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Smart Jewelry: Appearance-changing Necklaces and Emotions

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Abstract

Changing shape and color of a necklace is a rather novel approach in the fields of Human Computer Interaction as recent smart jewelries tend to mimic the functionality of a smartphone. Rather than finding another feature and testing it in interactions, this thesis takes a step back and focuses on the core idea of traditional jewelry: Appearance and nonverbal communication. Thus, a necklace with the capability to change its appearance is built. Different methods, categorized in shape and color change, are discussed.
Regarding the second idea of traditional jewelry, emotions play an important role in nonverbal communication. Therefore, in a user study, emotions of the person opposite to the wearer are measured using the necklace prototype. With a comprehensive knowledge about the emotional effects of the necklace, possible use-case scenarios are proposed based on the results of the user study.

Überblick

Form- und Farbveränderung von Halsketten ist eine wenig verbreitete Herangehensweise im Bereich der Mensch-Computer-Interaktion, da aktuelle smarte Schmuckstücke die Funktionalitäten von Smartphones nachzuahmen versuchen. Statt eine neue Funktionalität zu finden und sie in Interaktionen auszuprobieren, geht diese Arbeit einen Schritt zurück und legt den Fokus auf die fundamentale Idee des Schmucks: Aussehen und nonverbale Kommunikation. Daher wird eine Halskette gebaut, die ihr Aussehen verändern kann. Verschiedene Methoden, kategorisiert in Form- und Farbveränderung, werden behandelt.
Bezüglich des zweiten Teils in der fundamentalen Idee des traditionellen Schmucks spielt die Emotion eine wichtige Rolle in der nonverbalen Kommunikation. Infolgedessen werden die Emotionen der Person gegenüber des Trägers in einer Studie gemessen. Mit ausgiebigem Wissen über die emotionalen Auswirkungen einer solchen Halskette werden mögliche Anwendungsszenarien basierend auf den Studienergebnissen vorgeschlagen.

Acknowledgements

First of all, I would like to thank all people who spent their time in my user study that investigated the emotional effects of the appearance changing necklace prototype. I appreciate your constructive feedback and the time you spent.

Secondly, I want to thank all the people at i10 who helped me during my thesis to fulfill my work.

Thirdly, I thank my supervisor Anke Brocker for her help and feedback to improve my thesis.

Conventions

Throughout this thesis we use the following conventions.

Emphasized words and variables are *highlighted*.

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

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

Definition:
Excursus

The whole thesis is written in American English.

Unidentified third persons are described in female form.

All numbers are rounded up to two or four decimal points.

Chapter 1

Introduction

1.1 Smart Jewelry

Nowadays, many smart jewelries exist that can be bought, such as smartwatches or fitness trackers in form of a wrist band. They come with lots of functionalities, complex electronic circuits and maybe in an exaggerated size so that all features can fit. Sometimes, the *smart* part of *smart jewelry* gets too much attention so that the classification of the device as *jewelry* falls off. A reasonable line between the *smart* aspect and the *jewelry* aspect has to be drawn.

Smart jewelries shall still be jewelries.

1.2 Traditional Jewelry

One of the first jewelry we have found until now dates back to over 130.000 years, crafted by the Neanderthals. AncientFacts.net [2015]. It seems to be human nature to carry something precious, to wear a symbol, and to express ourselves to people surrounding us. It is a way of nonverbal communication as information is transmitted. It implicitly involves evoking certain emotions not only of the wearer, but also of others, as part of all the other non-verbally transmitted information. We will refer to this as the *traditional aspect of jewelry*.

The aspect of traditional jewelry must not be neglected.

Appearances and indirect communication have been and will continue to take an important role in jewelry. Otherwise, a designed gadget cannot be considered as such. Yet, research so far focused mostly on engineering rather than on user experiences about design; Väänänen-Vainio-Mattila et al. [2015] say there is a need for detailed understanding of user experiences when designing ubiquitous computing systems.

1.3 Goal

1.3.1 Making Jewelries 'Smart'

Due to lack of a precise definition, we will define the *smart* aspect of smart jewelry:

Definition: *The word 'Smart'*

THE WORD 'SMART':
A jewelry can be considered as *smart* if it has more features besides its traditional aspect. A feature can be anything; it can range from reading sensor data and outputting it on a touch display to a certain static shape that can be scanned like a QR code.

A change in appearance is also a way of nonverbal communication.

In this thesis, we will take the traditional aspect at its core and focus on changing the appearance itself. A jewelry shall perform a visual change in its shape and color. Since the change in appearance is technically the same as switching it out for another jewelry, self-expression changes and therefore, the way people perceive us will be different. Closely tied to this are the emotions. Depending on the jewelry type, the wearer cannot see it throughout the day. Therefore, instead of asking the wearer, following questions will arise for people surrounding the wearer:

- Are there any emotional differences when different traditional jewelries are being worn?
- Does it matter if a jewelry can change its appearance on its own?

