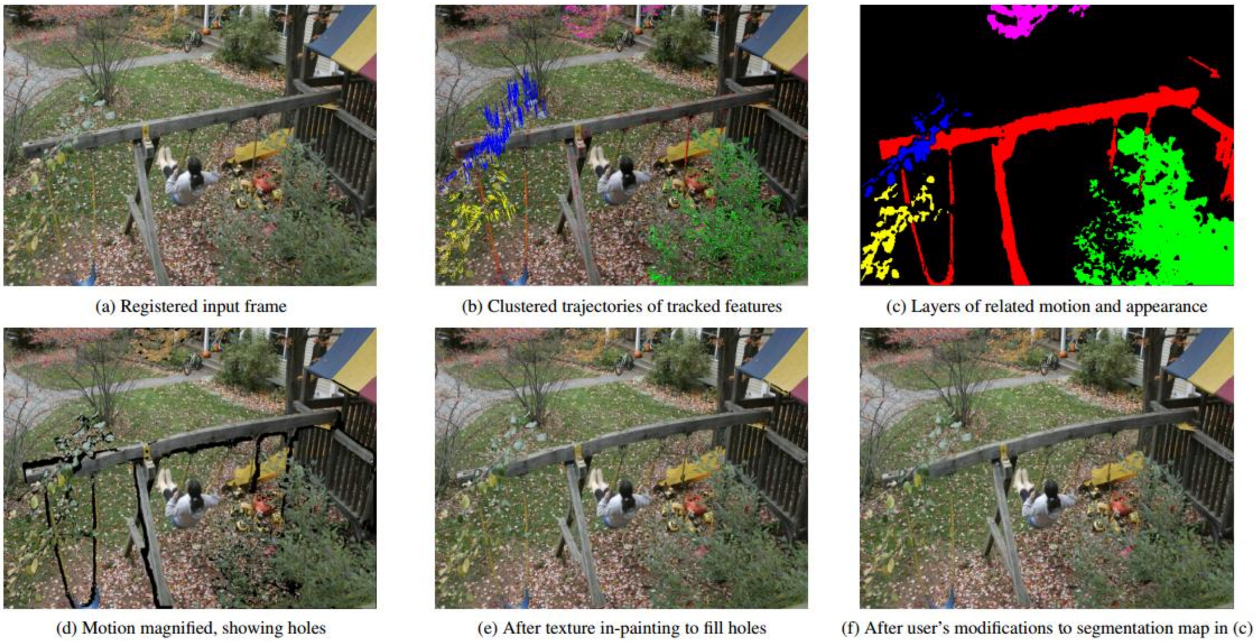


Figure 2.9. Motion magnification and its six steps (source: (Liu et al. 2005)).

When tracking pixels of similar motion, it is important that motions belonging to the same object are not split into multiple groups. By tracking certain feature points throughout the sequence, it is possible to examine movement from the reference points. This allows for assignment of motion with different magnitudes to the same motion layer ((c) in **Figure 2.9**). In the same figure, picture (d) shows the holes (black area) created by the motion of the horizontal beam. The left part is moving in one direction and the right part in the other. Using the reference points these can be assigned to the same motion layer, keeping the same object's motion in one layer – independent of motion direction. The trajectory of each pixel is added to the most commonly assigned group over all time frames. When a target layer has been specified by a user, all the translations corresponding to that layer is amplified by a constant factor, typically between 4 and 40. Finally the output video is rendered with the background layer constant for all frames and the magnified motion displacements written into the output sequence.

2.7.3 Comparing EVM and Motion Magnification

As mentioned in the paper regarding Eulerian video magnification, both methods have an equal sensitivity to the temporal characteristics of noise. On the other hand, the Lagrangian method (Motion magnification), has additional error terms proportional to the spatial characteristics of noise as well. EVM is more sensitive to high spatial frequencies and would be preferable over motion magnification for smaller magnifications and larger levels of noise. It is also mentioned that since the two methods take different approaches to motions, they can be used for complementary purposes. More specifically, quoted from the journal article regarding EVM, it is written that: *"Lagrangian approaches work better to enhance motion of fine point features and support larger amplification factors, while our Eulerian method is better suited to smoother structures and small amplifications."*

When measuring heart rate using the color changes in the face the EVM method is preferred since the amount of noise is fairly high and compared to very small motions (as with the swing set's crossbeam seen in **Figure 2.9**) the amplification required to make the color changes visible is quite small. Additionally, the EVM method is proven to be implementable in real time applications. This is especially useful for when the heart rate is measured since the results of the measurements will most likely be presented right away to the user. If not presented to a user, being able to capture information in real time is just as useful. On the other hand, amplifying small movements might not be as useful presented in real time. Most likely the sequence where the movements have been amplified is interesting, rather than seeing amplified frames in real time. This allows for study of the magnified sequence and the invisible movements that are brought forward using the implemented method.

2.8 Double Diamond Model: Discover

The underlying idea of this discovery phase is to understand how body close technology is utilized today and find new technology that might be used or could be used in a new way. Focus is also placed on encouraging users to further understand their body in a way that is not possible with designs currently available. To understand this, several different topics where investigated. The investigations made it possible to build an understanding of the perspective taken by Mobile Life and to get up to speed with their way of designing these kinds of interactions. The “discover” phase consisted of several different approaches. First of all, it is important to understand what products are available today and how they work. Furthermore, investigating in what sense the Kinect V2 is relevant to this area is important to be able to design prototypes using the Kinect V2. Finally, understanding Somaesthetics and to try practices that promote this – such as Feldenkrais. In extent to this, it was important to test the prototypes that Mobile Life created during their research and also understand the purpose and the paths their research took.

2.8.1 Previous use of Body Sensors

There exists several different devices with the purpose of informing users about their body, and it is nothing new as people have been walking around with digital pedometers since the mid 90’s (Bassett Jr et al. 1996). Taking the pedometer as an example, the interaction has since then not changed much. The device keeps track of the amount of steps and displays it back to the user. This type of feedback has not had a big or lasting effect on users (Rooney et al. 2005). The solution, tracking information and announcing it, can be seen in almost all of the modern devices that are used to measure other aspects of a user’s body or their movement. There are examples such as the Spire (Spire 2015), which is a device that measures a user’s breathing and sends notifications to their phone with phrases like: “Your breathing suggest you are tense. Take a deep breath?” or “You are focused”. The HAPIfork (HAPILABS 2013) is a fork that lights up when you eat “too fast”. Another example is the “Activity tracker”, which is a developed form of a pedometer with the ability to track information like sleeping patterns and displaying it to a user’s smartphone or computer. What can be seen is that the interaction lacks a part that encourages the user to reflect on their body. Instead the device gives a comment (“6893 steps”) and might even label the data with things such as: “You eat too fast” or “You are breathing wrong”. This might lead to the user reflecting on her body - but if it happens it lies outside of the interaction with the device.

On the other end of this kind of technology there is the Nintendo Wii (Nintendo 2015). Nintendo, one of the biggest companies in the video game industry, have had a huge success with the gaming console called Wii. Wii was innovative because it introduced a new way of interacting with video games that previously was much unexplored. The Wii uses a remote (Wiimote) that tracks how it is pointing in relation to a source of infrared light (placed over or under the television) and the direction it is being moved in using an accelerometer. The data is sent via Bluetooth from the remote to the base unit (gaming console) and is used as input to the games and applications. This allows the game to be controlled using movements. Nintendo took body interaction even further by releasing the Wii Balance board. The Wii Balance board consists of two scales measuring the force produced by the user’s weight, mainly transferred via the feet. The main application/game that utilizes the Wii Balance Board is Wii fit (Nintendo 2007 - 2011).

The general idea of this game is to give feedback to a user on how well they perform different physical activities, such as yoga. What differs from the earlier examples is that Wii fit manages to keep some sort of bodily reflection tied to the interaction.

2.8.2 Kinect V2

Building on the success of Nintendo Wii and this new type of interaction, other big gaming console companies followed. One of these devices was the Microsoft Kinect (2010), which comes with computer vision algorithms that has the ability to track users and their body in 3D. This was later followed up by the Kinect V2 (2013), providing increased functionality. The Kinect V2 is interesting from two specific perspectives; the first being that it is a sensor that measures the position of a user relative the camera as well as the position of individual limbs in regards to each other. This means that it is theoretically possible to gather a lot of body data without physical interaction with the user. Physical interaction is something that could potentially disturb an interaction, as the feeling of wearing a sensor might disturb a user's focus, which is avoided when using the Kinect V1. In the field of consumer electronics there are several companies which are pushing their own cameras similar to Kinect V2. The most notorious producer being Intel with their Intel RealSense 3D (Intel 2015). Microsoft, having adapted its OS platform Windows to function with the camera as input, and Intel putting their cameras in both laptops and smartphones, there is a possibility that this technology might soon be more available than it is today. This makes research based on the Kinect V2 relevant as groundwork for future applications.

2.8.3 Somaesthetics and Feldenkrais

Somaesthetics is a term coined by the pragmatic philosopher Richard Schusterman dealing with the esthetics part of our felt body which: "*offers an integrative conceptual framework and a menu of methodologies not only for better understanding our somatic experience, but also for improving the quality of our bodily perception, performance, and presentation"(Shusterman 2008).* An interpretation of this, in the context of this thesis, is that Somaesthetics allows for a theoretical foundation when designing technology with body/somatic interaction. Applying this enables the designer to take Somaesthetics into consideration and better understand the aspects of the body/somatic part of an interaction. Present in the previous examples presented is a lack of consideration regarding the body/somatic interaction, therefore making the concept of Somaesthetics relevant to HCI researchers – to prevent leaving the body out of the interaction. In the paper *Experiential Artifacts as a Design Method for Somaesthetic Service Development* by Petra Sundstöm et al. it is described how Somaesthetics could be seen from a HCI perspective in the following way: "*[Somaesthetics], relatively new to HCI, looks at our bodies as the center of our experiential existence and looks at design, from the perspective of providing for better bodily experiences. Ones, which do not harm our bodies, but rather allow for fuller and more pleasurable experiences and interactions.*" (Sundström et al. 2011). This further shows how Somaesthetics has been interpreted by the HCI community as a source of guidance.

Feldenkrais is one method of movements, among several, that aims to give a participant increased understanding of their body from a somatic sense (Feldenkrais 1991). The practice utilizes small controlled movements in order to get the participant to reflect over how they experience the body and how the body is connected. One example could be that the instructor asks the laying participant to carefully align and connect the forehead and the kneecap, then asking the participant to repeat the movement but now start with raising the opposite shoulder and moving it towards the kneecap. By simultaneously asking open questions to the participant in combination of movements, the participant is allowed to reflect on how their body feels and is connected in a practical and experienced sense – in opposite to theoretical anatomy.

2.8.4 Research carried out at Mobile Life

The prototypes developed at Mobile Life have been grounded in Feldenkrais. Two different prototypes have been developed – one called the “SOMA carpet” and the other “the pressure mat”. The SOMA carpet, which can be seen in **Figure 2.10**, consist of two parts; one top part with lights, speakers, and grades that separates the user from the surrounding environment. The other part is a mat with integrated heat pads. The speakers will play a recorded session of Feldenkrais asking the user to focus on a specific part of their body. During the session, the body parts mentioned are simultaneously heated by the mat – making it easier for the user to focus on that area. The pressure mat has not finished its full double diamond development process and is currently between the “develop” and “deliver" phases. The system is utilizing pressure plates to find the pressure point between a user and the floor and then visualizes that pressure on the ceiling as an aid in a Feldenkrais session. In the next prototype iteration this input will likely be kept the same but the feedback might be changed to something that allows the user to keep their eyes closed. However, one could draw parallels between the Nintendo Wii that utilizes a balance board to aid the yoga exercise and the prototypes aiding a Feldenkrais session; but the main difference is that the Wii tells the user that they are doing something wrong while the SOMA carpet helps the user to focus on her body. Emphasizing on not placing value on how the movements are being executed (Höök et al. 2015).

Figure 2.10. The SOMA carpet. At the bottom is a sketch of the first prototype. The top two pictures show prototypes later manufactured in collaboration with IKEA.

Key points gathered are that the interaction cannot judge the user; instead it should be reflective. The interactions should not force the user to move the body in a specific way, but allow for it or encourage it by providing an interesting and pleasant interaction. The interaction does not necessarily demand for users to have a total focus on themselves, but never the less entail a bodily focus. In order to understand and reflect on your body you need external stimuli tied to the interaction. One way of understanding the concept is looking at it this way: you do not feel your back, what you feel is your back against the backrest of your chair. From that you become aware of your back.

3. DESIGN PROCESS AND PROTOTYPES

In this chapter the design process is explained in detail. The subchapters are divided according to two of the double diamond model phases to reflect the design process and how the work was performed. The work is presented in chronological order.

3.1 Double Diamond Model: Define

When exploring how to design for close-to-body technology, the SOMA-project has previously been strongly based on Feldenkrais to get the somaesthetic aspect into the design. The concept of Somaesthetics is vital for this type of design. By providing an understanding of the somatic aspect of a human's interpretation of the world – how we perceive the world through our senses – the concept enables design suited for a human's way of perceiving the artifact or application. Feldenkrais has been a good way to investigate how to design technology that takes the somatic aspect of a human into consideration, but it would be beneficial to take a new, unexplored, approach in an attempt to widen the field of HCI and Somaesthetics.

