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Investigating affordances of haptic technology

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Abstract

This thesis investigates the assumed affordance of haptic technology in a wearable context. This work position itself within the internet of things where wearable and connected objects have established themselves as a sub-domain in the area. Some argued that haptic technologies provide certain benefits when creating interfaces for wearable technologies. However, their seams to be a lack of studies investigating the natural responses to haptic technology from a user perspective. To investigate the assumed benefits of haptic technology, we have developed a prototype of a wearable haptic system. This system consists of two jacket were each jacket contains 16 touch sensitive sensor and haptic actuators. All interactions with the sensor of one jacket are mirrored with a haptic feedback in the other jacket. The purpose of this system is to investigate the initial responses and accord of haptic technology by users. The reason for doing this is to develop guidelines for further investigation into haptic technology as a means for creating wearable objects with a non-screen based interfaces.

The study concludes there to be some merit to the use of rhythm for creating haptic interaction patterns as well as haptic technology affording a simple and natural dialog in human computer interaction. Further, we also conclude that there is some merit to haptic affording faster learning curves in novel non-screen based interaction and are suitable for providing clear feedback. This study also shows limitations for haptic technology. Haptics seem less proficient for interfaces existing in a system as well as handling errors. This study also proved problematic because of the lack in clearly defined methods for investigating novel non-screen based interfaces.

In chapter two of this thesis we first present a theoretical overview of wearable’s generally and how haptic technology position itself within wearable technology. In chapter three, we move on by introducing our methods of research. Based on our theory we then frame the technological outline of the project and practical implementation. We follow this by presenting the results in chapter five from our user testing conducted with the prototype. We end our thesis with a discussion in chapter six with presenting the principal findings together with our discussion and future developments in chapter seven.

Keywords: Haptic technology, wearable’s, telehaptics, haptic interaction, affordance, haptic icons, non-screen based interfaces.
Popular science summary

In this thesis, we investigate the assumed benefits of using haptic vibration technology from a user perspective. We advert to this as the affordance of haptics where we try to determine what are the natural responses to haptic technology by the users. We assume that determining these natural responses which can help frame and develop a standardized interaction through such technologies and to avoid potential design problems. The screen based technologies serve as the main interface for most of our interaction with computers; however, screen-based interfaces have clear disadvantages. Usually, they require the user’s full visual attention and are not accessible to the visually impaired. Haptic technology might prove beneficial to creating interfaces that circumvent these problems. Hopefully, the result in this thesis will help progress interface design and interface development base on non-screen technology.

We want to outline the natural benefits of using haptic technology so we can better design interactions with and through the technology. In our study, we found that haptic technology holds certain benefits where the technology in it self helps users to understand possible interactions with a system. Our study also shows that even if haptic technology has benefits, these are not without limitations. When introducing interactivity through only vibrations, there seems to be a limit to the levels of interactivity understood by the user. Haptic technology also proved less fruitful for avoiding and handling problems that might occur while interacting with a system.

Our study also points to a dilemma with novel interface design, and the methods used for investigating them. These methods where developed with screen-based technologies in mind and cannot easily be transfer to non-screen based technologies. The solution for our work was to incorporate a user centered focus to evaluate the result. For future investigation into the field we also suggest to develop methods more susceptible to interfaces that do not rely on established screen based paradigms and interaction.
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1 Introduction

We have moved beyond traditional desktop computing into an Internet of things (IoT)[1]. Everyday objects have become embedded with technology and connected to the Internet where their functionality is extended beyond their physical location. Through mobile technology, we can access and interact with objects and other humans without the need for being physically present. Human-computer interactions are no longer space specific where we need to place our self in front of the technology to interact with it [2]. Location awareness and the concept of places have become important design principles for designing interactions through and with technology [2]. Although we have adopted new ontological understandings in the interactive landscape presented by IoT we still rely on old technological design principles when we create interfaces for interacting with our new digital reality.

Wearable computing seems to be a natural response to the mobile technology developed within IoT, extending its functionality to the user beyond their space limitations. However, wearable computing is currently being defined by smart watches, wristbands and augmented eyewear [3]. Most of these products that embed technology in a wearable context still rely on old design principals that where developed for screen-based information, feedback and interaction. Some argue that relying on screen based interfaces in wearable computing fails to recognize the shift in our understanding of the new digital reality and the notion of embodied interaction [4] that proceeds it. In past research collaboration’s together with Andreas Göransson and David Cuartielles from the University of Malmö and Ståle Stenslie from Aalborg University, this hypothesis has been explored through an artistic explorations of haptic technology [17] in a wearable context.

![World Ripple](figure1.png)

Figure 1: The world ripple.
We first collaborated on a project called World ripple commissioned by Stenslie to create a piece of hardware to control a set of haptic output. This system connected to the internet through a laptop computer and used GPS coordinates to activate haptic patterns in a glove as part of the artistic experience. Since then we have worked on multiple projects, connecting haptic stimuli with mobile technologies. Since smartphones became commercially available in the late 00s all our system have been based on these devices to provide an internet connection together with the use of custom hardware as shown in figure 2.

![Figure 2: The Psychoplastics project.](image)

Even if each project from our past collaboration’s presented different technical solutions for each project, the development of these prototypes can be seen as an iterative process where we have implemented findings for past iterations into new systems. These projects have mainly been artistic explorations where the prototypes developed served as proof of technology. Most of the iterations we did were based on technological findings and few improvements made the through the different iterations of prototypes were based on user input. The lack of user input in the development of these prototypes also presented problems. In general, users lacked experience with non-screen based interactive technology and there seemed to be a lack of language for communicating with and about haptic stimuli.

The findings from our past collaboration’s have inspired this thesis, but also the failure to address what seems to be a fundamental problem within in all development of wearable technology. The field of wearable technology is driven by a strong technical focus and the user perspective is often overlooked as in our own past research collaboration’s. In order to improve the development of haptic technology, the inclusion of a user-perspective is inevitable.
In order to do so, we will address the pre-understanding or lack of understanding towards haptic technology in order to see if this holds any benefits towards the design of interactions with haptic technology.

In this thesis, we present a telehaptic system that incorporates the touch-sensitive and haptic sensor which was given the working name “the spider”. The spider system includes 16 touch sensitive sensors and haptic actuators which are worn like a jacket. The spider system consists of two jackets with touch sensitive areas and if these areas are touched the interaction is reflected in the second jacket through a vibration output. We use this system to test if the users of haptic technology can perceive certain affordances when presented with the technology in a wearable context. The system is still based on the hypothesis, that that relying on screen based interfaces in wearable computing fails to recognize the notion of embodied interaction.

Through the study and development of this system we hope to progress wearable interface design where wearable technology interactions become closer related to the goals and need of the users.

![The Spider jacket.](image)

1.1 Motivation

The assumed benefits of using haptic feedback are many, and haptics are commonly implemented as a substitute for auditory or visual feedback or when these types of feedback can’t be implemented (4). Haptics are used to enhance the experience from a user perspective or convey
information in a more discreet way. Haptic feedback is more than vibrations or alerts and offers interactive possibilities where traditional interfaces might fail.

Even if there are benefits to using haptic feedback the field is underdeveloped, (4) and haptic feedback usually acts as a substitute for other types of feedback and not as a primary source of information. The reason for conducting this research is to investigate the possible benefits of using haptics as the main source of feedback and interactive input. We aim to address the pre-understanding of this technology to develop design patterns, which better relates to how humans interact with tangible objects. The result might prove beneficial for a better adaptation of haptic feedback patterns but also progress non-visual interface design. Besides, the benefits of haptics in non-visual interfaces, many researchers have argued the benefit of tangible interactions since the late 90s (5). As we are moving beyond desktop computing, into an Internet of things, new types of interactions will become more important. The development of technology is also moving in a wearable direction where the embodiment of interfaces and user interactions into real space will become more common.

Because of the current technological advancement, we think the affordance of haptic is of great importance in the development of new interactions with computers.

1.2 Research question

This thesis is based on the following research question.

-What kind of affordances do users with a low-level experience in haptic technology perceive when introduced to interacting with telehaptic technology in a wearable context?

For the purpose of this thesis the term affordance should be understood as the actions available to the user in the given context. In our work, we define low-level of experience as users with no previous experience using wearable haptic technology as a primary means of communication.