- What kind of emotions can be evoked with an appearance changing jewelry compared to a traditional jewelry?

In the fields of HCI, proceeding questions are:

- What can we do if there are emotional differences when changing appearances?
- What are the use-case scenarios?
- Are there any specific interaction spaces an appearance changing jewelry can shine at?

Often times, smart jewelry is developed for a certain scenario without having investigated the effects in full detail beforehand (which applies to most of the smart jewelries presented in chapter 2 “Related Work”). Therefore, the goal of this thesis is to find out the emotional effects on people surrounding the wearer.

1.3.2 Necklaces

Out of all jewelries, we will focus on necklaces from now on. There are four main reasons for this selection:
First of all, necklaces are very visual. When we speak to and look at each other, the necklace is automatically in the field of vision . This ensures that the independent variables can be controlled accurately in the user study, chapter 4 “User Study”.
Second, the necklace comparatively does please others instead of the wearer. When not standing in front of a mirror, the wearer cannot see at her necklace. Thus, she forgets about it when wearing it for a long period of time. In contrast, bracelets , for example, allow the wearer to look at them anytime.
Third, there is already a lot of research done with bracelets and only little with necklaces.
Last, as there is much more space at the neck, a necklace is easier to build than an earpiece or a bracelet.

1.4 Outline of the Thesis

Following this introductory chapter, the second chapter, 2 "Related Work", presents related works concerning smart necklaces and appearance changing jewelries. The third chapter of this thesis, 3.1 "Design", describes the necklace design and elaborates on the main issues that had to be dealt with during the building process. The seven different states the necklace can take are also be defined here. Emotional effects to each of the defined states are evaluated in a user study in chapter 4 "User Study" preceded by a pilot study. Also, possible use-case scenarios are discussed here. Finally, chapter 5 "Summary and Future Work" sums up the main findings and contribution of this thesis and presents ideas for future work.

Chapter 2

Related Work

2.1 Smart Necklaces

There is only a handful of research in which smart necklaces have been designed and prototyped. Each of the following papers take different approaches for the application of necklaces.

2.1.1 Augmenting Traditional Wearable Self-Expression Displays

In 'Smart Jewelry: Augmenting Traditional Wearable Self-Expression Displays', Rantala et al. [2018] first conducted focus group sessions and an online survey in order to find out the expectations of users towards smart jewelry with Augmented Reality capabilities. Their findings through the focus groups revealed that necklaces are perceived far more personal for the wearer than rings or bracelets . Also, smart jewelry should not differ from *non-smart* jewelry in its appearance.

Necklaces are very personal for the wearer.

The online survey confirmed the rather reserved attitude of users towards this new technology. There are privacy concerns, but in emergencies, people like to have personal data shared by a necklace.

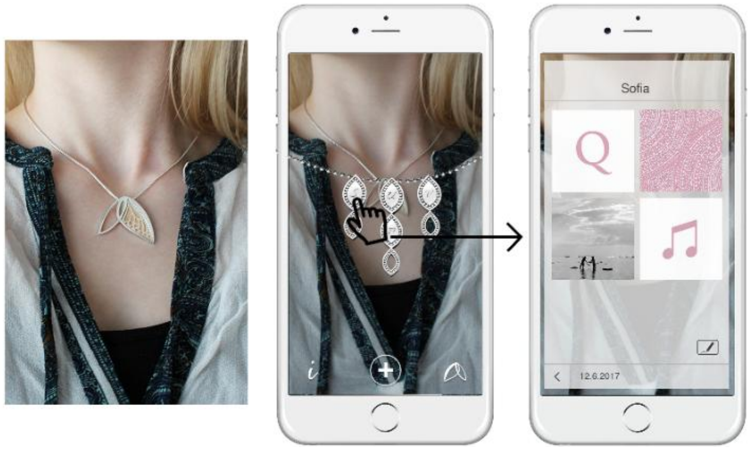


Figure 2.1: Left: Integrated pattern in the necklace. Right: Associated content to the pattern. Rantala et al. [2018].

With these results, Rantala et al. [2018] present a novel approach by combining jewelry and Augmented Reality. The necklace itself is untouched, meaning that there is no built-in electronic circuit. Only the core part is changed in such a way that it can be identified with a smartphone camera. Their necklace-linked Augmented Reality application allows friends of wearers to attach digital content to the necklace, thus, creating a friendship book.
All in all, the simplicity of this concept suggests that there are many simple ways to make a necklace *smart*.

2.1.2 Digital Amulet

The *Digital Amulet* is a multi-media necklace.