Based on the information collected during the initial "discovery" phase, suggestions and ideas where discussed with Mobile Life on how to investigate this area and possible paths the prototypes could take. The subject of using the Kinect V2 as a more precise sensor in this setting was discussed. More specifically, to use the Kinect V2 as a way of capturing basic human physical characteristics that is not usually reflected upon. These would be characteristics which are frequently occurring but are taken for granted and not looked into. This led to the choice of investigating if and how Kinect V2 can be used to sample breathing, heart rate, and small movements like swaying or shifts in balance.

The main reason for choosing breathing as one of the areas is because it is an essential human function, but can be executed in different ways depending on the user (i.e. by expanding the chest, the stomach or both). Even though it is such a fundamental human aspect, how different individuals breathe is not always reflected upon. The idea is to investigate if the bodily movements produced by breathing are large enough and distinct enough to be identified by the Kinect V2 and transferred into control signals, without locking the user in a specific position (e.g. lying down).

Heart rate was chosen as it is also a fundamental human function that is closely linked to both the physical and mental state of a person. Small and slow movements are used in Feldenkrais and other similar practices with the aim of increasing bodily understanding. However, to build a system around this, without incorporating Feldenkrais, is more challenging as the concept of "small movements" is not as predefined as breathing and heart rate. Additionally, the possibilities of dynamically changing the measured characteristics make the Kinect V2 a dynamic sensor. This enables the freedom of changing the points of measure according to user test results.

Based on the "discover" and "define" phases performed, it was decided to investigate how Kinect V2 can be used to find the three chosen human characteristics and evaluate the results with respect to accuracy. On a more abstract level the design ideas revolve around making mimicking prototypes. The SOMA mat was the main source of inspiration, where a LED light changes with the breathing of the user. This investigation is to be accomplished mainly by using physical actuators as feedback, e.g. different motors, since that is previously unexplored.

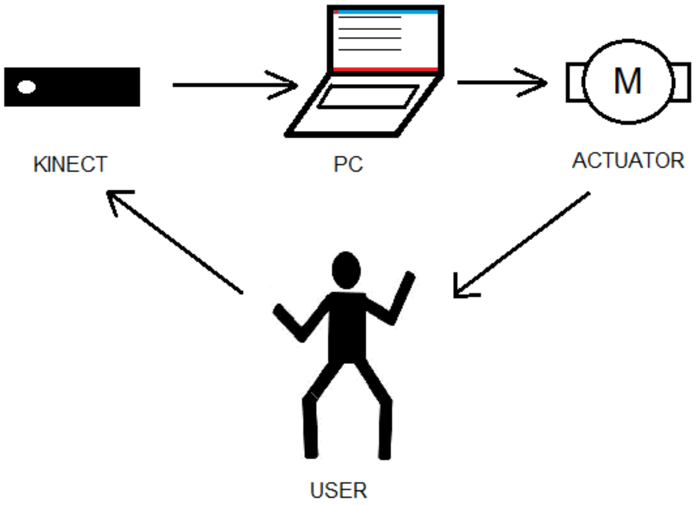


Figure 3.1. An overview of the fundamental prototype configuration.

The fundamental configuration of the prototypes can be seen in **Figure 3.1**. The Kinect samples data from the user and sends it to the PC for processing. Based on the information processed in the PC a control signal is sent to the actuator that creates an interaction with the user.

3.2 Double Diamond Model: Develop

The develop phase of the double diamond model entitles the design and development of the prototype or prototypes. As decided in 3.1 Double Diamond Model: Define, the investigation performed was divided into three different paths to explore using a mechatronic angle to design for increased body awareness in HCI. In order to aid in the progress of the development, user studies will be conducted. During the develop phase a number of prototypes will be constructed and re-iterated until they are ready for the deliver phase, where the final testing and evaluation will take place.

3.2.1 Initial Exploration of Kinect V2’s Functionality

Before initializing the investigation of the three decided project paths, it was important to understand the functionality and limitations of the Kinect V2. Since the software was planned to be implemented using Processing, the natural choice was the Java wrapper library called KinectPV2 created by Thomas Sanchez Lengeling. The library and its functionality is presented in 2.5 Processing. Mobile Life had previously used the same library when using the Kinect V2 and prewritten code existed for some of the functionalities. Furthermore, the library had documentation available in the form of code examples as well as documentation for the methods and classes provided (Sanchez Lengeling 2014b).

Development of Fundamental Applications

To gain an understanding of the basic functions in the KinectPV2 library a number of smaller applications were created. The initial idea was to write an application that tracks an individual and displays the various tracking points, the limb joints, on a computer screen. This fundamental functionality was present in each of the applications implemented in the prototypes. By utilizing tracking it was possible to determine a reference point when measuring distance to user and change in position. When collecting data from a user, regardless of data type, it is vital to be able to reliably track the same point over time. This means that the tracking has to be sufficient so that the tracked point is not prone to "jump around", failing to decide in which coordinate the joint is located.

Figure 3.2. First successful implementation of control of a servo motor based on the location of a user's hand.

One of the first successful implementations of user tracking can be seen in **Figure 3.2**. Included in the functionality of this program was the ability to control a servo motor using a hand gesture together with vertical movement. The application could be seen as an investigation of how the Kinect can be used as a means of controlling an actuator. For this implementation two different servo motors were used. Both of the motors are manufactured by Hitec and are of the model HS-322HD (Hitec RCD USA 2015a) and HS-442 (Hitec RCD USA 2015b) respectively, with an operational area of 180°.

Servo Motor Control and Body Tracking

Each tracking point (joint) is part of a skeleton and are represented by x and y-coordinates – explained in-depth in 2.5 Processing. Using this information it is possible to calculate the change in position between each frame captured. This is used as the control signal for the servo motor. To initiate the measurement, and control of the servo, the user's right hand state has to be identified as "closed". The first y-coordinate measured (vertical position), is saved as a reference and denotes the starting position. While the hand is closed, the algorithm compares the current y-coordinate for the right hand and sets the servo motor position as the difference in y-value between the current position and saved reference. Changing the servo motor position only while the hand is closed makes it possible to pause each movement by opening the hand. By closing the hand again a new reference is saved and control of the servo is resumed.

While this allowed for control of a servo motor using body-tracking, one of the major issues with the algorithm was that any skeleton being tracked was included in the measurements. If a second person stepped in front of the camera at the same time, the program would read both of the right hand values and try to actuate on both values simultaneously. According to the Kinect V2 for Windows documentation provided by Microsoft, the Kinect V2 can identify and distinguish different players from each other (Microsoft 2015b). Each player receives an ID when entering the camera field of view which is used to differentiate between individuals. Unfortunately, access of the identifier was not yet implemented in the software library used – KinectPV2. Despite this, when a new user is identified a skeleton class object is created and placed in an array. The skeleton object's position in the array is unchanged while the user remains inside the Kinect V2's field of view. By storing this position index, a single user can be identified and any additional user ignored. If the array element containing the object is cleared in the middle of a run-time loop, the program tries to access an element that contains null pointers. This causes a null pointer exception. To counteract this, the skeleton list is updated during the start of the run-time loop and each time the program tries to fetch an attribute from the tracked skeleton the object is checked for validity.

Following the body tracking test, a number of applications that investigated the depth, color and IR cameras were developed. Information about the features available with the Kinect V2 could be found on the Kinect V2 for Windows documentation web page (Microsoft). Regardless of that, there is no published information on how the data is sent from the Kinect V2 to the computer, which is needed to identify how to process the data into useful information. The information necessary to process the data properly is available through a tutorial blog post written by the KinectPV2's creator (Sanchez Lengeling 2014a).

Kinect Raw Data Framework

The KinectPV2 library is designed so that it extracts the information given by the raw data stream sent by the Kinect V2 and places it in an array. This array holds the requested data of each pixel in the captured frame. Calling the "getRawColor" (see Appendix A for commonly used functions) method creates an array that is the length of the total number of pixels of the captured color camera frame. Since there are 1920 pixels for each row and 1080 for each column (a color camera resolution of 1920x1080), the resulting array has the length of 2´073´600 pixels. Each element in the color pixel array contains three variables representing the red, green and blue value of that pixel. The data contained in the variable is accessed by bit shifting. Using a trial and error process it was realized that color, depth and IR all use the same type of stream data output and that it was accessible in the same way. The arrays representing IR and depth data are smaller since the resolution is less than the color camera (1920x1080 versus 512x424 (Microsoft 2015b)).

3.2.2 Calculating the Index of the Raw Data Array

All the values presented on the screen, and/or the tracking system, are represented as points in a coordinate system. The raw data needed to calculate distance to target and the color values are stored in an array each. A method was written handle the transition between the arrays of values and the screen coordinate system. Processing has the coordinates defined so that the point of origin is located in the top left corner of the application window. Moving to the right horizontally corresponds to an increment of x while moving down the vertical axis results in an increment of y. Similarly, the array containing the data has a zero index element representing the pixel in the upper left corner. The array then continues for each row of pixels, all the way down to the bottom right, i.e. the first pixel on the second row has the index of the width of the screen in pixels subtracted by one, since the array indexation starts at zero. To calculate the index of the raw data array that corresponds to a specific coordinate it is possible to apply the following equation:

$$index_{rawdata} = width \cdot y + x, \tag{2}$$

where *width* represents the amount of pixels on the x-axis (horizontal), and *x* and *y* the coordinates. Using this to calculate the index it is possible to access the desired measured raw data of that coordinate in the raw data array. For the color camera the "$width$" is 1920 pixels and for depth and IR the width is 512 pixels (Microsoft 2015b).

3.2.3 Heart Rate

Decided during the define phase of the double diamond model, presented in 3.1 Double Diamond Model: Define, was to conduct an investigation on using the Kinect V2 as a heart rate monitor. Previous implementations of camera-based heart rate monitors has shown that it is possible to determine a user's heart rate by measuring changes in facial color over time (Koninklijke Philips 2014).

Initial Heart Rate Application

An application was developed to test the capabilities of the Kinect V2's color camera and its accuracy. One of the tracking points is positioned at the user's nose. The cheeks and nose were assumed to provide the most apparent change in color, and were used as points of measure. To provide reliable measurements and remove irregularities the mean color value of five pixels in the vicinity of the measure point were saved as each frame's color sample.

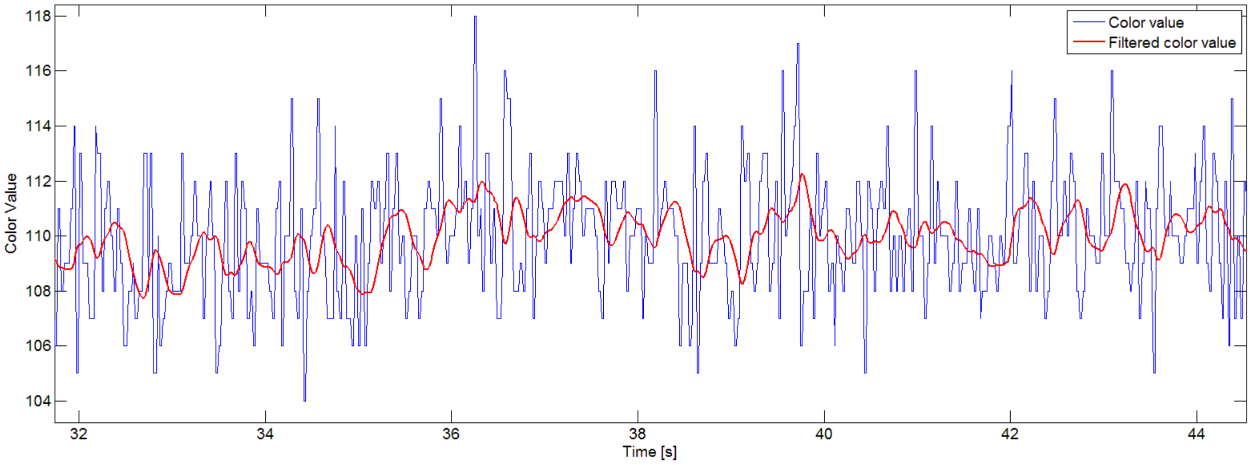


Figure 3.3. Red facial color, unfiltered (blue) and filtered (red).

By plotting the measurements in MATLAB it was apparent that the signal noise prevented the extraction of any valuable information. To resolve the issue a Butterworth filter was implemented according to a cutoff frequency of 1.5 Hz, an approximation of a resting heart rate, and a sample rate of 30. This procured a smooth signal, as can be seen in **Figure 3.4**. The filtered signal had a frequency of approximately 2 Hz. Using the information gathered from the plot it is not possible to assume that a heart rate is determined considering a light-sensitive color camera and the measurements taken below and in proximity of a lamp.

Further Heart Rate Application Tests

An additional test where the change of the three measured colors – red, green, and blue – were plotted against an approximation of the actual heart rate. A Phidget Vibration Sensor was used to measure the heart rate. The sensor is a piezoelectric transducer which is connected to a PhidgetInterfaceKit 8/8/8. The "kit" converts the analogue signal into a digital signal, which is then processed by the PC application. Tapping a finger on the sensor in tune with the heartbeat created an approximation sufficient for the validation of the changes in facial color. A general explanation of Phidgets is presented in 2.6 Hardware.