1.3 Expected results

By answering our research question we hope to provide an initial foundation for future explorations into the use of haptic as a means for non-visual interactions. The goal of this research is to provide areas of interest for such inquiries by clarifying possible affordances of haptics and how these could be used to help the design of interactions with haptic technology.

The affordance of haptic wearable’s has not yet been proven, but an initial analysis shows that it can hold some benefits in terms of the digital and physical layer of smart objects (6)(7). The contemplated result of our work is that wearable devices that utilize haptics hold certain affordances
when it comes to creating new interactions through them. We also hope to prove that the design of haptic icons based on rhythm is possible and enables distinguishable interaction patterns.

2 Literature review

This literature review was based on texts selected within the fields of interaction design, haptic interaction, human-computer interaction, wearable computing and computer science. The papers reflect both upon the foundation of tangible interaction and how new types of interactivity are developing in relation to users and a wearable context. This literature review aims to frame the history and technological outline for the technology developed in this thesis as well as to clarify haptic interaction in relation to human computer interaction. In order to better understand the need for the embodiment of technology we start this chapter by introducing the background of wearable technology and how the field has developed with a lack of user perspective. We then move on by relating wearable technology to the technical infrastructure of the Internet of things in order to clarify the areas where wearable technology is being developed today.

Later in this chapter we move on to the concept of affordance and the design of haptic icons in order to clarify the possible interactions that can be expected from telehaptic technology and how haptic interactions have been designed in the past.

2.1 Wearable’s

Wearable computers or wearable’s are body-borne computational devices. These devices incorporate low-cost sensors and are worn for long periods of time. Eighty million wearable devices have been estimated to be in use by the year of 2017 (9). As technology becomes embedded into
ordinary objects, our interactions with them become more seamless. Wearable computing stands as a subject for both the technology and the interaction with the user, where the interaction between them is constant. With the help of emerging technologies like near field communication, real-time localization, and embedded sensors, ordinary objects transform into smart and wearable objects. When these objects connect to the internet, they become the building blocks of a new digital infrastructure and enable novel computing and new applications (10).

Claude Shannon and Ed Thorp developed the first working wearable computer during the period of 1955 to 1960. It was a cigarette-pack sized computer that fit into a shoe and used to predict odds while playing on roulette tables (11). The system was tested at Casinos in Las Vegas, Nevada, but both creators claim that the system never worked because of a faulty circuit. Since then one man has driven much of the scientific development and many deliberate Steve Mann to be the father of wearable computing and he has been wearing different iterations of his wearable system since the early 1980s (12). Mann’s system is a full-featured computer with most of the functionality you can find in any desk or laptop computer but in the size of a pair of sunglasses. Mann’s inventions have inspired many of the recent development in wearable objects like Google glass, smart watches and life-logging devices.

Figure 4: The evolution of wearable computing[2].

However according to Mann, wearable computing extends beyond smart devices or smart clothing and likes to define them as “Body-Borne computing” or “Bearable computing” as to include all types of technology that can be worn on or implanted into the body[3]. In both the case of Shannon and Thorp as well as Mann, what has inspired them where short coming of the human body where they augmented themselves in order to gain abilities they do not naturally possess. Since then much of wearable computing have taken the same approach to the development of technology where the functional goal of these devices has been the main focus and where usability has been secondary if even considered. Melissa Dirth point to this problem in one of her articles.
where she argues that a distinction is usually made between developing aesthetical wearable devices and usable ones where the latter is often overlooked in the pursuit of technological advancements[5].

In many cases the functionality presented by most wearable objects already exists in other technologies. However, in order to gain these functionalities as an extension of our human bodies we need to adapt them to the same and this usually means making the technologies small enough to wear. So naturally the first step in the development of most wearable devices will be the technological challenge of making a piece of technology wearable. As in any technological or system driven process it is easy to overlook the user aspect, especially if the field has a strong history of doing so.

The idea of embodying technology is no longer novel but they actual implementation is still lacking. As presented by Ishii and Ullmer [5] the embodied technology explores interfaces that move beyond screens and into the real world. Dourish[6], argues that in this model physical objects are augmented with computational abilities so we can take advantage of the user’s physical skills. In order to take full advantage of the user’s physical abilities a sociological understanding has been applied to the design of interfaces. Dourish aptly describes this technological research that combines cultural and social studies as embodied interaction[6]. He argues that, the understanding of human activity is imperative to the design of technology. New patterns of interaction should be based on the users understanding of technology and should consider the cultural and social contexts where they are deployed.

### 2.1.1 Wearables in IoT

Deliberated as a sub-domain to IoT[14] wearable’s follows the same internet principal with an event driven architecture which focuses on context. IoT is the evolution of another field of studies called machine to machine (M2M). M2M focuses on the communication between digital devices whereas IoT appends the human aspect of users in this system of data communication [15]. As the technological infrastructure of IoT develops, we are moving from a mobile internet to an embedded internet [16]. IoT has a close relation to ubiquitous computing where the basic idea is for computing to emanate anywhere and everywhere [17]. The idea of IoT is to connect these computational devices through the Internet so they can share information. These objects connect to one and another and include different types of sensors and are also known as smart objects [14]. Alongside the evolution of IoT, innovative interaction models are being developed where the interaction has become embodied and where computer interaction has moved beyond screen-based interaction and
into the real world. Objects have become augmented with computational abilities which take advantage of our physical abilities [18].

Wearable’s has become a collection name for the technology that extends the IoT and adapts its functionality and interactions to the human body. Swan[7] defines the functional layers of the IoT ecosystem in four steps, the data acquisition, information creation, meaning making and action taking.

![IoT ecosystem](image)

**Figure 5:** IoT ecosystem [7].

The sensor and hardware platforms germinate the necessary data submitted for software processing where the actual information generates. To create meaning in data, the information needs to be visualized and based upon these visualizations, we base our actions. Kortuem et al[8] has developed a typology for smart objects, which consist of three key discrepancies in the design of these objects. These key discrepancies are awareness, representation, and interaction. Awareness adverts to the objects ability to understand the events of human activities by different sensor technologies. These could be any events that occur in the real world. The representation adverts to programing abstraction, also defined by the application of the programing model. The interaction adverts to the objects ability to converse with the user about user input and system feedback. Together these three discrepancies define the different types of smart objects. Kortuem et al[8] argues that smart objects have a dual nature where they are both digital and physical simultaneously and so the development of these objects must exceed hardware and software designs and includes human centred-activities and social aspects. By connecting wearable object to the internet we inherit an ecosystem and structure which is still being developed and was not primarily designed for a wearable context. Again the development of wearable technologies has mainly become a technological challenge. Connecting wearable’s adds a new layer of complexity that needs to be address by the development of technology which again, adds the risk of overlooking the user perspective.

In the context of the high mobility presented by wearable’s and sensing technologies in IoT, a new paradigm has presented itself where the aim is to enrich content provided to the user by taking the user context into account. Bandyopadhyay & Sen[10] points to a dilemma of a possible fragmentation of IoT. They argue that there is a lack of common ground where there is a need for
implementing a standardized approach for architectures, identification schemes and protocols. As of today multiple platforms and different architectures for deploying objects into the Internet exists, but many of these approaches lack a unified model for implementation. Wearable’s relies on the technological infrastructure of the IoT and tries to adopt current models for implementation. By doing so it, also adopts analogous technologies and design paradigms that where developed without a wearable context in mind. Some argue that to create affirmative and engaging embodied interactions we need to develop wearable technology form a non-technology, people centered point of view [9][10] that looks beyond existing paradigms. Connecting wearable’s devices to the internet creates new possibilities but will also create new challenges since there is no standardised way of connecting and interacting with connected object which extends to the wearable objects we connect.

2.2 Haptic

Some argue that certain technologies are better suited than others for creating interactions and that haptics holds certain affordances in relation to bodily communication (17). Haptic communication can be traced back to Giovanni Battista della Porta in 1558 which delineates a sympathetic telegraph [11]. This imaginary device would use magnetism to send and receive messages over distance. The messages would be encrypted and decrypted by tapping on the human body. Haptics are a version of tactile interaction, which can be used to enhance human computer interfaces. Tactile interaction moves beyond visual and auditory feedback and manipulate physical and virtual objects through the combination of movement, touch or tactile interaction [12]. Haptic technology adverts to recreating the sense of touch on the human body by applying force, vibrations or motion to the user. Haptics deals with controlling human movement and interactions through the sense of touch. In haptic interfaces, force is transmitted to the human body in a way that mimics the sensation of real objects [13].