The paper 'Digital Amulet: Smart Necklace' by Sorensen and Thummanapalli [2017] showcases a necklace with sensors, speakers and three integrated displays. The device is capable of playing generated abstract animations together with some music. As it is wirelessly connected to an Android Mobile Phone, wearers can also choose to change the mode. Sensors on the necklace can be used to read some biometric and environmental data to have animations and music in response to these data.

This project sets its focus on aesthetics in the fields of wear-

Figure 2.2: The Digital Amulet with three integrated displays. Sorensen and Thummanapalli [2017].

able technology. The authors argue that in contemporary design, bio-mimicry and interactive multimedia systems can provide new interpretations of traditional concepts regarding the role of jewelry, costume, and clothing.

2.1.3 Essence

The 'Essence: Olfactory Interfaces for Unconscious Influence of Mood and Cognitive Performance' is a paper by Amores and Maes [2017]. Here, a new form of feedback is being tested by providing olfactory cues. This necklace is able to release scent with varying intensity and frequency, based on biometric or contextual data. As one possible application, the authors suggest that this necklace could be used in Social Interactions as chemical signals communicate human emotions.

The *Essence* makes use of human sense of smell.

Figure 2.3: Left: Frontal view of the Essence when being worn. Right: Side view. Amores and Maes [2017].

The authors conducted usability tests for long periods of time. Their conclusion is that *Essence* is a robust and usable prototype which can be worn for longer duration and which is comfortable at the same time. We can note that, in order to influence the emotions of people surrounding us, olfactory cues are another valid approach.

2.2 Appearance-Changing Wearables

Many different methods exist to change the appearance of wearable devices. In the following, we will take a look at various jewelries, clothes and other devices people could wear alongside the necklace.

2.2.1 Color-Changing Bracelets

Ju and Spasojevic [2015] created multiple bracelets in the paper 'Smart Jewelry: The Future of Mobile User Interfaces'. These bracelets have the feature to change their color

Figure 2.4: Left: Multiple bracelets connected via Bluetooth. Right: Changing color in a performance. Ju and Spasojevic [2015].

based on the movement data provided by accelerometers in each of the bracelet . Changing color is done by using LEDs. The accelerometer data is sent to a computer through a Bluetooth connection which enables music creation.

Ju and Spasojevic [2015] use LEDs and accelerometers in bracelets.

This Wearable Sensor Network is mainly intended to be used for performances such as dances or in theaters, but the authors also suggest using the bracelets as gestural controllers with visual feedback.

Ju and Spasojevic [2015] underline that a stronger understanding of the traditional aspects of smart jewelry has to be built in order to utilize its expressive and communicative abilities.

The concept of changing the appearance of a jewelry with colors has similarities with the 2.1.2 "Digital Amulet". However, the aspect of a Wearable Sensor Network is unique and will be addressed in section 5.2 "Future Work"

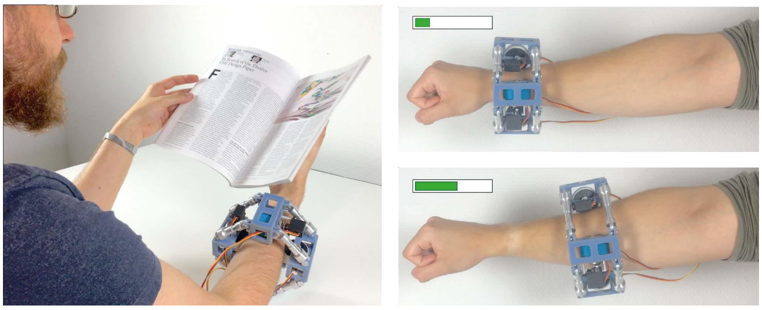


Figure 2.5: Left: Movelet being worn. Right: Movelet indicating some progress by climbing the arm. Dobbelstein et al. [2018].

2.2.2 Movelet

Movelet focuses on haptic feedback.

The paper 'Movelet: a self-actuated movable bracelet for positional haptic feedback on the user's forearm' by Dobbelstein et al. [2018] provides a bracelet which can move along the wearer's forearm on its own. As this paper deals mainly with positional feedback, it investigates how accurate participants can judge the location of the bracelet by tactile perception. Thus, the aspect of smart jewelry is addressed very briefly.

We can record that bracelets can not only be used to change color (see 2.2.1 "Color-Changing Bracelets"), but also to move across the body which in turn changes the wearer's appearance.

2.2.3 Awakened Apparel

The *Awakened Apparel* is a deformable dress.

The 'Awakened apparel: embedded soft actuators for expressive fashion and functional garments' by Perovich et al. [2013] is a wearable dress that can change its shape according to the needs of the wearer. Figure 2.6 shows a sketch of three different states the apparel can transform into which is accomplished by using pneumatic actuators.
This paper further explains how and why a certain origami-pattern design is being used in order to reliably deform

Figure 2.6: Sketch of the Awakened Apparel in different forms. Self-actuation via pneumatics. Perovich et al. [2013].

wearables of this size. Furthermore, the authors name three motivations as examples for state transitions: informational, emotional and functional.