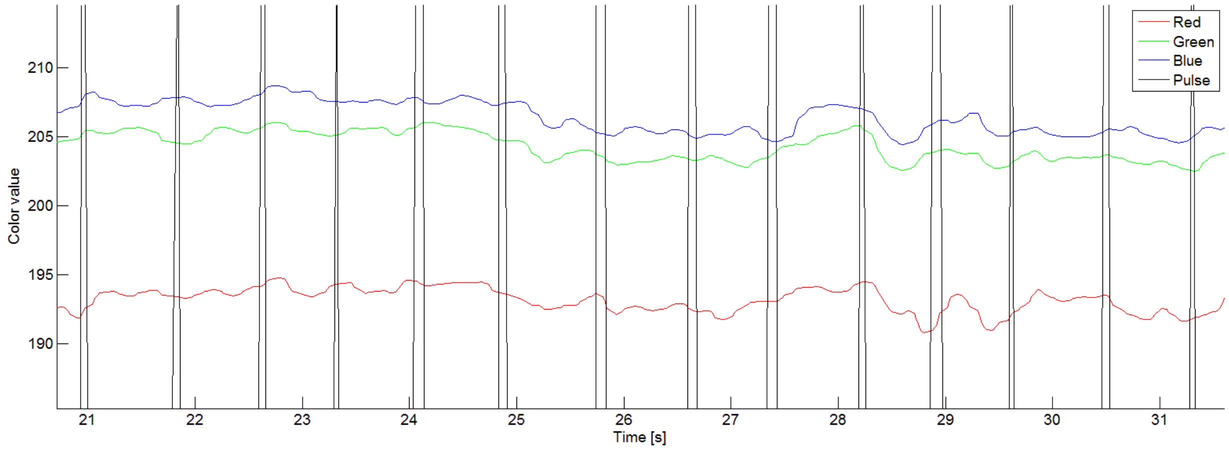


Figure 3.4. Facial color changes with pulse measurements as reference.

The data presented in **Figure 3.4** shows the comparison of changes in facial color data and the heart rate approximation. The tests were performed four times with two different subjects, two for each subject. Noted in the measured signals is a pattern that is too uncertain to be concluded as a representation of the heart rate. Instead the data was dismissed as filtered noise. The signal behavior was coherent in all tests performed.

Study of Existing Implementations

A literature study of other implementations of heart rate monitoring using a camera yielded a method developed by MIT. Explained in-depth in 2.7 Video Magnification, Eulerian Video Magnification allows for real-time detection of a user's heart rate. Important for the intended implementation was MIT's real-time implementation's use of a camera with lower resolution and 50% faster frame rate (45 fps compared to Kinect V2's 30). This meant that the Kinect V2 can provide a sharper image, making it easier to identify changes in color.

With a heart rate of 60 bpm, one "change cycle" occurs each second. Using the Nyquist theorem a minimum rate of two samples per second is enough to reconstruct the frequency when capturing the signal. The color change signal cannot be assumed to form a perfect sinusoidal but may rather appear as spikes or sudden changes. This means that a higher threshold is required to capture the signal in a proper way. A frame rate of 30 Hz provides a sample rate of 30 samples per second, which is 15 times higher than the Nyquist rate. While not ensuring that the information is captured, the chances are increased.

Although a proper implementation using the Kinect V2 was theoretically possible, it was decided that implementing a working EVM solution would take too much time to complete in parallel with the other intended design paths. Since the aim of the master thesis was to explore multiple design paths for Somaesthetics and HCI, focusing work on only one possible path would instead move the aim towards implementing EVM on a Kinect V2 driven application; which was not the intention of the master thesis.

3.2.4 Measuring Distance

For the depth data sent by the Kinect V2 to be applicable as relative measurements of the user's position it is necessary to process the data into a useable format. Using the KinectPV2 library it is possible to extract the raw depth data of a certain pixel. Apparent when using the depth camera, as can be seen in **Figure 3.5**, the depth of the screen is split in intervals – with a value range of 0-255. In order to convert this into a proper distance additional information is required. By keeping track of which interval the measured point is residing in the distance is calculable.

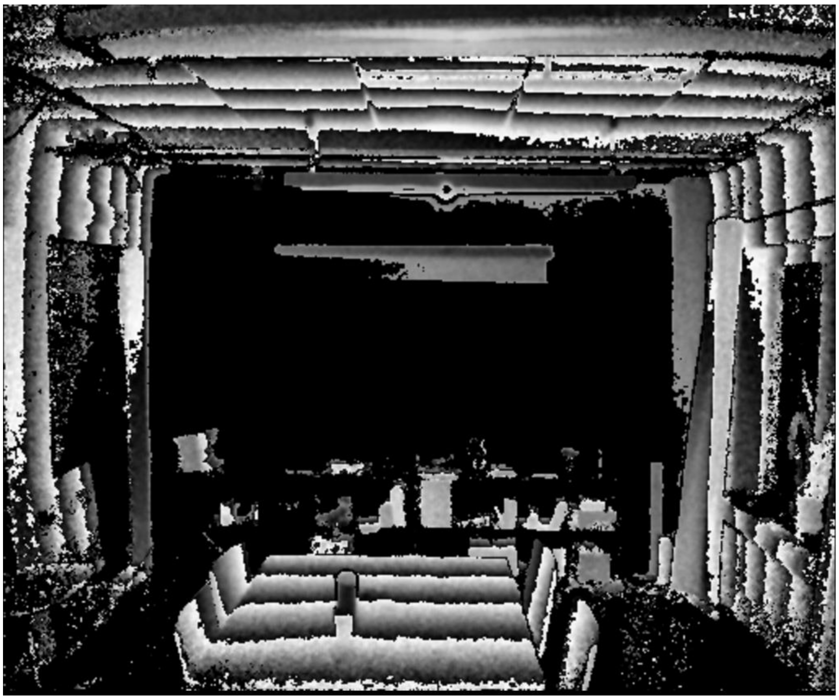


Figure 3.5. The signal from the depth camera transformed to greyscale with values 0 (black) to 255 (white).

The additional information needed is represented by the point cloud depth stream. What differentiates the depth value from the point cloud value is the ability to change the distance in which to divide the available 256 values. By changing the parameter of maximum measuring distance of the point cloud measurement to 6.5 meters the 256 available values are lined up along with the intervals of the depth measurements. For every tenth point cloud value the depth value variable overflows and starts at zero again, marking the end of that interval.

Figure 3.**6** clarifies the division of the point cloud values and their respective depth intervals.

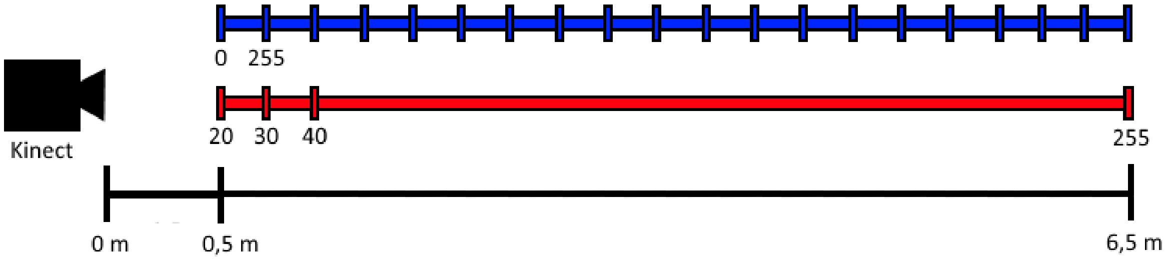


Figure 3.6. Illustration of the division of depth intervals (blue) along the point cloud interval (red) with distance in meters for reference (black).

Using this solution the relative distance to an object can be calculated according to:

$$distance = 255 \cdot \frac{PCV - 20}{10} + DV, \tag{3}$$

where PCV is the raw depth from the point cloud stream, and DV is the raw depth data from the depth stream. Subtracted from the point cloud value, PCV, is the depth value for the point cloud stream at 0.5 meters – the closest distance measureable by the Kinect V2. With these settings the depth measurements has an accuracy of approximately 0.992 millimeters, where the distance of one depth value interval is calculated using:

$$Idist = 10 \cdot \frac{6.5[m]}{256} \tag{4}$$

and the distance for one depth value, and the accuracy of the measurements, is calculated using equation (4) as:

$$DVdist = \frac{Idist}{256}. \tag{5}$$

3.2.5 Prototyping for feedback from small movements

Part of the main paths decided for the project was investigating the use of Kinect V2 to detect and measure small movements. A design meeting with the project group produced a number of ideas for implementation based on Somaesthetics. The ideas included a prototype that changes shape based on the user's movements, a prototype that is placed on a user's body and moves depending on input, and using vibrations as feedback on certain movements. Despite this, the choice fell on a prototype that visually amplifies small movements performed by a user. With the possibility of measuring a user's position with the Kinect V2, a change in position was chosen as the basis for the control scheme.

Using a balance board and a table tennis ball (Tecnopro 40mm), tilting the board would cause gravity to affect the ball. By mapping the tilt of the board to the movements of the user, the same movements would be amplified in the form of the ball moving. The user would control the ball using various movements and the small changes would be noticeable on the ball. By incorporating certain tasks and exercises in the experience the user would be forced to use small movements to control the ball effectively.

Calculating the distance to the user using equation (3) allows for measurements independent of the starting position. This starting position would be saved when the user initiated the prototype, using it as a reference point for position displacement.

Hardware and Prototyping

Full control of the position of the board was attained using two servo motors, allowing for two degrees of freedom (DOF). In order to not put the board-controlling servo motors under any unnecessary stress a light fiberboard was the material of choice. For rapid prototyping purposes a 3D-printer was used to create the sides of the prototype. A PhidgetAdvancedServo 8-Motor was used to control the two servo motors and allowed for control via Processing.

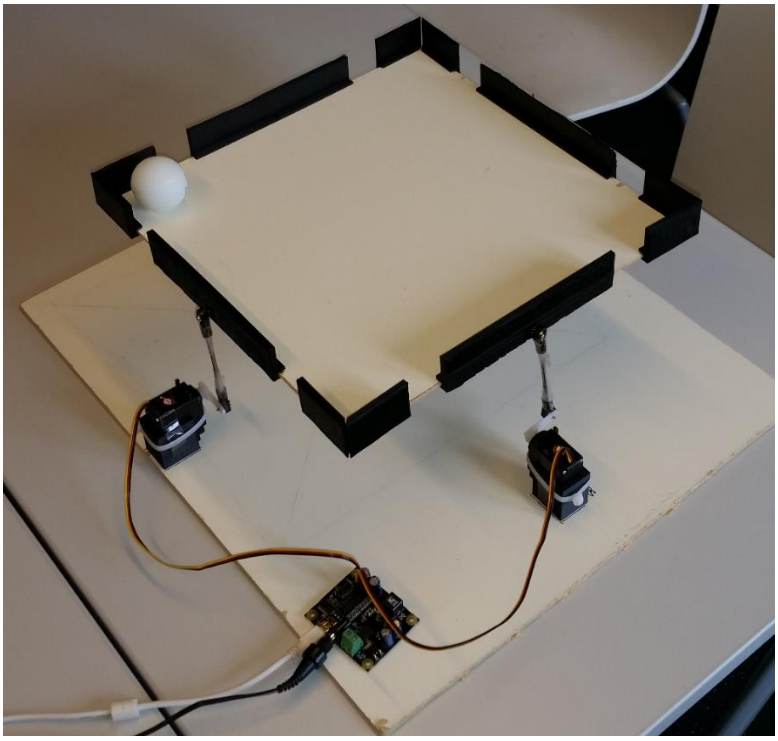


Figure 3.7. Picture of the balancing prototype.

The servo motor mounts seen in **Figure 3.7** were constructed using a 3D-printer. They allowed for a tight fit which held the servo motors in place – with added cable ties for stability. Ball joint clevises were fastened at the ends of the metal rods connecting the servo and the board. This ensured that some positional deviation was acceptable without pushing the plate off its mount.

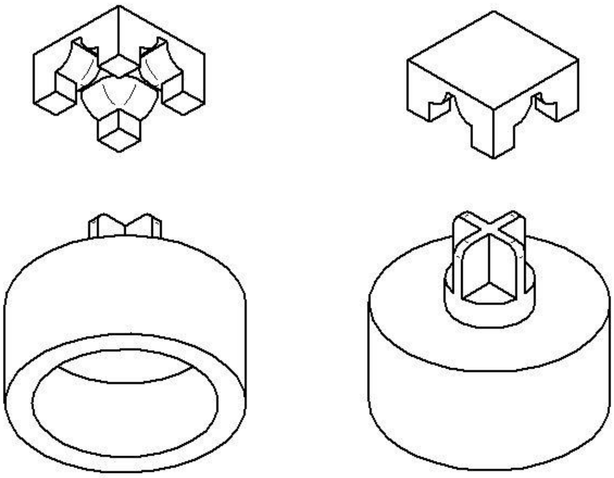


Figure 3.8. The design created to prevent the board from twisting or sliding.

Initially a dome was used as the balancing point for the board. This was replaced by a cross design which prevented the wooden board from sliding off the pillar during use. The top cap design with the inverse mount can be seen in **Figure 3.8**.

Software Application

Given that the input for the application is the lean of the user's body, the natural tracking point was the chest. Assumed to be relatively free of obstructions during measurements, the change in chest position is related to both the lean and balance of the user.