Mousette defines two tracks in the historical development of haptics, a human centric and a techno-centric one. The human centric approach haptics relate to our notion of reality and conciseness. We interact with our environment through haptic stimuli to comprehend and develop our accord of the world. The techno centric approach haptics concern artificial changes made to the environment made by humans. In this approach focus lies on the development of haptic technology while the human centric approach concerns haptics in relation to the human body. Even if divided into two fields, the connection between them has always been constant. Mousette also argues that there is an clear advantage to using haptics in the design of non-visual interaction [14].
The connection between the technological and human element is not always contemplated during the development of technology. Without the contemplation of the human element, it is hard to make any prediction on how the technology will work once placed in the hands of the user. In our research, we believe both approaches need to be addressed to prove the relevance of haptics in a wearable context. To test the usability of haptic, as feedback and input method the technology has to be developed with a user-centered approach. Through the embodiment of technology, the importance of the human aspect also becomes more elucidate [15].

According to Stenslie haptic technologies bridge the gap between corporeal and the virtual world where haptics can help to create affirmative immersive and multi modal communicational experiences [16]. As Mousette [14] argues the technological and human centric approach needs to be connected to achieve an immersive experience. Sjöström [13] also argues that there is great potential for using haptics in non-visual interfaces and that it is viable to translate both 2D and 3D information that is still comprehensible with haptics. But, to make information comprehensible it has to be contextualized and including the user into the development of the technology does this.

According to Maclean the digitalization of once tangible tasks, ubiquitous computing necessitates controllers with a closer connection to the real world adapted to the frequent needs to manage information through simpler inputs [17]. Maclean has defined haptic interfaces as a possible expressive interface. Expressive interface sadverts to the quality or power of expressing an attitude, emotion, or other communicative information. Maclean delineates the affordance of haptics as an expressive capacity which includes density, controllability, directness, responsive and emotiveness [17]. To create affirmative immersive and multi modal communications according to Stenslie [16] the expressive capacity of haptics needs to be utilized.

However, Maclean [17] also points out that there is a lack of common ground of creating haptic interactions. Even if haptics affords certain benefits of creating interactivity, there is no standardized way of doing so. Studies show that users lack a language to communicate haptic product and requirements [18]. Mousette [14] points out that part of the dilemma lies in the complexity of designing haptic interactions which make them hard to compare to other types of interactive technologies. The realization and evaluation of haptics are often short lived, and time limited to ascertain haptic styles and patterns on a larger scale [19]. Large-scale haptics advert to interactions that differentiate through haptic stimuli and are usually subjected to an elevated learning curve.
2.2.1 Haptic icons

To convey abstracted information through haptics, MacLean proposes the used of haptic icons[20]. Haptic icons are brief tangible stimuli with associated meaning where the design of icons demands association and identification in three steps, principal designs, heuristic for rhythm and large sets. Maclean [20] suggests we base the design of haptic icons on rhythm where variation in length and number of resets can be used to generate distinct patterns.

When information is presented through haptic stimuli, this information is abstracted. Both Stenslie [16] and Sjöström [13] argue that haptics holds great potential for developing non-visual interfaces but haptics are faced with the same problems as any novel interface. As Maclean [17] and Mousette [14] pointed out, there is a lack of pre-existing cognition regarding interacting with haptics among users. Either the development takes a technological or body centric approach, but both are needed to achieve positive results. A common ground for interactivity needs to be established to enable interactions through haptics, Macleans [20] refers to this common ground as haptic icons. Developing these icons with the use of rhythm, constrains are enabled that relates to the user’s accord of the technology and offers the possibility to distinguish different possible interactions when navigating a system.

2.2.2 Telehaptics

Telehaptics refers to generating haptic stimuli over a network between physically aloof people. Telehaptics deals with the area where wearable haptic devices connect to the Internet. From a computational perspective, a telehaptic system consists of a network of two or more nodes where all the nodes together share a virtual environment. These nodes can be operating together or autonomously [21]. Based on client-server architectures the hardware and software is divided into separate categories to better employ available computing resource and share data processing flows [22]. A client node provides the interface and some of, or all application processing. The server node provides storage capacity and data crunching. Typically, several client nodes connect through a network to a server. From a technical perspective, most telehaptic systems follow the same principles for connecting devices together.

The key component in a telehaptic system is that these devices are haptic, which means they are force-controlled devices which the user interfaces with to interact with a virtual or remote environment. The second key components are the virtual or real visual environment renderings in which the user interacts [23]. At one end-node data acquires and where information is created and passed into a network. The information is retrieved in another end-node where the information is outputted to the user which interprets the information and performs actions based on the
information. Telehaptic devices also manifest the dual nature of smart objects as presented by Kortuem et al[8]. The physical and digital layers become intertwined which puts focus on the close development of hardware to software. We have applied the same principals for developing the spider system where each jacket acts as a node and where both jacket connect through a server in order to exchange information. In order to test our assumption that haptic technology holds certain affordances we thought it was important that we conduct our test in a true telehaptic context.

### 2.3 Affordance of wearable’s

Some argue that wearable’s holds certain affordances. Affordance is a term introduced to the HCI community by Donald Norman and refers to the visual cues an object possess that indicates possible interaction with the object [24]. For example, the affordance of a chair is that the chair affords sitting. The term was however, coined by J.Gibson and as opposed to Norman’s use of the term, Gibson used it to advert to the possible actions available to an individual in the environment, independent of the individuals ability to perceive them[25]. Norman’s point however is that if one studies the possible interactions presented by an object, these can be used to shape a better design of forthcoming objects. For the purpose of this thesis we prefer the understanding of the term according to Gibson since it does not emphasis visual cues as we want to include affordance based on all senses.

Kanis et al[26] argues that wearable’s hold certain affordances since they can be shaped into objects, which takes the users pre-consisting understanding of objects, into account. In the case of Kanis et al,(35) they investigate a wearable prototype worn as a bracelet. In this form the wearable affords normal hand based gestures like handshakes, hugs, waving and more without the need to introduce the user to these interactions. Instead these interactions can be used as the basis for interacting with the wearable device. Wearable’s functions both as an affordance and a tool where physical attributes and properties inherited from the shape and placement of the wearable, used to guide the interactions with them [27]

However, Swan finds that wearable development in relations to IoT is not without its limitations. The sensor technology is still expensive, and battery life remains an issue. Data transmission is also a dilemma in terms of seamless transmission and ubiquitous locational data is problematic [28]. Wearable devices require a wireless connection to stay connected to the Internet where most cities do not have full wireless connection with seamless access. Even seamless connections presents a dilemma of the cognition surrounding wearable’s where data streams are not analysed in real time which might be problematic for the understanding of these devices [28].
The concept of affordance has different interpretations in Human-Computer interaction. Vyas et al.[29] argues that affordance is the interpretative relationship between the technology and the user. It’s by technology, the user forms and understanding of the technology. According to Vyas et al[29] affordance adverts to both the user and their environment and are culturally and socially constructed.

To wearable haptic, the technology in itself can afford certain interactions but also be constrained by its environment. The environment for wearable’s is both the bodily position of the technology but also the context in where used. As Vyas et al[29] points out that the interactions and the accord of the information transmitted will depend on cultural and social factors. To determine the affordance of wearable haptics, we must contemplate both the functional affordances as presented by Norman [24] to the underlying cultural and social aspects as presented by Vyas et al [29].

Dourish calls the combination of technological research and cultural social studies for embodied interaction[6]. According to Dourish the accord of human activity is imperative to the design of technology. When new patterns of interaction develop, they should include the user understanding of technology and should deliberate the cultural and social contexts where deployed. In relation to full body interaction Antle et al[30] suggest the use of embodied conceptual metaphors. A metaphor is the interaction between a target domain and a source domain, which includes schemas or concepts. To structure and organized abstracts concepts conceptual metaphors are used. Haptic icons as suggested by Maclean [20] serves as metaphor and abstracts the information transmitted through them. To investigate the affordance of haptics, one must both consider the conceptual accord of the technology and their social and cultural context.