2.2.4 Scarfy

In 'Scarfy: Augmenting Human Fashion Behaviour with Self-Actuated Clothes' by von Radziewsky et al. [2015], shape change of a scarf is performed by using Shape Memory Alloys (SMA). While the focus lies in the input functionality of the scarf, i.e. recognizing how the scarf is currently tied by the wearer, the output functionality presents another way of changing the appearance of wearables.

Scarfy can change its shape.

Figure 2.7: Scarfy. Self-actuating scarf by using SMAs. von Radziewsky et al. [2015].

2.2.5 Rovables

Rovables are miniature robots moving across the body.

The papers 'Rovables: Miniature On-Body Robots as Mobile Wearables' by Dementyev et al. [2016] and 'SkinBot: A Wearable Skin Climbing Robot' by Dementyev et al. [2017] differ in the applied techniques, but share the same idea: Tiny robots moving across the body. Instead of making an existing wearable *smart*, they introduce a new smart wearable. These robots can not only track human motions or move fabric, but they can also carry small displays or jewelry on the surface of cloths belonging to the wearer. Multiple robots can move around simultaneously.

2.2.6 Sparklry

Animating sparkling effects manually.

Oki and Tsukada [2017] introduce a jewel stone supported by LEDs in 'Sparklry: Designing "Sparkle" of Interactive Jewelry'. Instead of simply placing an LED behind a jewel, they investigate how to mimic the *sparkling effect* of jewelries in various ways. Two prototypes are presented covering two application scenarios: Earring-type jewel to be worn, and Showcase-type jewel for exhibitions.

Figure 2.8: Left: Rovable is attached to fabric through magnetic mechanisms. Center-Right: Rovable pulls at a scarf and wraps it round the wearer depending on ambient temperature. Dementyev et al. [2016].

Figure 2.9: Sparklry. Left: ordinal earpiece. Right: LED supported with Sparklry. Oki and Tsukada [2017].

2.2.7 Functionality in Wearable Tech

In 'Functionality in Wearable Tech: Device, as Jewelry, as Body Mediator' by Ju [2016], three jewelry pieces are created. These consist, as the authors state, of cheap robotic children's toys. One of the pieces with rotating and blinking components can be seen in Figure 2.10. It also plays

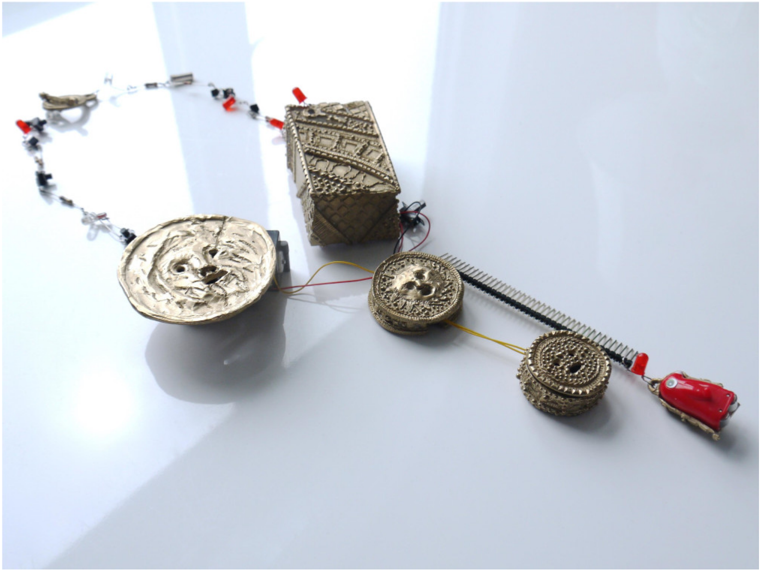


Figure 2.10: A large jewelry piece with rotating (via motor) and flashing (via LED) components. Ju [2016].

some music in a loop.

Smart jewelry can influence social experiences.

An experiment is conducted where a subject wears these jewelries and walks in public; reactions of passers-by are recorded in a video. The authors conclude that such jewelry can dictate the social experience one can have, whether by influencing others or by imbuing oneself with certain emotions.

2.2.8 Snowflakes

Snowflakes allow rapid prototyping through its modular design.

The 'Snowflakes: A Design Speculation for a Modular Prototyping Tool for Rapidly Designing Smart Wearables' by İnsel et al. [2018] proposes a modular design to rapidly prototype smart wearables. The Snowflake system allows one to develop wearable devices with sensors, LEDs and the required electronic circuit while being aesthetically pleasing. Figure 2.11 (left) displays a sketch of components which can be put together.

The authors created a non-working prototype and presented a plan to make a working prototype.