The first iteration of the prototype's software used the chest's depth measurement as the input for the first servo and the difference in shoulder height as input for the second. Since the reference point was saved as the first value measured after initiating the program it was vital that the test user stood still during the booting sequence. Furthermore, the implementation did not allow for any repositioning of the feet, since that would move the whole body and render the reference point unusable.

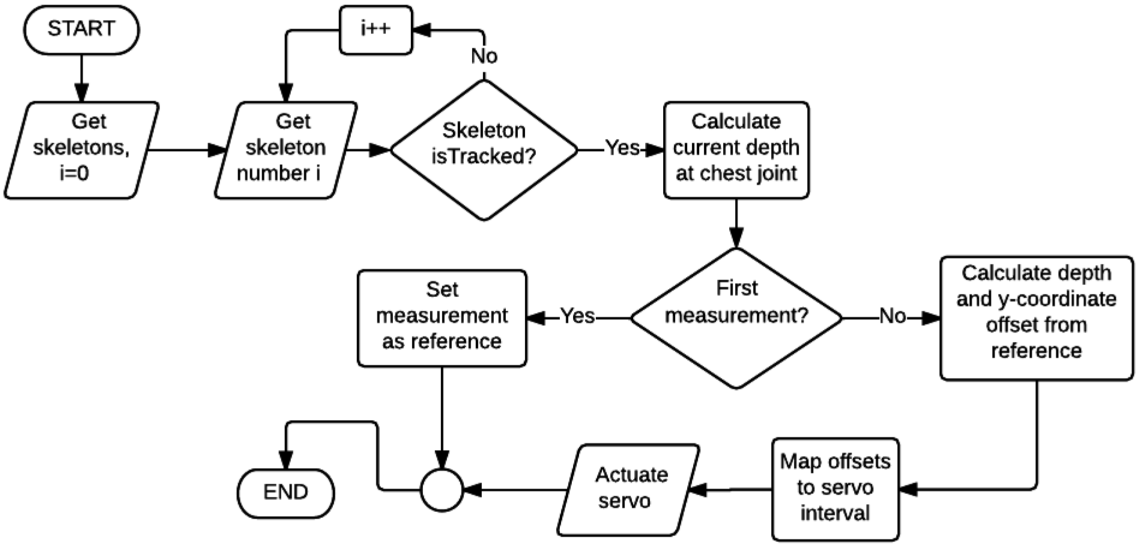


Figure 3.9. Flowchart over the algorithm behind the balance prototype.

At the start of each run time loop, the program fetches the list containing all of the skeletons present inside the camera field of view. Just as the Kinect has a tracking point located on the chest there is one point for each of the shoulders, as can be seen in **Figure 3.2**. Mentioned in chapter 2.5 Processing, each tracked joint contains coordinates of the current joint position. The first loop provides a reference point for future values. Using the shoulder's y-coordinates, the difference in height between the two is calculated and then sent as output to the second servo motor. When the program starts the servo motors are both set to a position where the board is horizontally aligned. This way the offset of the inputs compared to the reference can be used as the control signal. A flowchart of the run time loop can be seen in **Figure 3.9**.

To ensure that the control feels responsive the servos does not extend outside the 180 degree zone seen in **Figure 3.10**. The servos can extend a few degrees beyond 180°, which mean that a software safeguard is needed. If the servos should extend beyond this zone the feedback from the movements would be different from the feedback received by movement inside the operational zone – ruining the interaction experience.

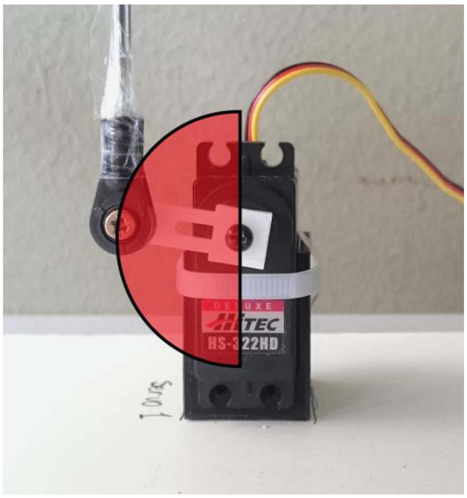


Figure 3.10. Operational area of the servo motor.

Safeguards against Faulty Measurements

Sudden signal spikes and faulty measurements run the risk of causing the board to tilt and ruin the experience. To ensure that this does not occur, the change in distance is checked for each run-time loop. If the absolute change in distance between two frames is higher than a value of 150 it is dismissed with the assumption that a human cannot move at that speed. A value of 150 represents a distance of 149 mm. With a frame rate of 30 fps, that value corresponds to 4.51 m/s. For a shorter hand, or arm, motion this value may not be enough, but since the prototype is designed for small movements it was deemed sufficient.

The depth measurement of the Kinect V2 is presented in intervals of zero to 255. When transitioning between two intervals, the value switches from either 0 to 255 – or vice versa. This means a change in distance value between frames that is substantially higher than normal and corresponds to a position change velocity of 7.67 m/s. The speed is highly unlikely for a human and is thus treated as an interval transition. Additionally, using the absolute depth measurement to evaluate the movement allow for data in the form of actual distance values. This can later be used when validating the measurements and the changes in distance calculated by the application's algorithm.

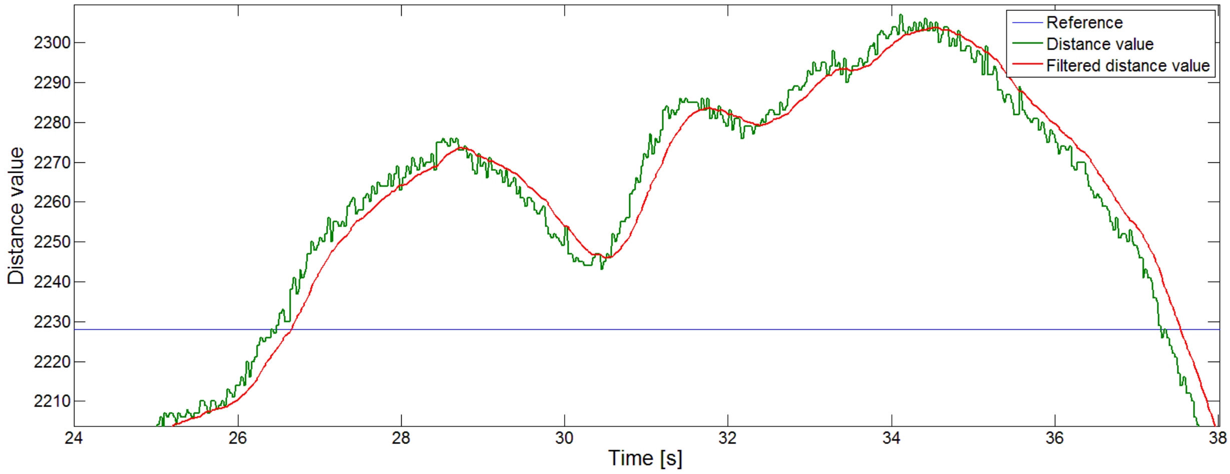


Figure 3.11. Measured distance to chest during balance prototype use, unfiltered (green) versus filtered signal (red). The blue line is the first value measured, used as reference for the lean offset.

Because of irregularities in the surface being measured, mainly due to clothes, a digital filter was implemented in the application. In the paper on Eulerian video magnification presented in 2.7 Video Magnification, the filter implemented when analyzing motions and small movements was a Butterworth filter. Using this as the main basis and the built-in Butterworth filter constructor function in MATLAB a filter fitted for low frequencies was designed. The filter was designed for a cutoff frequency of 1 Hz and a sample rate of 30 Hz.

User Tests during Development

To obtain design feedback regarding the next iteration of the prototype a small user test was conducted with the Mobile Life supervisor and one additional person part of the SOMA project. Following the test study a number of changes were made. Early on in the study it was decided that using the shoulders to control one direction of the wooden plate was far too unnatural. The control scheme was originally thought as a way of exploring a different, uncommon way of interacting with technology. This proved to be something that was not coherent with the controls for the other DOF – leaning back and forth, and hindered the control of the prototype. Instead the controls were changed so that the tilt of the body was taken into account instead. Using the same reference point joint as the other servo, the x-coordinate (horizontal movement) was used to decide the output sent to the second actuator. This allowed for control of the prototype by tilting the body in different directions and it was possible to resemble the tilt of the body using the output of the prototype.

Furthermore, the parameters that control the actuator output were changed. Instead of sending the raw change in position the values were scaled. The change in actuator output corresponded to one quarter of the change for movement forwards and backwards and half the change for tilt. While causing the prototype to require larger movements to change the position of the servo motors, this made the prototype less sensitive to noise and easier to keep stable. Presented in **Figure 3.12** is a plot of the signal sent to one of the actuators with two different modifiers. While lower in amplitude, the modified signal is more stable than the signal dependent on raw change in user position.

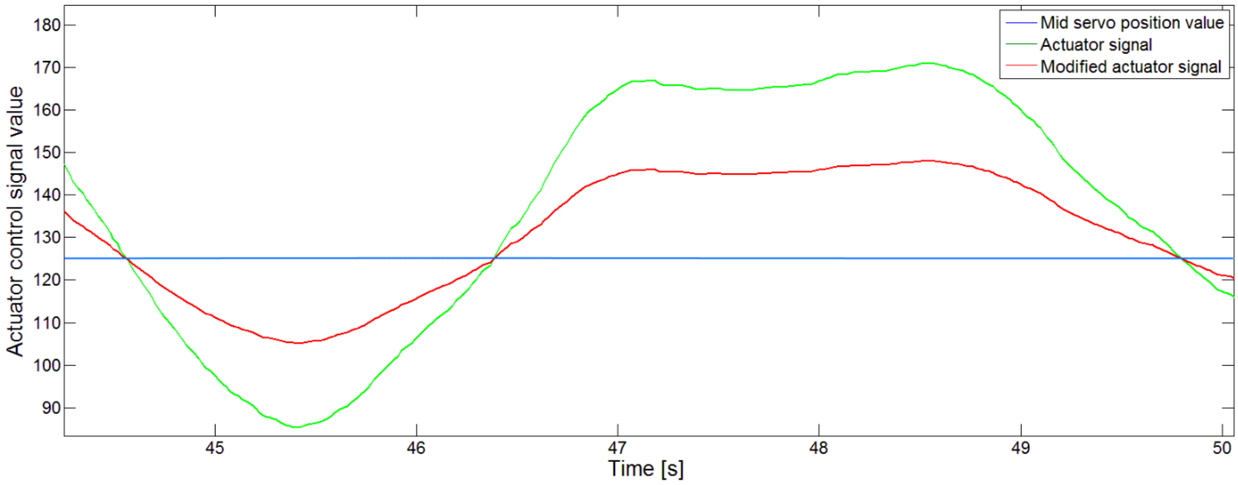


Figure 3.12. Actuator signals produced when using the raw change (green) and half the change (red).

3.2.6 Final User Tests of Balance Prototype

A study with seven people was conducted to investigate how the prototype performs in terms of evoking body reflection. The participants consisted of five researchers from Mobile Life, one HCI student and one design student with limited knowledge of the SOMA-project and body awareness. The test contained three parts that where slightly altered between tests. Additionally, control parameters were tweaked in-between two of the tests to see if the results would vary and how it would affect the outcome.

The first part of the test allowed the participant to get a feel of the prototype – how to control it and how responsive it was. The participant was allowed to do this for as long as they pleased and was encouraged to do this until they felt comfortable that they had full control over the prototype. Initially the table tennis ball was placed on the board from the start, but was later changed to adding the ball after the participant had gained control over the prototype.

The second part of the test consisted of different tasks that the participants were asked to do. These tasks included: trying to make the ball stay in the center of the board, drawing circles using the ball while avoiding the sides, and controlling the prototype with closed eyes using different body parts – i.e. hips, legs, upper body. By providing various exercises the user is encouraged to try different ways of interacting with the prototype and reflect upon which feels most natural. When removing the visual input by closing the eyes, the other senses are encouraged to explore the feedback from the prototype.

During the final part of the test a dialogue with the test participant was initiated with the intention of evoking reflection of the interaction. Open questions and allowing the participant to test ideas that crossed their mind during the dialogue further emphasized on body awareness and reflection. Every participant was asked if they felt in control of the prototype and if their movements were mapped in a satisfactory way.

The prototype was also shown for a number of designers at IKEA. The smaller, indirect user study performed in conjunction with this gave an impression on how designers with no technical background experienced the prototype and their thoughts around it.

3.2.7 Breathing synchronization

Presented in chapter 3.1 Double Diamond Model: Define, being able to measure breathing using a Kinect V2 was one of the main paths of this master thesis. The main restriction set on the prototype was that the user would be standing during use. Additionally, the user should be able to reposition them with no risk of disturbing the algorithm.

With a standing user there are no fixed reference points because of factors such as body sway and changes in posture. Furthermore, since there are no models for human behavior, it is impossible to model it properly. To solve this, a dynamic algorithm that adapts to user behavior is implemented.

The goal of the prototype is to identify the changes in position that correspond to breathing and map that change to an actuator. It is vital that the actuator provides a smooth mapping throughout the entire breathing cycle to provide a good feedback for the user.

Non-Static Reference Point

Mobile Life has previously constructed a breathing sensor using an ultra sound distance sensor. The user was provided with visual feedback in the form of blue LEDs with two light intensity states; high and low. When the derivative of the position switches signs, the current state is changed. A delay was added to the transition between the states. While functioning as an approximation of the stomach expansion and contraction during breathing, it was not precise enough to be considered good mapping of the positional input signal.