Gemperle et al [10] has developed a set of guide lines for designing for what they call wearability. Wearability focuses on the physical shape of the technology and their active relationship with the human form. Most of these guidelines concerns the physical aspects of wearable technology, but one point to the importance of affordance. According to Gemperle et al, [10] sensory interactions must contemplate their bodily positions and be place in an unobtrusive manner. They define seven unobtrusive areas suitable for deploying technology but by suggesting that the body can be defined in intrusive and unobtrusive also suggest that placement holds certain affordances that might prove different to technologically enhanced interactions.

2.4 Summary

Wearable’s have established itself as a sub-domain of the IoT where it extends functionality of the Internet to the human body. However, the IoT model struggles with finding a unified
implementation, which is reflected within wearable’s where these devices where developed from technological and interactive paradigms that where not developed with these devices in mind. Some argue that wearable’s need to be developed with a non-technological and user-centered focus to reach their full potential which has become to be known as the embodiment of technology. Others argue [16] [31] [14] that to create interactivity with wearable systems, haptic hold certain benefits considering the creation of true embodied experiences. The assumed benefits of haptics, also called their affordance are defined arguably by their bodily position [10]. Still most of the authors fail to address how haptic are best utilized or how to design interactions with them. Maclean [20] suggest we base the design of haptic on rhythm but says very little about what the expected outcomes are in doing so.

The history of wearable technology seams to show a lack of usability and has mainly bee concerned with technological progression so far. In recent years the field of wearable technology has also entered into the field of IoT with a new set of challenges which again has focused the development of these devices towards the technology. What we are suggesting in this thesis is not to abandoned the technological view towards wearable devices but to combine it with a user centred view. Even though parts of our research is highly technological our main focus will be user-centered. This is where our research differs from the history we present where most of the technology developed has been done from a technological perspective primarily. Since we aim to investigate the affordance of the technology we are presenting we need to move beyond the technological implications and include the human user aspects in order evaluate the meaning of technology beyond its function.

To evaluate the affordance of wearable haptics, we will develop a prototype implementing all four layers of the IoT ecology as describes by Swan [7]. Data will be acquired through the use of modified vibrators, which will act as both sensors and actuators. The data will be passed to a server and then downloaded into a mirror system where the information will be regenerated as haptic stimuli. The meaning creation of the information will happen in the mind of the user. Base on their interpretation, the users are asked to act accordingly. As Vyas et al[29] argues we hope that through the use of the technology, the user will form their own accord which we will use to test our hypothesis. The typology presented by Kortuem et al(10) will act as the core of the design[8]. To test the prototype, the prototype needs to be designed so it understands the user and their interactions with the system. We need to visualize these interactions appropriately so that we can communicate them through the system. In our case, the visualization of the information is based on rhythm (39) which will act as a metaphor to relate to the lack of pre-understanding of the technology by the user. The lack of a pre-existing accord of the technology might be proving troublesome for
the research, but by using rhythm we hope to utilize the expressive capacity of haptics which are a key feature to create an affirmative immersive and multi modal interactive experience [16]. By testing the actual system with users, we hope to provide a data set that will indicate what types of affordances telehaptic technology could provide in a wearable context and how these can be utilize in further designs of the same technology.
3 Research methodology

Since we aim to investigate the perceived affordance of novel haptic interfaces we needed to develop the technology we aim to test. Therefore this thesis combines an action research approach[1] with a user centered design approach[32] where action research is applied to the technological development made and where user centered design was applied to user research and testing. In action research an iterative process uses experiments and where the results lead to further developments during the research process. This approach put emphasis on changes during the process encouraging collaboration with the user. The action research approach relies on multiple data generating methods which can be both quantitative and qualitative. The reason for choosing action research is to accommodate useful insights that might occur during the development that comes from including practitioners into the process. Another reason for choosing an action oriented approach is that it will enable us to focus on what happens when the practical aspects of our work is deployed into real-world situation.

Since our investigation will include actual users we have chosen to complement the action research with a user centered design approach. The user centered approach focuses on the user’s needs and goals and lets them guide the design. Usability is at the core of user-centered design and used as measurement of the interactive user experience associated with the use of an interface or digital object. Usability can be tested in multiple ways which can be either quantities or qualitative[32]. The reason for including a user-centered approach is the poorly defined role of practitioner’s in action research. Sometimes loosely called clients of the research conducted[1], very little is said about specific treatment of these clients and their role in research. Both methodologies use the same argument for including practitioners into the process. To avoid the research becoming affected by external or internal interests, the people affected by the research is introduced into the process in order for their needs to be included into the information aggregation. However in the action research approach, one might include anyone affected by the research whereas the user centered approach focuses only on the actual user of the research. The user-centered approach bestows a better account of the role of the practitioner or user and what the purpose is for including them. Since the goal is to investigate the affordance of haptic technology the answer will partly depend on the user perception of the technology, which will also define how we will evaluate the results.

For gathering information we have chosen to implement observations, interviews and prototyping as our methods as they are commonly supported by both the action and user centered research approaches[1][32].
Figure 6 visualises the processes in relation to the different methods used during the development of the prototype, user testing and evaluation. However, in nature of being an action oriented study in part, figure 6 should not be understood as a linear process since iterations have been taken during all part of the study. Figure 6 only illustrates the coupling of methods to the different parts of the process.
3.1 User group

The target group for this research where people with a lack of prior experience with wearable haptic technology. The inclusion criteria for the test were mainly based on availability where we used a random and convenience strategy (4) where the sample universe was adults at the university. Since we were not looking to make generalizations beyond the assumed affordance of haptic technology we conclude that a sample size of 6 users would be sufficient for the results to locatable within the study. The user sample consisted of four males and two females in the ages from 25-38.

The threats to the external validity are clear considering the user group used for conducting the test was very small. The generalizability of the treated outcome of the study can, also, be questioned because of the small user group. But since we do not make generalization beyond the outcomes as areas of interest for future investigations we perceived the sample size big enough to support these claims. In our studied we are not trying to provide proof to what affordances haptic technology provide, merely what possible affordances perceived. Also the lack of research and studies into people’s prior experience with wearable haptic technology made it hard to conclude any relevant selections criteria’s for our study beyond the ones presented above.

3.2 Observations

The observations implemented in the research where highly systematic observations of pre-defined types of events [1]. Most events based on the digital prototypes developed where not devices commonly used which limits the possibility of conducting observation outside a controlled environment. The structured observations where mixed with supported user tasks where the supported user task aims to provide a formalized and objective dataset for interpretation [33].

The reason for mixing structured observations and supported user task is that the prototype deployed in the user testing where novel devices where the assumption is that the user had no cognition of how to interact with them. The assumed benefits of structured observations are that this will minimize the risk of distorting information and affecting the behaviour of the users. Potential problems are that the test conducted has very little to do with a natural setting where the technology aims to be deployed. Other possible problems with the observations also include the danger to lose the sense of detachment from what is being observed[1]. In our case we where physically engage in the test where we are supposed to observe, which might have affected how the participants would normally react in the testing scenario. On this note one must take precautions and learn how to recognize and distinguish between ones own assumptions and pre-conceptions surrounding the tests[1]. At the same time observations are one of the most fruitful methods for
investigating a design since it brings the research very close to how the participants acts in a conscious manner[32]. Observations can also be hard to evaluate objectively since they depend on a subjective understanding of what is being observed. Even though observations as a method has its limitations some argue for the importance of observations when searching for unexpected results and the need to experiment more in computer science[34]. Our theoretical research can predict the affordance of haptic but it cannot confirm it since the affordance implies the usability found by users. Observations will hopefully enable us to gain some insight into the affordance of haptic technology presented in the thesis.

3.3 Interviews

To evaluate the prototypes one-on-one semi-structured interviews where implemented [1]. These types of interviews rely on a pre-set list of themes, which we used but we did not limit the questions asked to these themes as found in appendix 1. Questions during the interviews should aim to create a natural conversation with the interviewer to enable the participants to bring up issues of their own [32]. We conducted the interviews after the structured observations and the contextual inquiries. The reason for conducting interviews is to investigate the concept of affordance in depth. From the interviews, we hoped to provide a qualitative data set about the user’s accord of haptic interaction. One-on-one semi structured interviews also provide a higher response rate where any ambiguity can be clarified and followed up. Potential problems with conducting these interviews might be the time constrains since interviews take a long time conducting and transcribing them might affect the results.