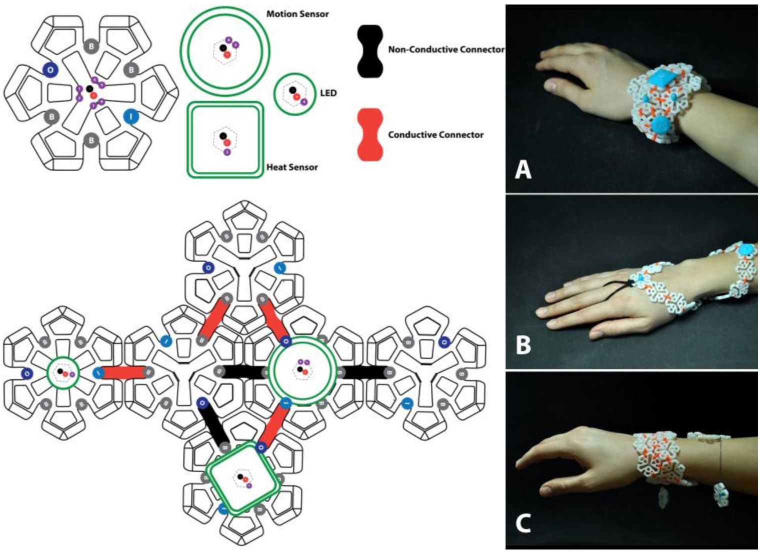


Figure 2.11: Left: Concept of the Snowflake system. Right: Different design alternatives. İnsel et al. [2018].

The Snowflake is related, as a necklace is built in this thesis. In chapter 3.1 “Design”, the concept of modularity has also been used.

2.3 Contribution of the Thesis

In this chapter, recent research topics on smart jewelries have been presented. We have seen many kinds, ranging from necklaces with integrated patterns to be scanned and with olfactory cues to color changing bracelets and shape changing clothes.
A lot of appearance-oriented papers, such as 2.1.1 “Augmenting Traditional Wearable Self-Expression Displays”, 2.1.2 “Digital Amulet” and 2.2.1 “Color-Changing Bracelets”, point out the importance of the traditional aspect of jewelry when developing smart jewelry. Most of them present their work and dive deeper into the construction and methodology. It is important to note that even technically-oriented papers as 2.1.3 “Essence”, 2.2.2 “Movelet” and 2.2.5 “Rovables” do come back to the aspect

of appearance or how their presented jewelry can influence people.

Investigation of true user experience is missing most of the time.

They all present novel ideas in this relatively new and experimental field. However, none of the above projects go into detail with emotional effects and conduct a user study. Out of them, 2.2.7 “Functionality in Wearable Tech” is the only paper heading this direction by capturing reactions of passers-by in a video.

Systematic analysis and evaluation of the emotional effects seems to be what is missing in this chaotic field. New ideas are great and welcome, but fundamental steps have to be taken. This is the intended action of this thesis. It seeks to fill the gap by conducting a user study by using the well-established PrEmo by Desmet [2003], a tool to measure human emotions.

2.4 Overview of Existing Research

paper	presentation of a prototype	user study	investigation of emotional effects
Augmenting Necklace	✓	✓	
Digital Amulet	✓		
Essence	✓	✓	
Color-changing Bracelets	✓		
Movelet	✓	✓	
Awakened Apparel	✓		
Scarfy	✓	✓	
Rovables	✓		
Sparklry	✓		
Wearable Tech	✓		minor
Snowflakes	✓		
This thesis	✓	✓	✓

Table 2.1: Content overview of related works and clarification of this thesis' contribution.

Chapter 3

Necklace Assembly

3.1 Design

Reasons for building a necklace have been explained in the introductory section 1.3.2 "Necklaces". The next step is to decide what kind of appearance change the necklace should be capable of. In the following, appearance change will be categorized into shape and color change. Shape change is the act of deforming the necklace while color change refers to optical differences. To provide a wide range of changing appearance, five methods have been designed in total. Three in shape and two in color change.

Appearance change is categorized into shape and color change.

Two moving parts are shown in 3.1: The rear box, which glides downwards by releasing some string, and the front plate, which is pulled upwards by the orange pneumatic actuators. Initially, the two moving pieces lie together with the central blue piece on top of each other, so that a vertical arrangement of these three square pieces results in tripling the visual surface of the core part. This is possible as the rear box and the front plate can be moved independently from each other.
Inspired by the Metamaterial Mechanisms, a paper by Ion et al. [2016], a metamaterial shape is displayed in figure 3.2. This form can be squeezed and stretched, as it follows the metamaterial structure. It is the third shape change method and it is the same blue piece that was mentioned before.

The three shape changing methods are: Moving front plate, moving rear box and deforming metamaterial component.