With a standing user the signal will be affected by noise caused by body sway. The noise is assumed to be of a higher frequency than breathing. Assuming the user's body to be straight and near-stiff when swaying and the point of pivot being the ankles, the change in position caused by body sway increases when the point of measure is placed higher on the body. By choosing a point of reference positioned low on the body the influence of body sway is reduced.

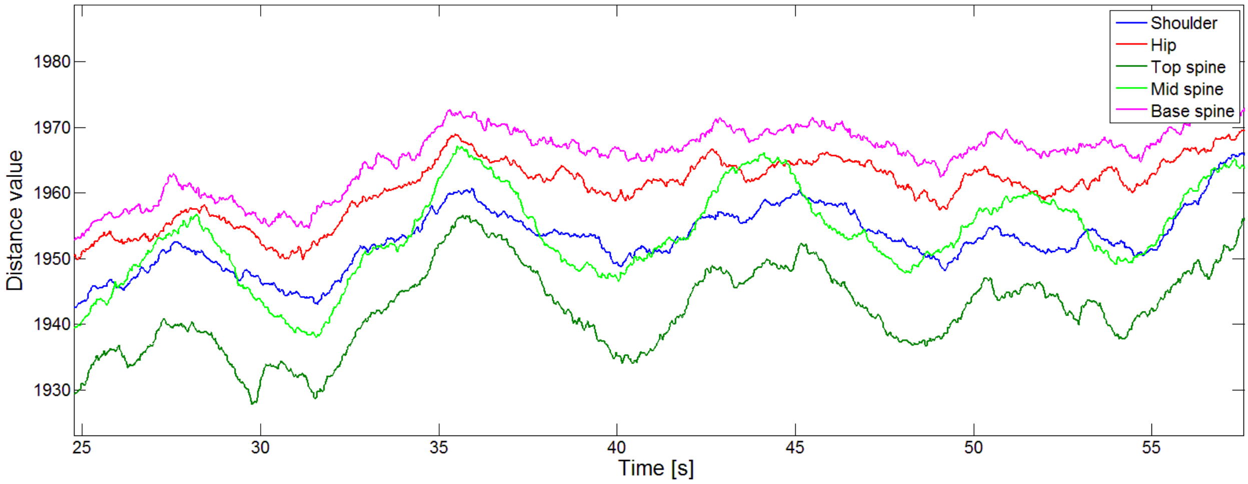


Figure 3.13. Change in distance values of five potential reference points.

To find which of the joints provided the most stable reference point, positional data for the joints during breathing was logged. In order to reduce the risk of corrupt data, three different instances were recorded with two different individuals. Analyzing the data collected, which was plotted in MATLAB and can be seen in **Figure 3.13**, the hip joints provided the most stable reference. Most affected by breathing was the middle spine and top spine joints. The middle spine joint is located at the celiac plexus, which is between stomach and chest, and was chosen as the point of measure. Since the movements caused by breathing varies between individuals and the area affected by the breathing depends on how the individual is breathing (Macklem 2014), the changes in top spine was included in the signal. Reference points included in the study is shown in **Figure 3.14**.

Software Application

The first implementation of the breathing application was not dynamic. Using the first measurement as the reference the application was built on an algorithm that found the maximum and minimum distance to the point of measure. Each run-time loop the current distance was mapped to the distance value interval and the output interval – the actuator min and max values – which is sent to the actuator as a control signal. A servo motor from Hitec, model HS-422 (Hitec RCD USA 2015b), was chosen as the actuator to represent the position in the breathing cycle.

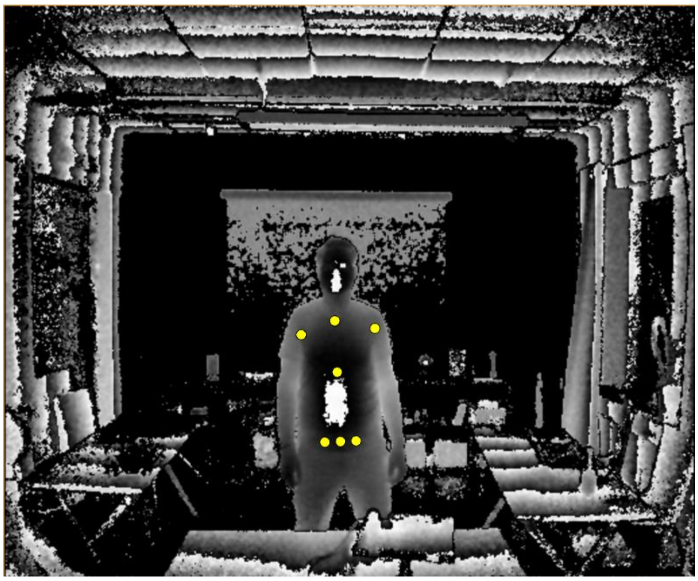


Figure 3.14. The position of the joints investigated.

While the reference point is somewhat stable, the maximum and minimum offset values will change along with the sway of the body. As seen in **Figure 3.15**, the highest and lowest values are changing for each breathing cycle. This became very apparent when the first application was tested on people not involved in the development of the prototype and represented the main problem of the algorithm. This was also the reason for not using the derivative of the position as the control signal, which Mobile Life had tried previously.

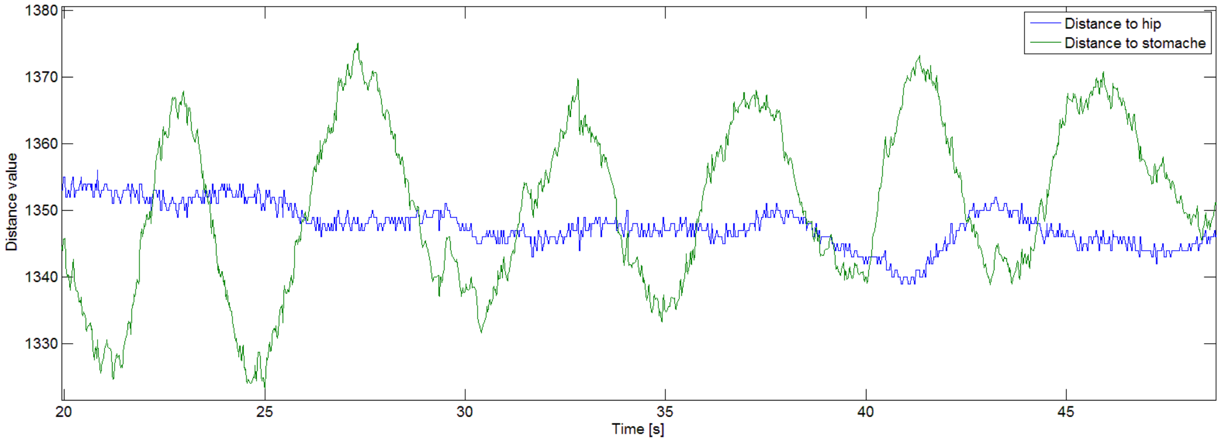


Figure 3.15. User depth values of the chest area (green) and the hip (blue) during breathing.

The final iteration of the breathing prototype had extended functionality and added error handling. Improving on the previous application was an algorithm that dynamically looks for a new interval takes the ever changing interval maximum and minimum into account. For each cycle, a new minimum value and maximum value is identified so that the current distance is properly mapped. Flowcharts of the algorithm are presented in Appendix B. As the previous implementation the actuator was a Hitec HS-422 servo motor.

To be able to adapt to the user in real time, values representing the current interval is identified simultaneously as the previous interval is used to actuate the servo motor. This provides feedback to the user while dynamically adapting to changes in the interval border values.

Final Iteration of Algorithm

With no definition of how long a breathing cycle will take, the algorithm must be able to handle an input that does not change for an unspecified amount of time – without changing the interval. To solve this, the algorithm has two states during run time. They represent which of the max or min value is being updated. Additionally, the breathing cycle is split into three different sections. The sections and a clarification of the thresholds separating them can be seen in **Figure 3.16**.

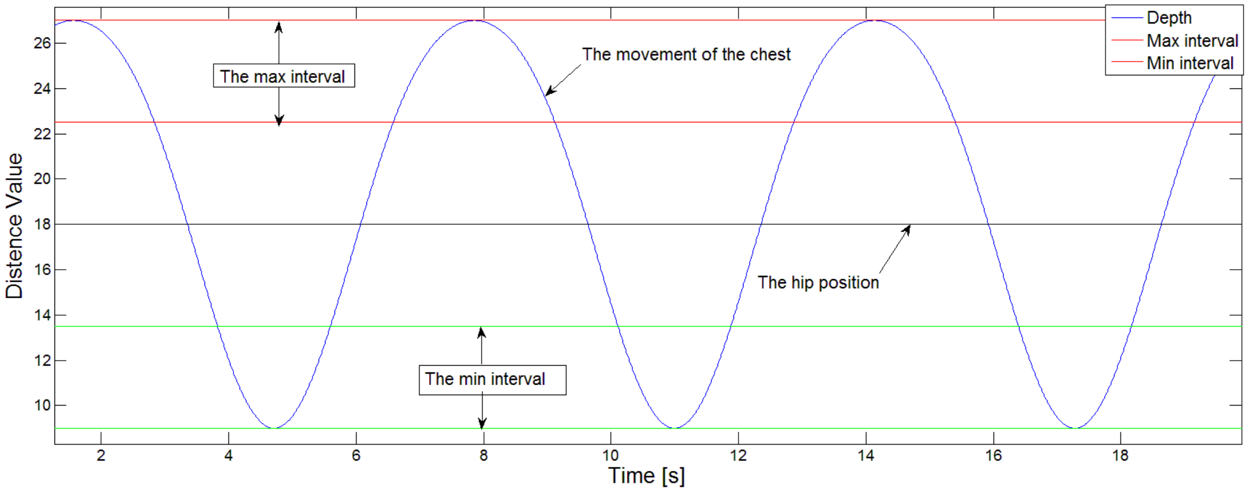


Figure 3.16. Clarification of interval threshold. Lower red is 75% of max and top green is 35% of max. Blue sinusoidal wave is a representation of the breathing measurements.

Initially, a breathing cycle is run through where the maximum and minimum values are identified since the algorithm is dependent on a previous interval existing. Starting with state one and finding a new maximum value, the current measured distance is compared to the interval from the previous breathing cycle. When the current input is above 75% of the previous maximum, the current value is overwritten for each loop the current value is higher. This continues until the current measured values have fallen below the 75% threshold. The new maximum value is saved, the algorithm transitions into the second state and repeats the process for the new minimum value. Here the threshold is 35% of the previous interval maximum.

Incorrect measurements may create an interval that is too large for the current values to cross the threshold. Since the interval border values are only updated when the thresholds are crossed, a safeguard was implemented. If no threshold is crossed for 200 samples, the interval length is reduced by 25% with the middle value (black line in **Figure 3.16**) unchanged.

If the current value jumps outside the interval, the value is changed depending on the previous interval. When higher than the previous max, the value is set to the max and vice versa.

A flowchart of the final version of the breathing application can be seen in **Figure 3.17** where the two process-blocks, “get depth measurements” and “breathing algorithm”, are shown as flowcharts in Appendix B.

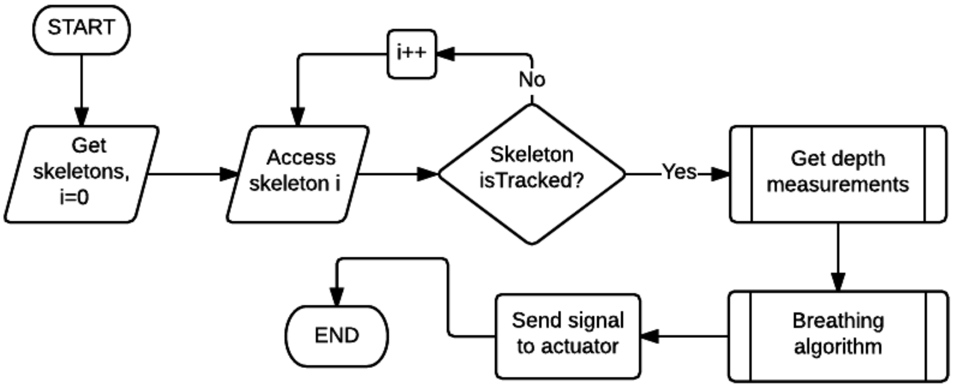


Figure 3.17. Flowchart of breathing application run time loop.

Prototype and Haptic Feedback

In order to provide feedback related to the user's breathing cycle a small prototype was constructed in the form of a pillow. The pillow contained a servo motor that was mapped to the measured distance value and its position in the determined interval. The prototype in its disassembled state can be seen in **Figure 3.18**. When the servo changes position it forces the prototype to protrude on one side. It is designed to convey the feeling of an object that breathes in sync with the user.

Figure 3.18: Prototype for investigation of different ways to map breathing. On the left an assembled prototype and in the middle the servo, its 3D-printed holder, and the Tempur used to create a soft feel.

To try an additional type of feedback the previous application was modified to map breathing to the opacity of a colored application window. Both the feedback types were tested in a small user study to receive feedback on the performance of the breathing synchronization. The results are presented in the *4.1 Double Diamond Model:* Deliver chapter.