3.4 Prototyping

Prototypes commonly are used as representation objects while exploring interactive systems and often used within system development [1]. Prototypes can range from low to high in terms of fidelity where low fidelity prototypes include prototypes built in cheap materials with limited interaction. High fidelity prototypes often incorporate digital materials and provide a higher level of functionality [35].

We divide the tests made in three categories, functional, esthetical, and orientation. To evaluate the functional and orientation tests; we implement user task and observations. The benefit of using prototypes is that they help eliminating ambiguity and help improving the accuracy in interpreting a system. The prototype would help us to explore different design patterns, and help identify problems early on. We also hoped that the prototypes will help elucidate the concept of affordance
illustrated to the user and not merely explained it. However, in terms of the prototypes technological complexity they also pose a potential risk to the research in the case they would break. The prototype developed in this work is a form of technological mash-up [36]. These types of prototypes combines’ different hardware and software parts and implement different services that can be either self made or based on existing hardware, software, or services.

3.5 Evaluation and validation

In relation to our action oriented research we aim for a reflexive-practical result where the goal is to gain both practical understanding as well as academic insights [1] into the affordance of haptic. In accordance with the user-centered approach the evaluation of our work will be guided by the user’s needs and goals[32]. The user goals are not easily defined in our work since part of this thesis is presenting a novel technology and interaction.

The combination of action and user-centered research is also an attempt to circumvent the dilemma of lacking models for investigating novel-interfaces. As it is not our intent to developed new methods for evaluating novel-interface design in the scope of this thesis, we have relied on the methods available to us and have taken steps to re-interpret them so they might include non-screen haptic technologies.

To evaluate the results of the technology, we will execute the product by implementing the prototype in a real environment. Since the prototype is only a prototype, we can only hypothesise possible interactions with the technology and how the user will react to the technology.

The evaluation process has been divided into four parts:

1. The development of the hardware: practical implementation of the sensor/actuator with developing the firmware for processing data and external communication.
2. The development of the Android application: developing the bridge software that connects to the hardware and passes the data to the net.
3. Connecting the hardware with the software: establishing the connection between the hardware and Android application and passing data in-between devices.
4. User testing: testing the actual design with users in a task oriented setting.

For achieving practical outcomes[1] we will submit the actual prototype system to interface testing[37]. The prototype developed for this research is partly a message passing interface[37] where multiple components will request services from another component by passing messages to it. The main reason for submitting the prototype to interface testing is to avoid interface misuse and timing errors since they will effect the human interaction with the system. We based the prototype
on several interacting composite components and objects where the goal is to test how the system behaves according to their specifications. The prototype was not tested in parts since most of the potential errors might occur when the different parts interact with one and other. For example, the delays on the server might cause unexpected problems on the hardware side.

To study the human element in our work, according to the user centered approach[32] we will be using a set of fundamental requirements to be fulfilled by the evaluation methods as formulated by Witt and Drugge [38]. These requirements where formulated as suggestion for conducting studies in interaction aspects surrounding wearable computing in a realistic manner.

1. Real physical task abstraction. Most tasks in a wearable system are manual tasks. To evaluate the system, we need the system to realistically simulate manual activities by abstracting their fundamental characteristics.

2. Easy to learn. The system has to be easy to learn to make the user testing proficient. The time to train the user with the system should be short enough to make a practice period before the test without actually interfering with the test.

3. Adaptable to different simulations. The system has to be adaptable enough to test various user’s skills. It should also allow simulations of different tasks with different characteristics.

Most evaluation methods for analysing interfaces rely on the evaluation of usability where the ISO 25,010 standard designates the following five factors for satisfactory usage [3].

- Effectiveness
- Efficiency
- Satisfaction
- Freedom from risk
- Context coverage

As suggested by the factors above, these mainly focus on software attributes whereas we wanted to investigate the relationship between the design and context of use. This is why we will apply a heuristic evaluation of the prototype developed as presented by Nielsen [39]. The heuristic evaluation developed by Nielsen is a means for passing judgment on interfaces according to ones own opinion [39]. This is an informal method of usability evaluation where the evaluation of others contrasted, averse to certain principals. To empirically evaluate according to the heuristic evaluation method, the user test will be matched averse to the usability principles developed Molich and Nielsen[40]. This is a set of nine heuristic principles:

- Simple and natural dialogue: The interface should not contain irrelevant or rarely need information.
• Speak the user’s language: The dialog should be clearly expressed in words, phrases, or concept familiar to the user.

• Minimize user memory loads: The user should not need to remember information from one part of the dialog to the other. Instructions of use should always be visible and retrievable by the user.

• Be consistent. The user should not need to wonder if different actions mean the same thing. A particle system action, when appropriate, should always be achievable by one particular user interaction.

• Provide feedback. The system should always provide the user with information about what is happening and provide suitable feedback within reasonable time.

• Provide clearly marked exits. The system should never chapter the user. The user should always be able to exit an unwanted state without extended dialog.

• Provide shortcuts. The user should provide shortcut in order to cater to both experienced and inexperienced users.

• Good error messages. The system should provide defensive, precise and constructive error messages. Messages shall never blame the user but it should provide messages that provide information about the problem and suggestion on what the user needs to do next.

• Prevent errors. Prevent misunderstandings at all costs.

These principles where developed as a means for identifying different types of usability problems. However, the set of heuristic principles where developed, as most methods for evaluating usability, for screen based interactions. We have failed to find methods for evaluating novel interfaces and especially those that focus on non-screen based interaction. With this in mind, we took the freedom to understand these principles in a broader sense so they can include non-screen based interfaces.
4 Prototype

The prototype named the Spider Jackets consist of three major parts. The two jacket containing 16 haptic actuators/sensors, the android application that handles the communication in between the jackets and the online server where the information is stored. For the purpose of user testing the system was always presented as one product “the spider jacket” and the actual technology was never discussed during the test beyond the functionality of the actuators and sensors.

In this chapter we explain the how the hardware, software and serve was developed and how each individual part relates to one and other in the system.

4.1 Hardware

The hardware of the system consists of two main components, which have been developed into a prototype board, which combines the Bluetooth radio module, microprocessor and the actuator/sensor extensions. In order to connect the prototype to the Internet we chose to use an Android phone to act as a proxy for sending and receiving information between an online server and the prototype. The prototype was name the “Spider” because of its slight physical resembles to an actual spider when fully mounted. The reason for developing two jackets was that this would enable us to wear one of the jackets during the user test and change the feedback and interactions patterns without the need for reprogramming the system. This could also have been done by developing a software interface for conducting the user test. However, the initial idea was for one person to conduct the user test and we conclude that making the control interface the same as they user interface would help to avoid some of the practical issues of conducting one on one user tests.
4.1.1 Microprocessor and BLE

We based the core of the Spider on the Blend micro development board. This development board is based around the Atmel ATmega32U4[41] and the BLE Nordic nRF8001[42] chipsets. The ATmega32U4 is a low power 8bit micro controller which features 32KB flash programmable memory and 26 programmable pins however in the Blend micro design only 17 pins are available for programing. The nRF8001 is an integrated single-chip Bluetooth circuit which supports Bluetooth smart v4.0[42]. The reason for choosing the Blend micro was that this development board implements both the ATmega32U4 microprocessor, which contains the sufficient programmable memory and programmable pins and the Nordic nRF8001, which implements Bluetooth v4.0[43] also known as BLE which stands for Bluetooth low energy. This update to the Bluetooth wireless standard focuses on improving usability with seamless interactions with cell technologies. The nRF8001 also supports simple serial interface, which makes it suitable for interfacing with micro controllers. The benefit of this combination is that the power consumption is 2mA on an average, which makes the development board suitable for wearable devices. The Spider, was originally designed to be powered by a 9-12V, 2A battery pack but was changed to be
powered 3.7V, 1.2A lithium batteries which have a smaller form factor more suitable for wearable devices.

4.1.2 Sensor/actuator

For the prototype we have developed our own sensor/actuator, based on a shaftless vibration motor(52), commonly found in mobile phones. This actuator has a small form factor of only 10mm in diameter and can be powered at low voltages and produces 1200rpm.

The reason for developing our own sensor was to maximize the use of the seventeen programmable pins of the Blend micro. In essence of keeping the hardware at a minimum we wanted to be able to both read information form the interactive parts of the system and simultaneously display feedback in the same area. From past experience researching haptics[36] we have found that visual presence of the vibrating motors acts as interactive cues for users. As the vibrating motors are cased in metal, we could use the actual casing as an interactive surface by implementing capacitive sensing. Capacitive sensing is a technology that implements capacitive coupling which takes the human body capacitance as input[45].