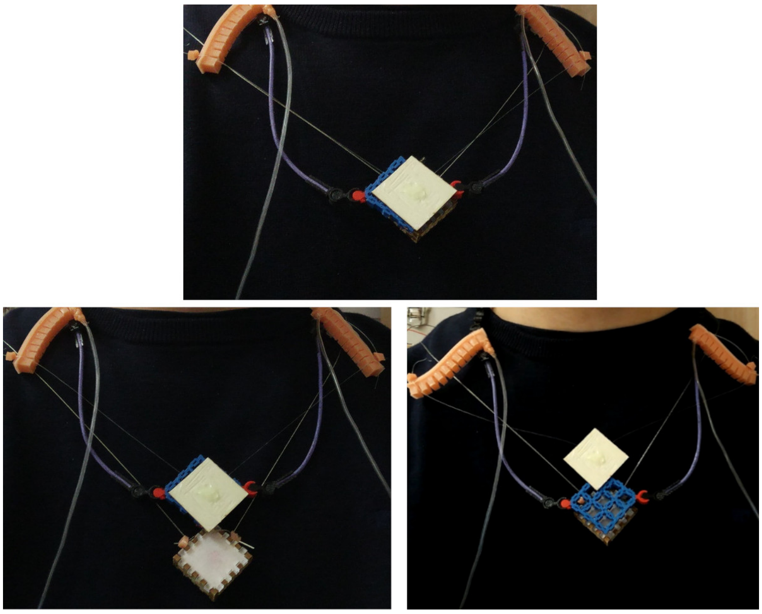


Figure 3.1: Two expanding shape change methods. Top: Initial position. Bottom left: Position of the rear box after gliding downwards through releasing some string. Bottom right: Position of the front plate after pulled upwards by the orange pneumatic actuators.

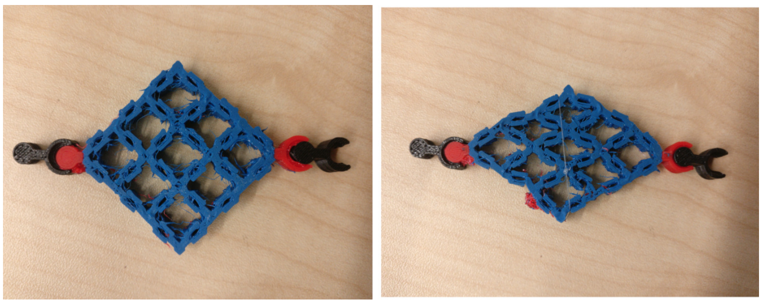


Figure 3.2: Structure inspired by the Metamaterial Mechanisms, Ion et al. [2016]. Left: Initial state. Right: Squeezed vertically and stretched horizontally.

The metamaterial deformation is a rather subtle change, but it can stand out by being the only rhombus in line.

The two methods to change color are installed on the moving squares. One is a red LED and is built into the rear box

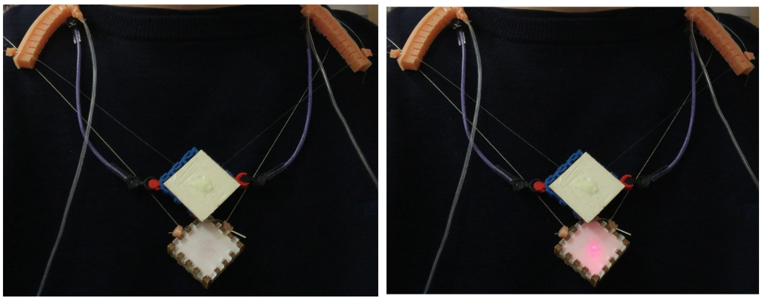


Figure 3.3: Left: Initial state. Right: Red LED glowing, built into the rear box.

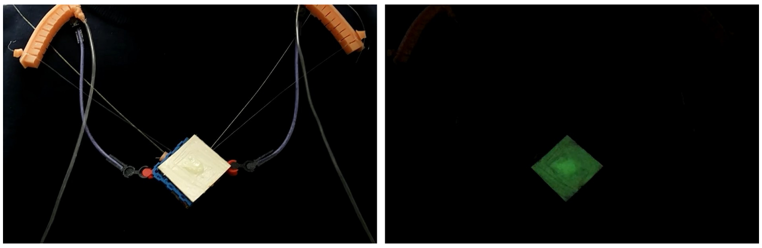


Figure 3.4: Left: Initial state. Right: Neon green phosphorescence material glowing in the dark, built into the front plate.

as presented in figure 3.3. The LED requires its box to be shifted downwards in order to be seen. In contrast to the LED, phosphorescent material glows automatically in the dark. A thin layer of this material is applied on the surface of the front plate in neon green, whose effect can be seen in 3.4. As the front plate is never covered by another part, the glowing effect does not require other parts to move in order to be revealed.

Phosphorescence and LED are the two color changing methods.