3.2.8 Vibrations as feedback

Extending the experience of the previous prototypes required an additional type of feedback. Expressed by Mobile Life was an interest in haptic feedback based on vibrations. Previous attempts at incorporating vibrations in their prototypes have been dismissed early in the development due to the intense nature of high-amplitude vibrations – which distracts the user. One prototype was constructed for each foot.

Available in-house was two vibration speakers and an amplifier made by Lepai; model LP-2020A+. An additional Processing library, Beads, allowed for frequency and amplitude control of a computer's sound output (Bown 2011).

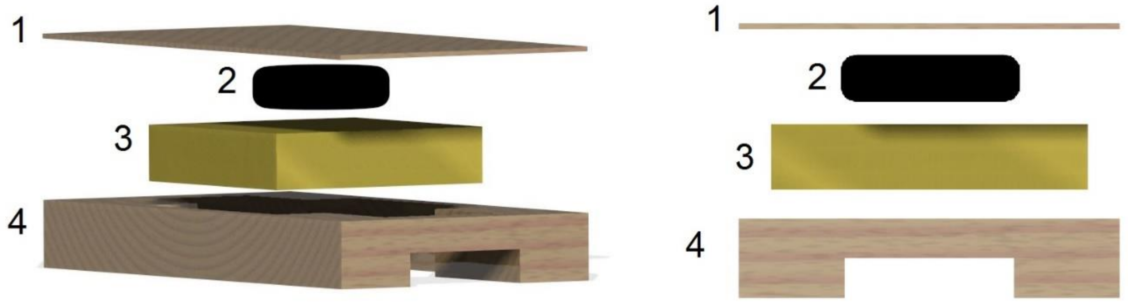


Figure 3.19. Exploded-view rendering of the vibration prototype. 1 is the cover plate that the user stands on, 2 is the vibration speaker. Number 3 is the memory foam and 4 is the wooden frame.

The intended design of the prototype can be seen in **Figure 3.19** as a CAD-model. To support the full weight of a user a wooden frame (4) is constructed for the top plate (1) to rest on. The inside of the wooden frame is filled with memory foam (3). When the board is fastened, the speaker (2) is pressed down into the memory foam, which also forces the speaker to press against the back of the board.

By trying out different thicknesses of the wooden board and the memory foam, it was possible to find a setting that allowed for good reception of the vibrations through the material while keeping the speaker pressed firmly against the back of the board. If not attached firmly enough the speaker vibrates enough to bounce against the plate, creating rattling noises disturbing the feedback.

3.2.9 Final prototype

Knowledge gained during the literature study, the design of the previous prototypes, and the results of the user studies performed shaped the idea behind the final prototype iteration. Concluded was the negative effect of the prototype esthetics – specifically with users that have little or no experience with Somaesthetics or body awareness. The prototype tended to be dismissed by designers since it is common that the esthetics play a big role in design. Additionally, a rebuild of the original prototype is advantageous for Mobile Life as it allows them to further explore the interaction with a more robust and reliable prototype.

With the previous balance prototype the user controlled a ball. The user tests showed that a lot of focus was placed on the ball, and not the interaction itself. In an attempt to solve this the table tennis ball previously used was replaced with 50 yellow plastic pellets.

Hardware and Prototyping

The prototype was constructed using plywood with a thickness of 6 mm. Each of the wooden pieces was cut using a laser cutter – ensuring that the measurements were correct. Cutting a pattern on the sides enabled easier assembly. The pattern can be seen on the edges of the right side in **Figure 3.20**.

Compared to the previous iteration the balancing board is 33% larger, corresponding to a side length of 400 mm. Even though the previous table tennis ball was exchanged for yellow pellets, the prototype was designed to be able to use both. To prevent the ball from falling off the board the height of the sides are equal to the radius of the table tennis ball – 20 mm. The length of the board is the same as the bottom box. Additionally, the height of the box sides are 100 mm. The total height of the prototype, from bottom to the top of the balance plate edges, is 185 mm.

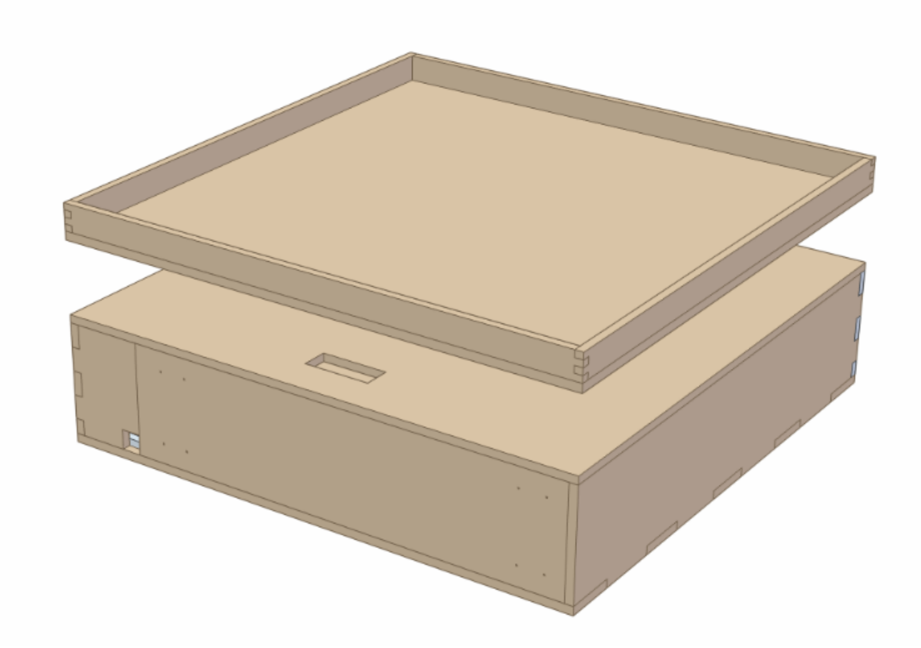


Figure 3.20. CAD model overview of the final prototype.

Two of the sides doubles as sliding doors for maintenance of the servo motors and the control circuit positioned inside the box. A 3D-printed pillar is positioned near the corner with two removable sides to keep the roof stable at all times.

Given the new material for the balancing board, the total weight moved by the servo motors was increased. The servo motors used previously were sufficient for the new weight. Since the new prototype is slightly bigger than the previous, the servo motors were connected to the bottom of the balancing board instead of the sides. The servo motor struts are fastened on the bottom of the balance board at the same distance from the middle point as before – 150 mm. This ensured that the old code could be implemented without modifications. Additionally, the important characteristics of the previous prototype were kept – i.e. angle change per servo value and max board angle. A picture of the finished prototype can be seen in **Figure 3.21**.

Figure 3.21. The final prototype with sides open.

Vibrations of the balance board against the cross mount caused by the software implementation was identified during testing. This was solved by placing a small piece of memory foam between the cross and its inverse mount, damping the vibrations.

Vibration Feedback

To add upon the previous functionality, the vibration speaker prototype was implemented together with the final prototype. The speakers were set to play 110 Hz sinusoidal waves generated using the Beats library and the amplitude was adjusted so that the vibrations did not produce an audible sound at maximum output. Just as the balance board the speaker amplitude is mapped to how the user is leaning.

The output amplitude of the two speakers is separated into two parameters each. Leaning back or forth corresponds to 50% of the maximum output for both speakers, i.e. leaning back 10 degrees produces the same response as leaning forward 10 degrees. Adding to this is the sideways lean. If the user is leaning to the left, the left speaker output is increased and leaning to the right increases the right speaker output. Sideways corresponds to the other 50% of the maximum output. Leaning diagonally to the left produces the maximum amplitude for the left speaker, which also applies for the right speaker.

3.2.10 Final prototype user tests

In total five individuals in their mid-twenties conducted the test individually – which lasted approximately 30 minutes. The participants consisted of one student in economics, one in computer interaction, two in sustainable energy engineering, and one working as a digital designer at a tech company. All of the tests were recorded on video.

The test consisted of three parts. The first part was a dialogue regarding the purpose of the project and prototype. Participants were introduced to the reasoning behind using Somaesthetics as the base when designing for technology promoting body awareness. By allowing the user to reflect upon the purpose of the research, the focus was placed on a subject relevant to the investigation. Previous user tests showed that the participant often placed their focus on how well the prototype is mapped to body movements instead of reflecting on the interaction from a body awareness perspective. By more thoroughly explaining the idea behind the project and the prototype, the goal was to encourage the participant to focus on the aspects important for the investigation. The basics behind how the prototype and feedback worked was explained so that the participant was aware of how the interaction would work before initiating the test.

The second part of the test functioned as a warm-up. The participant was asked to take off their shoes, stand comfortably on the floor and lean gently in different directions – while keeping their eyes closed. By asking the participant to start reflecting on what they experience while performing the exercise a body reflective mentality was evoked. This also gave the participant an experience they could later compare to the prototype interaction.

In the last part the participant interacted with the prototype. The participant was first asked to familiarize themselves with the prototype and was encouraged to explore how it responded to different kinds of leaning motions. When the participant felt that they had tried the interaction for a satisfactory amount of time they were asked different questions, aiming to start a dialogue regarding the experience and how the feedback was received. The participant was encouraged to try ideas that came to mind during the dialogue with the prototype, e.g. how certain parts of the interaction felt. The questions asked were directed towards the vibration feedback, where the user placed their focus during the interaction, and if the interaction was enjoyable.

4. RESULTS

In this chapter the results of the user studies performed for each prototype are presented. The chapter also contains results from the investigation of the Kinect V2's performance.

4.1 Double Diamond Model: Deliver

This is the final phase of the double diamond process. Here the user tests are presented along with the results for each of the prototypes and their iterations.

4.1.1 Balance prototype user test results

The balance prototype tests were performed on seven different people from Mobile Life. During the interaction the majority of the participants felt like they controlled the ball and not the balance board. They also directly related the inertia affecting the ball during acceleration to delays caused by indirect control over the prototype. Instead of seeing the delay as a phenomenon of physics they thought it was related to the response time of the system. When the participants started the exercise without the ball present, it was easier for them to realize that it was the board that was being controlled and the feeling of delay was diminished.

The actuation parameters were purposely changed for one of the participants, making the prototype four times more sensitive to changes in position. This participant was also the only case of frustration over controlling the prototype. The high sensitivity together with the delay caused by inertia affecting the acceleration of the ball caused the participant to tense up, disturbing the feeling of control over the prototype.

Notably, the subjects familiar with Somaesthetics, Feldenkrais and/or other types of body awareness exercises experienced the prototype to be promoting body awareness. The individual not familiar with body awareness noted that at the start of the test, all focus was placed on controlling the prototype. When body awareness was encouraged during the exercises (second part of the tests), the participant immediately started reflecting on what they felt when interacting with the prototype.

Given the answers provided during the tests, the prototype/interaction was seen as successful in the way it promoted body awareness and bodily reflection – which was the goal from the start. Mobile Life saw the prototype as something that could be built upon and further developed.

During the indirect tests performed during the IKEA visit, the designers focused on the Kinect V2 and what it could do instead of the prototype. The impression was that the prototype was dismissed because of the unfinished esthetics of it.

4.1.2 Breathing prototype user test results

The final version of the breathing algorithm and the prototype was tested on two different people. During these user tests, two different behaviors were identified. When a mapping was unsuccessful the values were reset – restarting the procedure.

Of the two behaviors, the most prominent was the inability to identify any change in stomach position. This resulted in an operational interval which was set according to changes caused by signal noise and user body sway. Because of this, the distance sample was mapped according to the noise-based interval and the servo motor was never able to stabilize – changing position according to the noise.

In two cases the interval was mapped close to the breathing cycle, but not in a satisfactory manner. Body sway caused the interval to be slightly larger than the actual breathing cycle, causing the actual change in stomach position to represent 10-20% of the interval. The algorithm was unable to remap the interval when this position was attained and a value reset was necessary. The resulting mapping was not seen as acceptable by the two participants. Because of the unpredictable behavior the application was deemed insufficient for the task and user tests did not continue.

Despite this, when tested during the development the resulting mapping of breathing and output signal were successful with the servo motor properly following the movements caused by breathing. A smaller delay in the algorithm was caused by the digital Butterworth filter implemented in the code, which is explained in 4.2 Investigation.

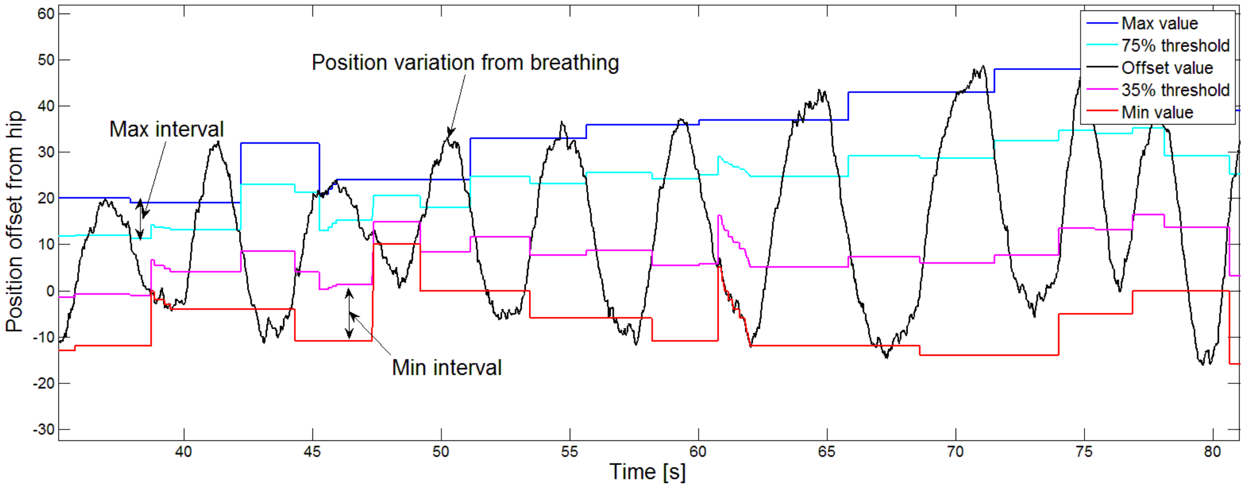


Figure 4.1. The stomach depth value, the interval border values and their thresholds during breathing.