![Figure 8: The sensor/actuator schematic.](image)

The figure above illustrates the sensors circuit, extended to the case of the vibrator. When the vibrating motor is touched, the signal is grounded, and we can detect this on the microprocessors. The same pin will control the same vibrating motor. This means that we can't control the motor simultaneously as we are reading it as a sensor; however, we are using the clock speed of 8Mhz Atmega processor to our advantage turning off the motor in-between readings. Clocking the readings at high speeds mean that this does not affects the vibration amplitude. To provide feedback to the user, even if the sensor activates we have designed the circuit so that the capacitive sensing
also switches a transistor which will activate the vibrating motor when direct control from the microprocessor is not possible.

### 4.1.3 Hardware proxy

To be able to connect the system to the Internet, for wirelessly communication with the database we choose to use an Android phone as the hardware and software proxy. One of the priorities for the hardware was to keep it as small as possible so the user would not find the technology intrusive and minimize the effect of the technology on the interaction during the user test. During the design and development of the system, we could not find a suitable Wi-Fi module that would fit our wearable needs. A second reason for implementing a hardware proxy in the form of an Android phone was that this bestowed us more flexible options in terms location since phones can connect to the Internet over GPRS. Other appended benefits of using Android phones was that we could utilize the screen for debugging the system and monitors the dataflow in real time during the tests.

### 4.2 Software

The software of the prototype consists of three parts, the program operating the Spider actuators and sensor sensing, the Android application to send and receive information from and to the Spider and the online database.

#### 4.2.1 Online database

Firebase[46] is an online service, which provides online storage of data and data transfer in real time which works cross platform. Firebase enables an event based architecture and connected devices can be automatically synced once data changes. Firebase is a Nosql[47] database and offers synchronization without delay but network latencies up to 100ms should be expected.

The reason for using Firebase was to restrict the development of the Android application to front end code and that Firebase offers the low latency synchronization to test the intended interactions through the system. Firebase is also open source, which was also important in terms of reproducibility of our work. The client libraries provided also enables integration with IOS, JavaScript, Java, Objective-c and Node.js, which opens for future developments based on the results in our research.

#### 4.2.2 Spider firmware

The Blend micro development board is compatible with the Arduino programing language[48], which is a combination of C and C++. The firmware operates the actuators and human interactions...
with the sensors. The program is continuously reading each of the seventeen sensors and once
finished; the information passes to the Android application through the Bluetooth connection. If
information is available from the Android application this will be received and processed. The
information passed to the Spider is simple to activate or deactivate each actuator. This information
generates in a mirror system, which is a duplicate of the Spider. If one of the sensors is touched this
information passes to the second Spider, which will activate the actuator in the same place. We
transfer the data raw since the Android application handles the packaging of data.

4.2.3 Android application

We based the Android application on an example Bluetooth chat application supplied with the
Blend micro development board and basically acts as a proxy for the Spider boards. Once received
the data establishes a connection to a Firebase server and passes the data. The application listens to
a second channel on the Firebase server whereto the mirror Spider jacket connects and if an event
registers on this channel, the data passes back to the first Spider when received. The test versions
of the application display the data flow in real-time inside the interface of the android application
and implement a text view to manually send debug messages.
5 Evaluation of findings

We evaluated our research in three different steps. First, we developed the hardware and tested according to the functional requirements based on the research questions. Secondly, the interface has been stress tested to assure the connection between all the components and to evaluate the response time of the system. In accordance with the action research methodology[1] the goal of the hardware and interface testing has been the evaluation of practical outcomes. Both the hardware and interface testing have been a part of the prototyping stage conducted through an iterative process where findings has led to changes to the design during the development.

Last the prototype has been tested with users in a controlled environment by implementing task-oriented tests with the users. This is where we have relied on the user-centred design approach in order to investigate the needs of the user[32].

5.1 Hardware testing

We developed the hardware and tested it through an iterative prototyping process[1]. The sensor/actuators where developed through a trail and error process based on previous experience with developing sensors. We gradually develop the sensors and the firmware using a standard Arduino board[48] to test the functionality of the sensor/actuator. Once we achieved a successful version of the sensor/actuator they where duplicated to the desired amount and the firmware was revised to test if the appended amount would have any effect on the response time.

Since the user feedback is a hard wired connection that turn on the vibrator without the use of the micro controller there where no perceived delay in feedback. Moving on, new test where made by sending information from a computer serial terminal to test the functionality and response time of the hardware. While communicating at a speed of 9600 baud there where no perceivable delays in the activation of the actuators. The hardware was also tested by powering the system on batteries. Powering the system with batteries showed no distinguishable demise in output effect but while testing the connection link revealed and issue with the power source.

The initial test of the Bluetooth connective showed promising results. Once paired with another device the connection would manually remain until broken. None of the test showed any signs of interference in the connection. The Red bear company which manufactures the Blend Micro has developed an open source application supplied with their SDK[49], which we used to test the transfer of information and the wireless control of the sensors/and actuators. The applications come with its own firmware which we deployed on the Blend Micro offers basic control and read out options on all the pins on the Blend Micro board from the applications user interface. Again, none
of the test showed any notable delay in response time and the connection between devices remained secure. The hardware testing did not include response time readings beyond the human readable ones at this stage since we deliberated this was unnecessary because of the lacking connection to the cloud database, which would affect the final response time.

5.2 Interface testing

As mentioned the firmware developed for the Spider was tested in iterations through the development of the prototype hardware. Once the firmware could successfully pass data to the Android application, we implemented the connection to the Firebase database. We verified the connection to the systems early on. We can access the Firebase database through a graphical debugger in any web browser which displays the different data channels and where the dataflow is visualized whenever new data is received. From the Firebase web interface, it is also possible to manually append data to verify the sending of information to the spider. The Android application was simply tested using the debugger in Android studio. The communication between the components was also verified by the haptic output on each Spider.

The test showed that packages of data could pass up to the database with a response time under 100ms without any package loss. However, at high speed updates from the Spider the Android application struggled with receiving data from the servers since it seems that the allocation of processing power was passing information before receiving. We implemented a delay to contain a steady refresh rate on both sending and receiving and not overflow the Android application on the Spider side where the data package would only update every 100ms.

5.3 User testing

The user test where conducted in multiple settings with six participants in the ages from 25-38. Two of the participants where female and four of them male. The participants where chosen resulting from their availability to partake in the test and if they physically would fit the jacket. The reason for not structuring the selection of participants was that the relevance of doing so was ambiguous. At this stage, we wanted to test the natural responses to the technology by users not familiar with this type of technology. The reason for only performing six tests where owed to the time each test would take and that we thought that this would give us the same indication as a larger set of user tests. At this stage we where not looking for quantifiable result rather qualitative indications to areas of interest that can be used to frame design principles, that could act as the basis for a quantifiable study.
During the test, both the user and the person conducting the test were wearing a spider jacket. The test where conducted both faces to face during the introduction to the jacket and afterwards the user faced the opposite direction from the person conducting the test as illustrated in figure 9.

![Figure 9: Showing the location of the user and interviewer during the test.](image)

After the introduction, the user could not see the person conducting the test but the person conducting the test could see the user's back and arm movements. Each test took approximately 20-40 min to conduct. We first introduced the user to the system and how to interact with the sensors. Then, the users were asked to try the system in any manner they preferred to get familiar with the system. When the user indicated that they were ready the actual test started.

![Figure 10 The Spider on the back of the jacket.](image)
The first part of the test focused on recognizing feedback on the different sensor locations on the upper body. The entire tests where done in a systematic way first activating the sensor one by one after one and other. The person preforming the test would start by activating the sensor on the left arm, and then the sensor located nearest the previous sensor. Each time the person conducting the test activated a sensor, the test subject was asked to responded to feedback by touching the same sensor in their jacket. Next the person conducting the test would go through all the sensors, activating them in a random order where we asked for the test subject to respond to each feedback by touching the sensor.

In the second part, haptic icon recognition was tested where the person conducting the test would provide an icon as multiple vibration to the test subject and where we would ask for the test subject to repeat the icon provided on the same location. Haptic icons where tested on all sensor locations in a random directive. The person conducting the test chose the amount of vibrations in each icon.