3.2 Modularity

The traditional aspect of jewelry also comes down to personal preference. To allow the wearer to customize each part of the necklace to the limits of their own imagination, a modular design has been chosen. In the following, we

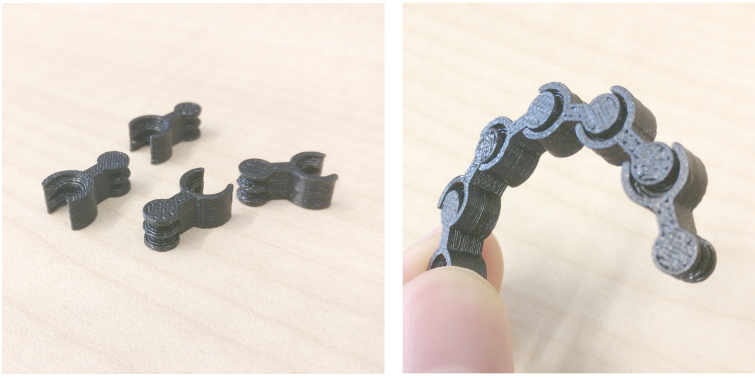


Figure 3.5: Left: Basic connector. Right: Linked with multiple connectors, forming a chain.

will breakdown each component of the necklace and take a look at its construction process.

3.3 Components

As indirectly pointed out in section 3.1 "Design", the necklace consists of three main components: The basis, the front plate and the rear box.

3.3.1 Basis

For the basis of the necklace, the 'Linkable Bracelet or Necklace' by Clark [2014] has been used. By linking multiple of these connectors, as shown in figure 3.5, a chain for a bracelet can be created. Black PLA (Polylactic Acid) has been used for the material in which the connectors have been 3D printed.

The basis consists of many small *connectors*.

One joint in such chain allows an angular rotation of up to about 30 degrees in one dimension. Since the design by Clark [2014] does not allow to change the direction of the rotation, the chain lies always in a plane which can also be seen in figure 3.5. This is fine for a bracelet, but in case of

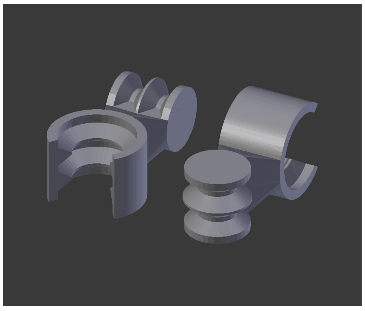
 

Figure 3.6: Left: Twisted connector in *blender*. Right: Linked with multiple connectors in an alternating order of original and twisted version.

a necklace, this restriction hinders the necklace to really lie on the neck of the wearer.

Twisted Version

To circumvent the above problem, a twisted version has been designed using blender[1], shown in figure 3.6. With an alternating order of the original and the twisted version, a very loose chain has been created.
Any module that has a male and a female end of the connector can now be linked with the chain, resulting in a necklace.

The twisted version makes the necklace loose even in the third dimension.

Thread Holder

Similar to the twisted version, the thread-holder is also an adaption of the basic connector. It allows to pull some string through the connector as shown in figure 3.7, to organize all the strings and threads.

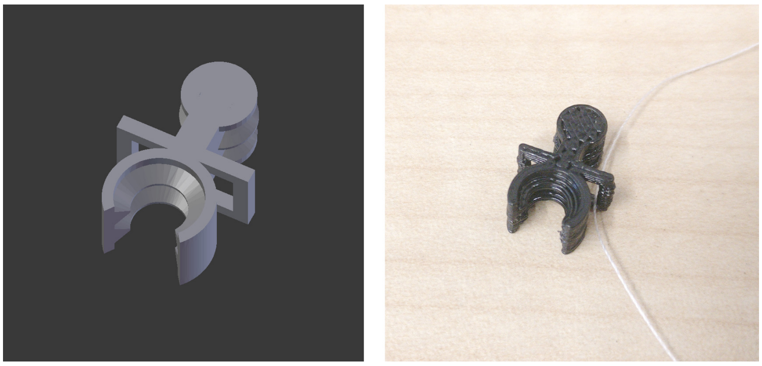


Figure 3.7: Left: Thread Holder Connector in *blender*. Right: Thread Holder Connector with a string pulled through.

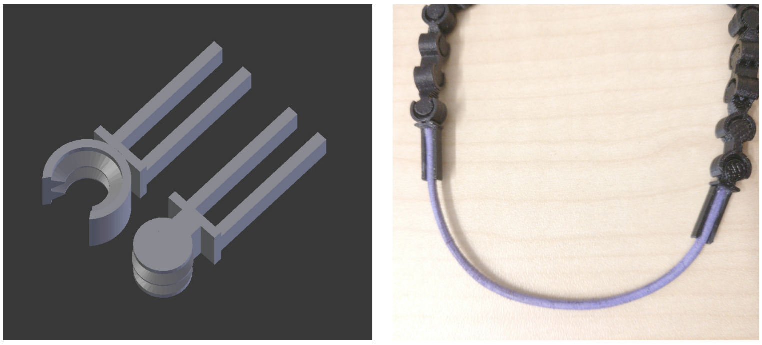


Figure 3.8: Left: Band Connector in *blender*. Right: Modularized purple band.