In **Figure 4.1** the signal of the tests performed during development can be seen. The blue line represents the current interval maximum value and the cyan line is where the threshold for the upper interval starts. The black line is the measured distance to the stomach. The red line represents the current interval minimum value and the magenta line is the threshold for the lower interval. By analyzing **Figure 4.1** it is possible to see that the system sets a new max value when the current depth value has gone below the threshold for the max value. The process is repeated for the minimum value during the next half cycle. An example of a faulty measurement and the algorithm's recalibration can be seen at 48 seconds.

During the user test case seen in **Figure 4.1** the movement of the stomach was emphasized on purpose, making it easier for the algorithm to identify the interval for breathing and actuate the servo motor accordingly.

4.1.3 Final prototype user test results

The second part of the user tests conducted, where the user reflected on how it felt to lean the body, showed that there are a lot of sensations occurring in the body that seldom is reflected upon. During the second part, leaning with eyes closed, one participant stated that: "*The truth is that you have never reflected on this, how your muscles feel when you do these [movements]*". This realization occurred during multiple user tests. Based on this, it was concluded that by utilizing a Somaesthetic perspective it is possible to design for increased body awareness. Using the Kinect V2 as the sensor of choice was concluded to be a viable option and the versatility of Kinect V2 together with Processing makes it possible to rapidly alter the parameters of an application. The ability to quickly change the behavior of the application according to the test participant's reflections allowed for an even deeper dialogue during testing.

Every participant stated that the prototype and user tests helped them reflect on their own body and increase their body awareness. However, it was noted that for the participants to engage in reflection they had to be introduced to the purpose of the prototype or have previous experience with exercises based on body awareness.

During the first three tests, the sideways lean of the board was not calibrated properly and did not reflect the lean of the user. This was considered as disturbing and reduced the quality of the interaction. The lean sensitivity parameters and the maximum position offset of the servo motor controlling the lean was changed during testing. With parameters changed according to the preference of the user, the interaction was described as “natural” and “pleasant”.

The vibration feedback delivered to the user’s soles was considered to be the most important part of the interaction by one of the participants and only noticed when mentioned by the remaining four. Despite this, the feedback was considered pleasant. When the participants were asked to step down from the prototype and control the board without vibration feedback, each participant stated that the experience was more pleasant with vibration feedback included. The consensus was that the feedback provided by the vibrational speakers was suited for the interaction and helped them identify how they were positioned.

By exchanging the initial table tennis ball for approximately 100 yellow plastic pellets the focus was placed on the prototype’s entire motion instead of a single ball’s behavior. Each of the test participants felt the sound created by the pellets to be soothing; despite it being louder. This sound also covered the servo motor noise which disturbed the experience of the previous balance prototype.

4.2 Investigation of Kinect V2

Here the results from the investigation of Kinect V2’s usability as a sensor when designing for increased body awareness are presented.

4.2.1 The Resolution of the Kinect V2

During the tests, the Kinect V2 was placed on a distance of approximately 2.5 m from the users. From this distance, calculated using equation (1), the resolution for values along the x-axis was 1.82 mm/pixel and 2.673 mm/pixel for the y-axis. Using the depth-to-distance equation implemented in the applications (equation (3)) the measurements attain a resolution of 0.998 mm/value.

4.2.2 Kinect V2 camera noise and implemented filter

The values received from the Kinect V2 have noise issues as can be seen in both **Figure 3.4** and **Figure 3.5**. To tackle this problem a Butterworth filter was designed using MATLAB which had a 1 Hz cutoff and a sampling frequency of 30 Hz. By applying the Butterworth filter on saved data, the filter could be adjusted to reduce the signal noise while still keeping the delay at a minimum. The digital filter was implemented in the Processing code which runs on the main computer. **Figure 4.2** shows the filter implementation for the breathing algorithm.

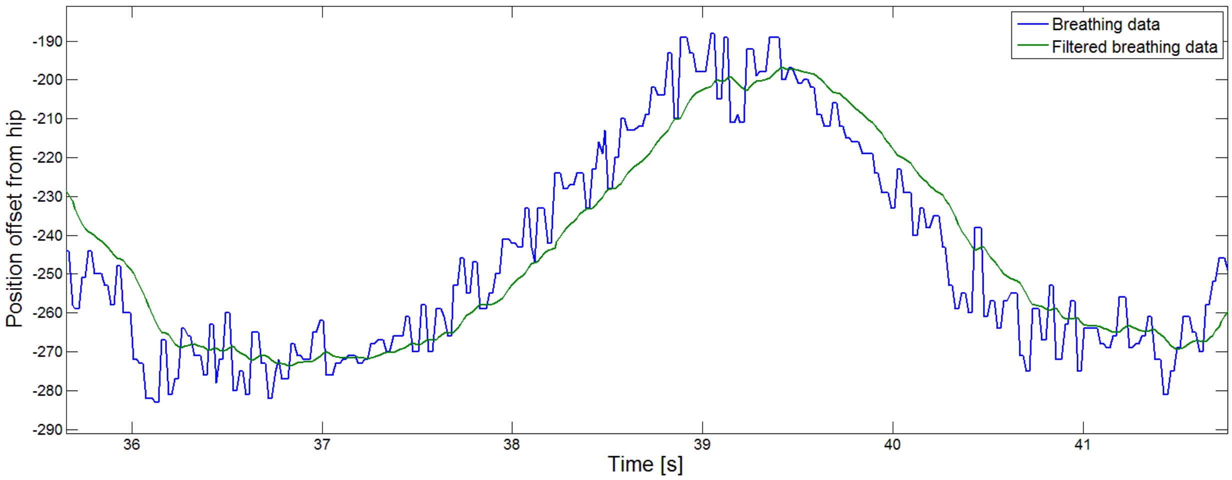


Figure 4.2. Filtered (red) and unfiltered (blue) depth signal from a user's chest while expanding and contracting during breathing.

As can be seen in **Figure 4.2** the filter implementation caused a delay of circa 150 ms. The filter was implemented on the color camera as well as in the heart rate investigation which can be seen in **Figure 3.4**.

4.2.3 Delays in the system

In the system there are various delays. The delays are caused by: The Kinect V2 GPU, Kinect V2 capturing images and processing them, communication from the Kinect V2 to the PC (USB 3.0), the running PC application, and the signals sent from the PC (USB 2.0) to the actuators. In this case, the processing power of the hardware is several times faster than the frame rate of the Kinect V2 camera. Since the Kinect V2 captures frames at 30 Hz, the delays caused by the computer (which operates with an i7 processor of 2.3 GHz) are negligible. Additionally, the serial transfer of information between these units is much faster than the speed at which the units process incoming messages and data as well as construct new messages to be sent. The messages represent the measurements sent from the Kinect V2 to the PC and from the PC to the actuator.

Caused by the implementation of a Butterworth filter in the algorithms of the prototypes is a delay that can be approximated to 150 ms using the information given by the captured data – shown in **Figure 4.2**. This is the only major delay affecting the application performance.

5. DISCUSSION AND CONCLUSIONS

A discussion of the results and the conclusions that the authors have drawn during the thesis are presented in this chapter. The conclusions are based on the discussion with the intention to answer the formulation of questions that is presented in chapter 1.

5.1 Discussion

From the prototypes built and tested in the master thesis, as well as the ones built by Mobile Life, we see tendencies for a concept regarding what a system have to deliver in order to provide a somaesthetic experience of the own felt body. What we see is that when designing for body reflection with somaesthetic qualities, the design/interaction has to mimic the experience of/in the felt body - and amplify that by the same channel or in an equal way though other sensory channels. One example of this is the SOMA mat and the accompanying breathing light. By using shifting light intensity the feeling of your chest increasing in volume together with the feeling of pressure in your lungs from the air in every breath is amplified - making the experience of breathing more "present". The heat intensifies the Feldenkrais exercise by highlighting the area of the body in contact with the floor while ensuring that the focus is kept on the current exercise. In this way of seeing somatic interaction the other prototype constructed by Mobile Life, the pressure mat, should not result in a good somaesthetic experience. The pressure mat prototype utilizes pressure plates and the center of mass is visualized as a dynamic cloud of pixels in the ceiling. When the center off mass moves, so does the cloud. The main issue here is that you do not feel your center of mass, which is what is displayed. During evaluation and user tests of the pressure plate system participants have expressed that the visualization is pleasant but draws the attention away from the body. We believe this is not mainly because it is an incorrect visualization, but because it is not consistent with the experience felt in one's own body. Instead what is felt is the contact points with the floor - the shoulder blades. Our suggestion is that it might be more in line to highlight the areas of contact in order to create a somaesthetic interaction. Other things that might be highlighted instead of this are the specific parts active in the movement of the body. We believe that the abstraction level of this knowledge qualifies it as a strong concept.

5.1.1 Methods

In 2.2 Double Diamond Model it is mentioned that the model is often used in projects where a finished product is the result. During this master thesis both the double diamond model and the design-oriented research method are used. It might sound contradicting to develop with the double diamond model, which produces a good prototype, when research through design does not have a prototype as the goal. However, in order to gain useful knowledge from a prototype it is favourable if it is designed with interaction in mind, as if it were to be a real product. Furthermore, the idea behind the double diamond model is to promote the use of interdisciplinary work and teams that contain individuals of different, complementary, specializations. This is an important part in a project that has the purpose of uniting different fields of research. Generally, the methods used while performing a project differs between engineers and designers. In this master thesis the solutions to problems are affected by both engineering and design. While developing the prototypes and their code, a more engineer-based approach is preferable. To be able to evaluate the Kinect V2's ability as a sensor a more quantitative approach has been adopted and its performance has been evaluated over a number of sessions and tests.

On the other hand, there are no distinct requirements for the prototypes and it was important not to specify the final prototype during the early stages of the project. The more design oriented part of the project consisted of user tests with results that vary depending on the user's personal preference and requires a more qualitative approach. These results are then to be evaluated and applied to the prototype, where the more engineer-oriented approach is taken. This transition between engineering and design practice was paramount for the master thesis and was realized by utilizing the double diamond model in conjunction with research through design.

5.1.2 User tests

The configuration of the user tests means that the results must be seen as guidelines rather than facts. This is not seen as a concern as one of the goals of this master thesis was to investigate how the perspective of Somaesthetics can be used when designing for increased body awareness/body reflection.

The user tests where set up so that the user would only test the prototype once. They would simultaneously be asked questions that encouraged the users to reflect on the interaction from a body awareness and somaesthetic perspective. An alternative to this could have been a longer study, where the user performed the tests frequently during a longer period of time. While the results from this longer study would be interesting from a somaesthetic perspective, this is not in the determined scope of the thesis. A longer study would provide information on the user's progress regarding body awareness. The goal of this thesis is to explore different prototypes and how they can be used for increased body awareness. Additionally, the studies conducted required input from several participants. If a longer study is to be performed, a larger quantity of prototypes would have been required.

The participants received background information regarding the project and the reasons of the user test, something necessary to get the participant to reflect on the aspects of interest. The user tests were recorded on video for post-test analysis.

To say that people in academia is a coherent group from the perspective of Somaesthetics is – according to us – incorrect. The results of the user tests performed in this thesis are dependent on each participant's individual reflections and their way of experiencing the world. We have noted that the concept behind the prototypes is easier to grasp if the participant has previous experience with body awareness practice.

With that said, the initial tests were performed with a coherent group with researchers from Mobile Life. These results were useful for the further development of the prototypes, which laid the foundation for the final prototype. The knowledge gained from these tests also helped shape the layout of the final user tests.

The final prototype was tested with a group of users that had no previous experience with body awareness exercise and with different background. With people inexperienced in this area the prototype's ability to promote body awareness could be tested with less risk of bias.

5.1.3 Kinect V2

The Kinect V2 has great potential to be used as a sensor in applications aiming to give users increased body awareness. As seen in 4.2 Investigation, noise from the camera can be successfully filtered. Additionally, the user tests show that system delay caused by the Kinect V2 is too small to be noticeable by the average user. The Kinect V2 provides great possibilities for a designer to use different aspects of a user's movements. The resolution has made it possible for the implemented applications to measure small movements, one user even noted that: *"It is almost as if I only have to think about the movement for the prototype to react."*

The thesis shows promising results for using the Kinect V2 as a way to identify the movements caused by breathing without physically interacting with the user. However, for a successful implementation using the current approach, a number of restrictions on the use case are needed – i.e. tight clothes and/or user sitting down. This was not investigated in this thesis as it was considered too similar to the prototypes previously developed by Mobile Life.