In the third and, final step of the user test multiple feedback recognition was tested where multiple sensor where activated and where the test subjects asked to how many feedbacks point they could distinguish. One to five sensors where activated throughout the upper body in no particular directive.
6 Results and findings

In our study none of the users showed any signs of problems understanding the system and how to interact with it although they had never seen a haptic jacket before. All the test subjects needed only a few seconds to get familiar with the system until the user was ready to proceed with the test. In the first part of the test, the users had no problem following the feedback pattern in the sequential and random directive. The users managed to identify most of the sensors without errors with the exception for a few. However, in these cases we suspect that failed feedback was resulting from connectivity problems and not the test person’s ability to perceive the feedback.

In the second part of the test, some of the users struggled with identifying the haptic icons once the person conducting the test moved beyond one vibration at the time. The users managed to identify half of the 2-vibrations icons but when it came to identify two 3-vibration icons all the users struggle at some point even if the affirmative response rate were still high. When it came to the 4-vibration icon all the users had trouble identifying the icons. They had trouble with icons delivered too fast which made it hard to distinguish the vibrations. But, also if the icons where too slow since the user felt it was hard to tell when one icon started and where another one ended.

In the third part of the test the users had no problem distinguishing multiple feedbacks if they did not include sensors next to one and other. For example, distinguishing feedback on both arms and one of the arms and feedback on the body was not a problem. When feedback was presented on two sensors located next to one and other, the user had a hard time distinguishing them as separated vibrations. Most of the user struggled to distinguish multiple vibrations in close relation as separated vibrations with certainty.

6.1 Interview finding

The free-form interviews were based around the nine heuristic principles presented by Molich and Nielsen[39]. The where no specific questions prepared for any of the interviews, instead the title of the principles where asked as questions and explained if needed (see Appendix 1). The following list are the general impressions form the interviews according to the nine principals.

P1, Simple and natural dialogue: While discussing this topic with the user’s, none of them could argue for or averse to the system creating a naturals dialogue. All the participants agreed that the basic functionality was simple enough to understand in order to interact with the system. However, some pointed out that ease of use depended on the intended functionality. If we connected more than one function to the individual sensor, the user might perceive the system as more complex.
P2, Speak the user’s language: None of the user claimed to be familiar with haptic technology but still seemed to perceive the interaction as natural. One of the user explained it as although they have not used haptic technology in a wearable context before, using your body and hands to interact felt normal in this situation.

P3, Minimize user memory load: Again all the users agreed that the it was very easy to ascertain the basic interaction possible through the use of the system. Only one of the users said that they needed visual guidance to understand how to interact with the system. One of the users pointed out that the visual aesthetics of the jacket were confusing first but once they had the jacket on, it was very easy to understand how to interact with the system once they could “feel the feedback”. Two of the users focused their conversation of the later parts of the test where we tried multiple-vibration haptic-icons. They argued that there was a limit to how many levels of vibrations that could be remembered in one haptic interaction immediately, but they had a hard time specifying an amount of vibrations the could be remembered.

P4, Be consistent: When discussing the principle of consistency most of the users adverted to the interaction as being consistent even if the icons and they’re bodily positions would change. But again most of the users also indicated that this would depend on the context of use and functionality. Since the system had no clear use, it was hard for some of the users to imagine a situation where the interaction with the system would perceived as in consistent. However, all indicated that they thought that this could become a problem depending on the context.

P5, Provide feedback: All users agree that the feedback given by the system was sufficient to understand that the system registered their input.

P6, Provide clearly marked exits: Discussing this principal needed some explanation to the users where we discussed it in terms of screen based applications and where we made the analogy to the close button in the right or left coroner on desktop based applications. Using this parable lead most users to conclude that there is probably a one/off switch in the back of the jacket. One of the users stated that even if we did not use it as an exit, we could use the zipper on the jacket to turn the system on and off.

P7, Provide shortcuts: While discussing shortcuts most of the users did not perceive the system as a self-contained system where vibrations are the sole means for interacting. Most of the users discussed the system as a “companion” system where the jacket can be used for or in combination with other applications. One of the user said that it would be great as a feedback system for games with the two-way communication used for something in the game.

P8, Good error messages: None of the users thought the system had good error messages and one of the users even said that they did not think they could use the system in the wrong way. When
discussing this topic none of the user could imagine how the sensors would provide for error messages since these would be very hard to distinguish from other haptic-icons. When asked to suggest a means for outputting error messages all the users answered that sound might be a good option.

P9, Prevent errors: All the users answered that once they were told that the vibrations where the active interactive point in the system, none of them had any problems with interacting with the system. Some of the users brought up feedback as a possible area of creating problems. One of the users explained that when they were not contemplating feedback, the haptic icons including multiple interaction where hard to remember.

Beside the nine heuristic principles, we also discussed which body part was more susceptible to the haptic feedback and which locations the users preferred for inputting interaction. All the users answer the upper arms except one user that preferred the upper torso. The only reasons bestowed upon the preferred locations where that it was easier to feel the vibrations on these areas. Two of the users claimed that this could also depend on the jacket itself since the size was not an optimal fit for all and that it was tighter in the areas where the user would feel vibrations better.

To evaluate the test, we matched each user test averse to the heuristic principles developed Molich and Nielsen[40]. Then each of the principles where evaluated through the observation made during the tests and through the interview conducted after the test. Depending on these observations and interviews with the users, the system was awarded a number on a scale from one to ten as shown on the Y-axis in the diagram in figure 11. A low number refers to a poor result in regards to the heuristic principal and a higher number would indicate a good result. None of the principles where specifically stated as a question to the users during the test or during the interview. However, during both the test and interview the principles where use as a “base of topic” which the person conducting the test would use to engage the test person in conversation around the principal.
Figure 11: Showing the correlation between the answers from the users.

The X-axis in figure 11 represents the nine heuristic principals. Each principal block shows all the answer from each test person. The result show consistency throughout the user-test to the principles of usability with two exceptions. User four show a significantly lower perceived relation to the principal of “user’s language” (P2). User five also diverged from the group on the principal of providing short cuts (P7).
7 Discussion

In order to answer the question what possible interactions telehaptic technology provide in a wearable context we decided to develop a prototype that addresses the four layers of IoT objects according to Swan[28]. The reason for using these four layers as a base for the design of the prototype was that in order for the research question to hold any value beyond this thesis we concluded that technology has to be developed with its future context in mind. We have since long moved beyond desktop computing[6] through an internet of things into an internet of people. Without a physical connection to the human body, haptic technology has no purpose and to extend its functionality beyond the physical presence, it has to connect to the digital reality of other objects.

Data acquisition and information creation[28] proved very little problems since this has been the basis and purpose for extensive research done within computer science. We relied on proven technologies that where verified during our interface testing. However, this is only affirmative in the creation of the technology. As long as the development and research only concerns technological realization, the constrains are self-contained. Most technological shortcomings can be over come by the implementation of additional components or a redesign of existing technology and code.

When addressing the layers of meaning making and action taking (9) a new form of complexity arose. When addressing, the meaning making of digital information Kortuem et al (10) points to the dual nature which technical devices are forced to address. To create affective interactions with a digital object, these objects have to become aware of their surroundings to design sufficient abstractions of digital information. Some argue that haptics holds certain benefits of abstracting information (6)(7). Assuming we have some type of pre-understanding of tactile feedback since it concerns our cognition of the real world, we can utilize this to help alleviate the accord of digital information. But, even if we agree to this it has been pointed out that we lack a common language for communicating through haptic stimuli (30). As Maclean (39) suggest we aimed to base the abstraction of information on the concept of rhythm in order to enable some type of meaning making. The Android application would not let us refresh the data flow faster than every 100ms, which clearly would affect the design of possible haptic icons based on rhythm. This presented an interesting question before the user tests, if this was a dilemma or not and if so, is it a technological dilemma or a user problem? From a technological standpoint, one can argue that it was a problem since the system would not be able to receive data at higher refresh rates. Nonetheless, one can argue that this is not a technological problem since the system is working within its limitation. The
same is affirmative from a user perspective. If the delay is perceived as interference in the interaction this could be perceived as a dilemma but not if the delay were not perceived at all.