5.2 Conclusions

Throughout the project, the Kinect V2 has been seen as a black box sensor. In this case, the various algorithms and image processing procedures implemented in the Kinect V2 has been excluded from the technical evaluation of the prototypes. Never the less, the limitations of the Kinect V2 have been investigated together with the constructed prototypes. From the perspective of this thesis, the Kinect V2 is a powerful sensor. It allows for almost all parts of a user's body to be analyzed in several aspects – providing plenty of freedom for a HCI designer.

The limitation of the Kinect V2 is mainly due to its frame rate, however in the setting of small and slow motions this has not been considered a problem as all of the test participants have expressed that they do not experience any delay between their motions and the response from the prototype. Furthermore, the frame rate is sufficient enough to capture movements caused by human motion.

The resolution that the Kinect V2 delivers is also sufficient for the smaller movements to be properly captured. It is other factors that has been making some of the prototypes hard to finalize. One particular example being the task of identifying motions caused by breathing. Loose clothes hide the expansion and compression of the chest and stomach - making it hard to find these changes with the Kinect V2. Additionally, since there are different ways to breath, it is hard to identify which of the changes in depth corresponds to breathing.

Other than disturbances caused by non-smooth surfaces (clothes), the Kinect V2 has difficulties with certain use cases. Specifically when the user is not facing the camera or when the user is close to a flat surface (i.e. laying down or standing against a wall). On the other hand, even though the camera does not have vision on the entire user, when it has successfully identified a user and started tracking it has the ability to assume position of certain joints to some extent. Here the legs and joints below the hips seem to be easier to approximate than others. Realized through empirical studies, the arms seem to be the most difficult to approximate the state of - especially the hands.

Even with the Kinect V2 ability to track users and collect information regarding their movements and position, one of the greater difficulties was to find a reference point that is accurate enough to be reliable for changes in the user's position or smaller changes in body part position. When user's joints are measured and compared in relation to each other, a reference point is needed and as with the case of the breathing prototype an approximately stable point of the user's body is not always sufficient for that task. The method of using the derivative of the stomach's position was discarded during development due to the dynamic breathing interval and noise polluting the signal.

The more prominent point of this master thesis was using the Kinect V2 to investigate the field of HCI and Somaesthetics. During the design process a number of prototypes has been constructed with the aim of increasing a user's body awareness. The user tests performed during and at the end of the design process point towards that the successful balancing prototype did in fact deliver an experience that the user's found to increase their body awareness. A majority of the users felt that the tests performed made them contemplate on how they were standing, how they were moving their body to control the prototype and how the weight of their body was distributed.

The work performed during the master thesis and the results of the prototypes provided to give insight on what approach should be taken when using technology to increase a user's body awareness. The area of HCI and Somaesthetics is young and is yet to be explored fully. What has been realized through this master thesis is that for the potential to be utilized properly, it is important to bring in knowledge from other disciplines as well. Practitioners of Mechatronics provide a system overview that is similar to the somaesthetic way of seeing the human body – where sensors and actuators are realized as important components in a greater system.

6. RECOMMENDATIONS

In this chapter, recommendations on how to proceed with the results of this master thesis are presented.

Mentioned in 5.1 Discussion, we see tendencies for a strong concept when designing for body reflective interactions. Our recommendation is therefore to investigate this argument by further developing prototypes with this notion as a foundation, or to investigate if this is found in other “working” interactions. It is also important to continue exploring the possibilities of using dynamic prototypes to increase body awareness. We believe that the prototypes have to be able to dynamically alter their behaviour according to the user in order to provide an interaction that

We also believe that mechatronics will play a significant part of the future of HCI and we therefore recommend people of mechatronic background to be part of the HCI research. We believe that it can bring new perspectives and the abilities to see potential areas of interest as the future of internet of things approaches.

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APPENDIX A: COMMONLY USED KINECTPV2 FUNCTIONS

Commonly used KinectPV2 functions				
Function name	**Class**	**Input**	**Return type**	**Comment**
getRawColor	Device	N/A	int[]	Gets array of pixel color data for latest frame.
getRawDepth	Device	N/A	short[]	Gets array of pixel depth data for latest frame.
getRawPointCloudDepth	Device	N/A	int[]	Gets array of pixel point cloud depth data for latest frame.
getRawInfrared	Device	N/A	int[]	Gets infrared pixel data for latest frame.
getColorImage	Device	N/A	PImage	Gets the latest color frame as a PImage object.
getDepthImage	Device	N/A	PImage	Gets the latest depth frame as a PImage object.
getInfraredImage	Device	N/A	PImage	Gets the latest infrared frame as a PImage object.
getSkeletonColorMap	Device	N/A	Skeleton[]	Returns an array of skeletons mapped to color coordinates.
getSkeletonDepthMap	Device	N/A	Skeleton[]	Returns an array of skeletons mapped to depth coordinates.
getFaceData	Device	N/A	FaceData[]	Returns an array containing FaceData objects for each tracked user.
getFaceFeatures	FaceData	N/A	FaceFeatures[]	Returns an array of FaceFeatures objects.
isTracked	Skeleton	N/A	Boolean	Returns true if the skeleton is being tracked.
getJoints	Skeleton	N/A	KJoint[]	Returns an array containing the tracked joints of a skeleton.
getLeftHandState	Skeleton	N/A	int	Returns an integer representing the current state of the left hand of that skeleton.
getRightHandState	Skeleton	N/A	int	Returns an integer representing the current state of the right hand of that skeleton.
getX	KJoint	N/A	float	Returns the x-coordinate of a joint.
getY	KJoint	N/A	float	Returns the y-coordinate of a joint.
getType	KJoint	N/A	int	Returns an integer representing the type of a joint.

APPENDIX B: FLOWCHARTS FOR BREATHING PROTOTYPE

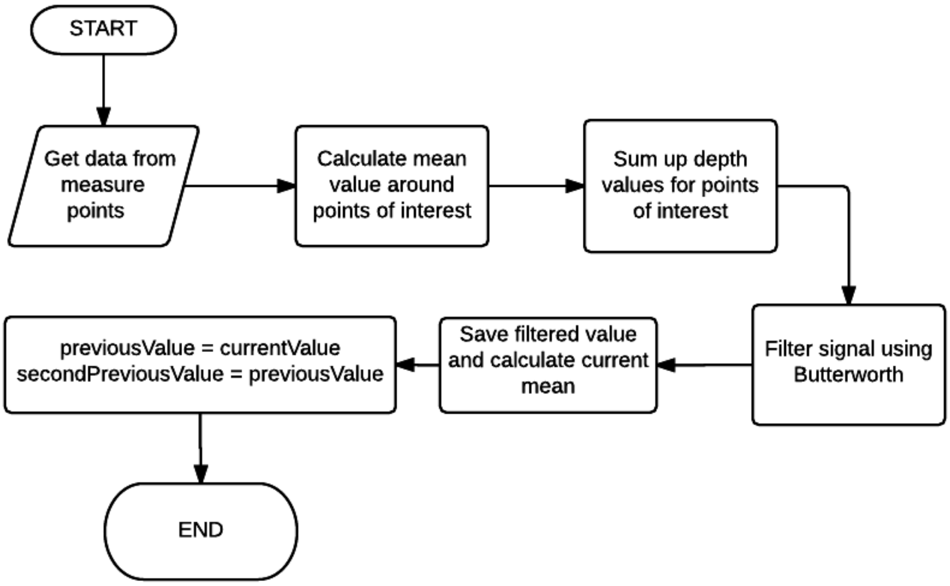

Figure B1. Flowchart explaining algorithm for obtaining data for breathing prototype.

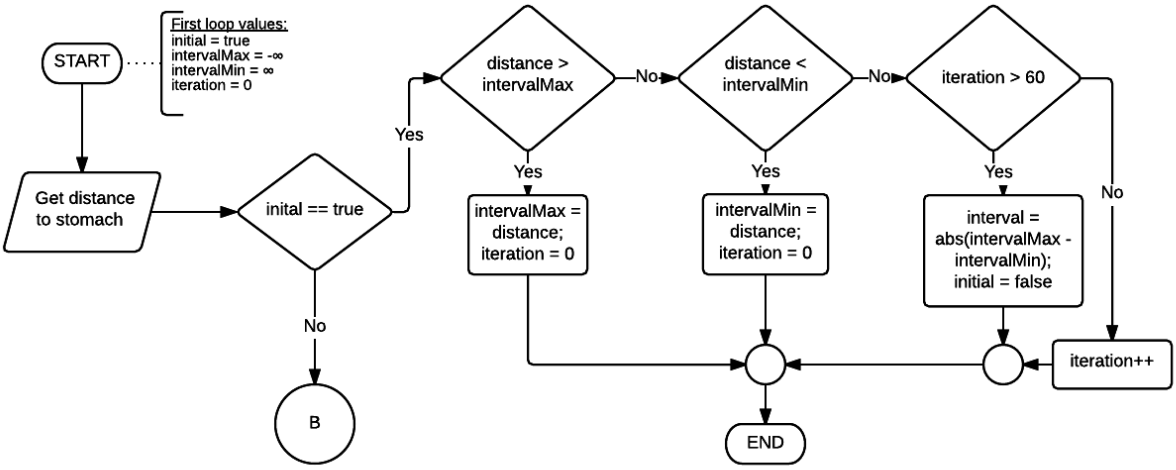

Figure B2. In-depth explanation of breathing algorithm, part 1.

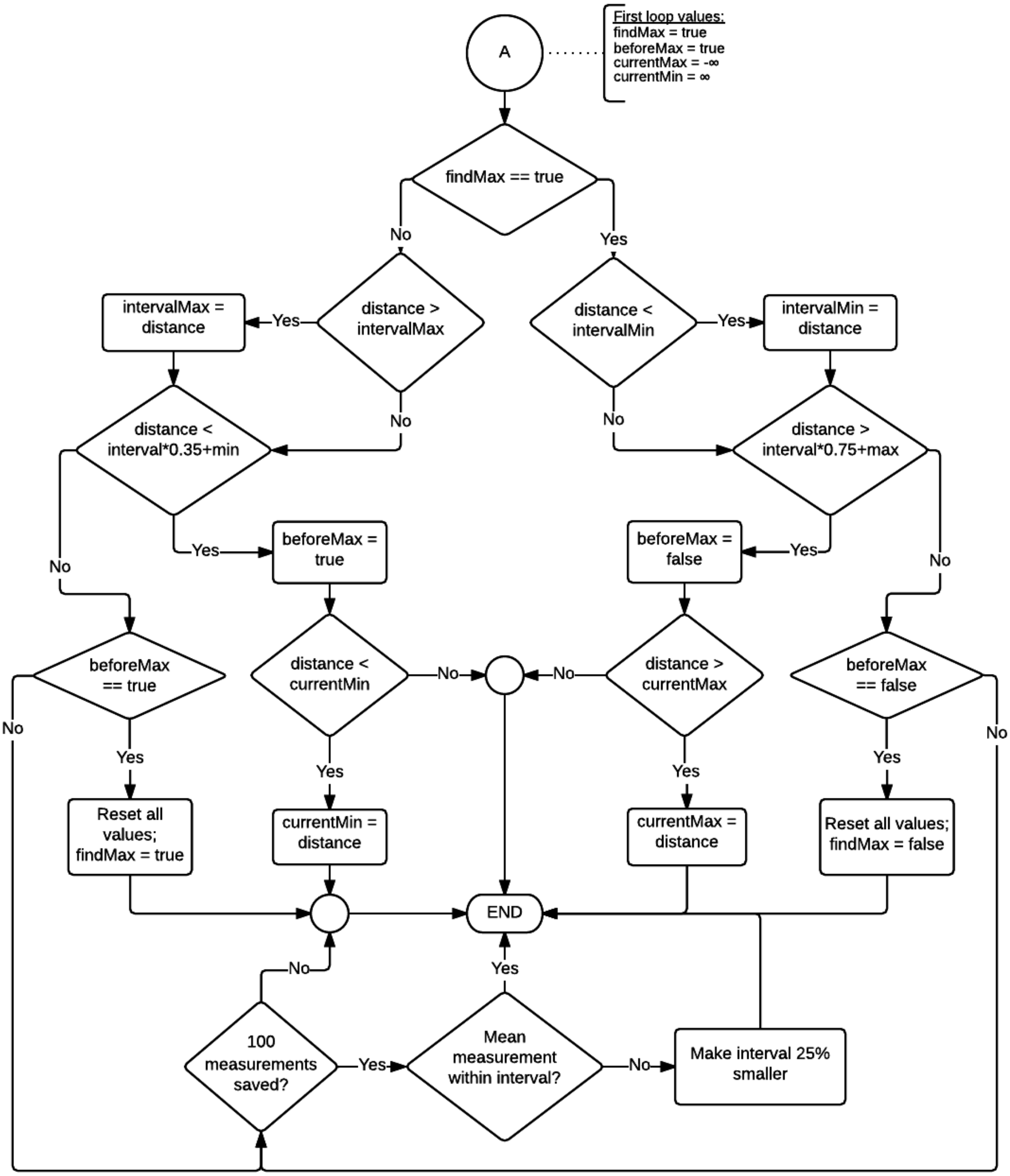

Figure B3. In-depth explanation of breathing algorithm, part 2.

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