There was no need to confirm the delay issue in the hardware and interface tests since this delay was hard coded into the system. The interesting part was that the hard coded delay or any delays because of connectivity issues were not perceived as delays in feedback by the users during the tests. One obvious reason was that the users were faced at a distance from the person conducting the test. However, when asked, if they perceived any delays at all the users responded that they did not. Some users explained that they expected a slight delay since the different jackets connected over the Internet. Once the users received messages through the system most of them showed signs of trying to create some type of meaning of the information visualized and how to perform a proper response. One participant took the test one step further and started developing their own responses instead of just responding with the same haptic icon as asked. The reason for this was that they thought that it felt wrong to respond with the same interaction as the same feedback bestowed upon them. The user explained it, as they wanted to participate in a conversation instead of just respond to stimuli. This leads us to believe that the users participating in the test had some type of accord of IoT infrastructure analogous to the functional layers as presented by Swan (9). Though most of the users had never interacted with a wearable system, the observations and their response also seem to incline that there is some merit to the research presented [22] [35] [21] which claims that haptic technology holds certain benefits of creating embodied experience.

Our findings also support the claims put forward by Gemperle et al [17]. The bodily position should be considered when developing wearable technology as some areas seem more susceptible to haptic stimuli. Our study showed that the preferred location for haptic interactions on the upper body was on the top side of both arms. This came as a surprise to us as our assumption was that the upper torso would be more sensitive and therefore the preferred location for interaction. This could partly be because of the construction of the actual jacket holding the system, which might have been tighter around the arms. But, it can also be because of the upper arms where perceived as less intrusive space for interacting with a digital system although none of the users made any claims towards the upper torso as an intrusive area of the body. However, we can’t make any claims to intrusive spaces of the body beyond that there seems to be some merit to a difference in location. However, the actual size of the jackets affected this results since the jackets had a tighter and looser fit depending on the user’s body size. To make any future assumptions to the claims on intrusiveness depending on location, this would require future investigations with the jackets available in more than two sizes.
The use of haptic icons also showed promising results during our test and the users perceived them as a natural way of distinguishing between feedback and interactions as suggested by MacLean [26]. The results also show an elucidate limit to how many interactions we can place in one location although this limit seemed to vary among the users. Though MacLean’s suggestions to base the design of haptic icons on rhythm seems reasonable, we still question the value of this insight since MacLean never presents an alternative to this method. The technology affords only two states of action, either on or off. So naturally the only way of distinguishing between them is to append duration. The next natural step would be appending variation to the duration to create multiple actions. Still, one aspect was overlooked during the development of the system presented in this thesis which is that the technology also affords intensity. To conclude that we should base haptics on rhythm, further investigation needs to be made into affordance of intensity in haptic stimuli.

Our research struggled with some limitations through the process. The lack of preexisting data and studies made it hard to make predictions on the outcome which in turn affected the focus of the study. The main concern has also been that the data collected has mainly been self-reported. Self-reported data can rarely independently be verified and the relationship to some of the users in the test could have affected the interpretation of the interviews and observations. The project also struggled with the practical issues that the prototype was only developed in two sizes due to cost and time issues. We are sure that for the purpose of this thesis, size mattered but we are unsure to what extent because we had no time test these suspicions during the duration of this thesis.

The findings put forward in this thesis are eminently subjective, and we argue that this is with good reason. When investigating methods for evaluation our contemplated study we had a hard time finding methods for evaluating haptic interaction that moved beyond measuring mechanical aspects of haptic technology. Turning to other methods for evaluating usability showed promise, but most of the methods found were developed for screen based interaction either as input or output sources. What we are presenting in this paper is multi modal non-screen based system and therefore none of these method’s where applicable. The dilemma with evaluating the prototype in terms of usability it that this is done by contrasting good aspect to bad ones. In this study, we investigate the affordance of the technology used and as Vayas et al [33] has pointed out, affordance is an interpretative relationship between the technology and the user. It’s through the use of the technology, the user forms their accord of the technology and environmental; cultural, and social aspects affect this accord. The goal of this study was not to pass judgment on the accord framed by the user. Instead, we wanted to investigate if their understanding of the technology can be used to frame future interactions with haptic technology before one needs to make assumptions to design.
interactions that we can evaluate. We wanted to present haptic technology as naturally as possible to observe and investigate the user’s natural responses to the technology.

In relation to the method developed by Nielsen we used the nine heuristic principles he developed with Molich [45]. These principles were developed to evaluate the usability of interfaces but we could easily adapt them to the concept of affordance. When the test results where matched to one and other they seem to show consistency with the exception on two of the principles by one of the users. Deliberating the content of the results this also show signs of consistency among the observations and interviews made. Again, we can question the validity of these results since they were amassed through a subjective analysis of the interviews and observations. In turn one can also argue that concept of validity is not applicable since we are not dealing with quantifiable data which aims to measure a definitive result. Either way it seems clear that methods for evaluating novel interfaces are generally underdeveloped and even more so when it comes to non-screen based interaction through haptic stimuli. For this study, we argue that heuristic method of evaluation still provides a good account for determining the basic affordance of a novel interface technology which makes for a good starting point in order to frame design principals for future investigation in relation to haptic interaction and feedback.
8 Conclusions and future work

To answer what affordances can be perceived through interacting with telehaptic technology in a wearable context we developed a wearable system named the Spider jacket, which incorporates sixteen interactive vibration sensors. To evaluate the affordance of wearable haptic devices, we submitted the Spider jacket to user testing in an informal setting. We submitted the data amassed through interviews and observation in a heuristic evaluation process where data was matched with nine heuristic principles for usability. From the results, we conclude the following perceived affordances which can be used to improve the design of wearable non-screen base interfaces based on haptics. Haptic interaction can afford for simple and natural dialogue with a system as well as clear feedback. The test answers also indicate that haptic technology could afford for faster learning curves when it comes to introducing users to new interface of feedback and interaction. Haptic interactions can also afford consistency in interactivity in parts, but the consistency depends on the design of haptic icons where it seems that haptic icons have some cognitive limitations. Our study also showed indications to limitations regarding haptic technology affording for clear exits while interacting with a system, a lack of providing short cuts through the system and did not provide for good error messages if haptic stimuli are the only means for interactivity. Haptics did not either show any elucidate affordance to preventing errors while interacting with the system.

We also conclude that there is some merit to the claims made to haptic icons being developed further. However, we argue that in order validate the use of rhythm; this contrasted to the development of haptic icons based on intensity which might hold certain other affordances. The results presented in our study where eminently qualitative resulting from the limited methods for evaluating novel non-screen based interfaces based on haptic stimuli. We still argue that the findings presented are valid starting point for developing haptic interface design, but we suggest that future development would include investigating a more standardized method for evaluating novel non-screen based interactions. Future work also includes a more systematic evaluation of the interface and hardware as well as further investigations into the use of intensity in relation to haptic output.

In conclusion we have found some merits to the affordance of haptic technology in a wearable context, but our investigation also showed potential limitations. The findings are not presented as design principles on their own but even with the limited tests done in this thesis we still think they serve as a good starting point for the development of haptic interfaces.
References


Appendix 1

Topics used for framing questions during the semi-structured interview part of the user test.

- Simple and natural dialogue: How do you perceive the interaction with the system. Did the feedback make sense in relation to your interaction? Was it easy to understand what to do?
- Speak the user’s language: Does the feedback relate to what you were doing? Could you figure out what the feedback meant or did you need additional information? Is there any difference/similarities to how you normally communicate and the haptic interaction in the jacket?
- Minimize user memory loads: Did you feel instruction for the system was needed? Could you remember all the possible interactions? How many levels of “icons” could you remember?
- Be consistent: Did you feel that the different interactions follow the same concept or did they feel different? Did you think the interactions followed any rules? Was the interaction and feedback the same all the time?
- Provide feedback: Did the system provide you with feedback? Was the feedback enough? Was feedback given at the “right” time?
- Provide clearly marked exits: Was it easy to “exit” the system? If you think of the X in the corner of application that closes the application, can you think of something similar in the jacket?
- Provide shortcuts: Where there any ways to skip part of the interaction and achieve the same results? Can you think of any ways to improve the speed of the interaction with the jacket?
- Good error messages: Did the jacket provide you with information when something went wrong? Was this information enough to understand that there was a problem? Can you think of other ways of presenting information?
- Prevent errors: Can you think of ways to prevent things from going wrong while using the system?