Band Connector

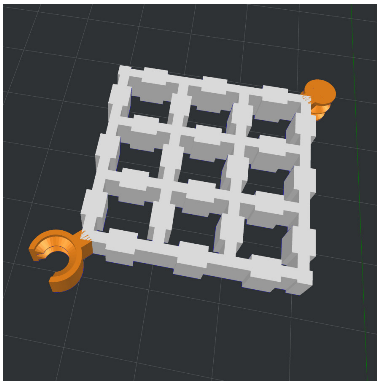
Different looks for different tastes.

Integrating a purple band shown in figure 3.8 is a way of personalizing the modular necklace. It has no function, but it allows to show something different rather than simply back PLA from the connectors.

Metamaterial

As introduced before, the metamaterial component is one of the methods to perform shape change. For the soft mate-

[1]https://www.blender.org/



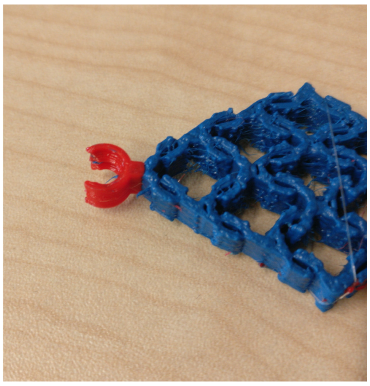


Figure 3.9: Left: Metamaterial Component in *ideaMaker*. Right: Printed Metamaterial Component with two different materials. Orange/Red: PLA. White/Blue: WillowFlex.

rial property required for the metamaterial structure, blue WillowFlex has been used. For modularity reasons, a 3D printer with dual extruders was necessary to print the red connectors with PLA simultaneously. The blue metamaterial structure has a dimension of $31mm \times 31mm$. The resulting module can be seen in figure 3.9 and is ready to be attached to other connectors.

The metamaterial component consists of two different materials.

Stretching and squeezing this metamaterial component could be performed using Shape Memory Alloys (SMA). For this thesis, however, two of this component have been printed, one in its initial shape, and one in the squeezed form instead of using SMAs. When the wearer prefers the other shape, the current component can be swapped out with the other one. The possibility to simply exchange modules highlights the advantage of using a modular design.

3.3.2 Front Plate

The front plate is in front of the metamaterial component and is able to slide upwards. The plate itself consists of a paperboard with the same size of $31mm \times 31mm$ as the metamaterial structure. The light weight of such material enables the plate to be pulled by the orange pneumatic actuators with ease. These are also modules of the necklace

The front plate is lifted upwards by pneumatic actuators.

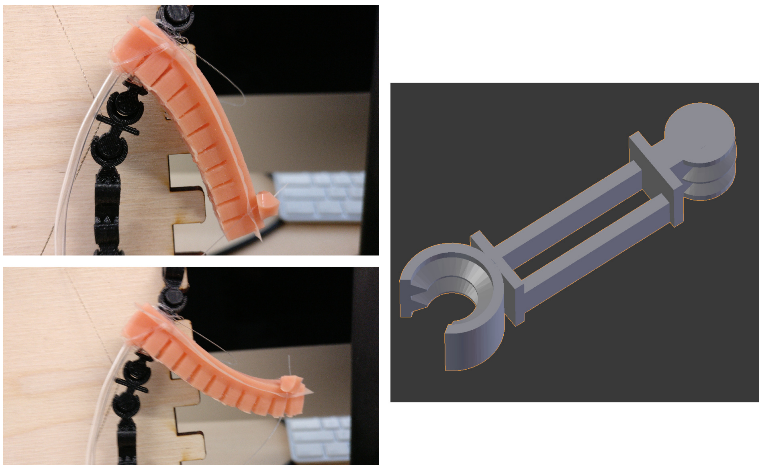


Figure 3.10: Left: Actuator is deflated and then inflated with air. It pulls at some transparent nylon thread. Right: Special connector for the actuator to be tied to.

on the sides. They pull at their respective thread simultaneously, resulting in a linear and vertical movement of the plate. Transparent nylon thread is used to hide these mechanisms as good as possible.

Phosphorescence

On the surface of the front plate, a thin layer of acrylic paint with neon green phosphorescence is applied. Having this material on the front allows it to reliably charge during the day. Its effect can be seen in figure 3.4.

Pneumatic Actuators

A mold was 3D printed for the silicone to cast the actuators.

The pneumatic actuators are cast in silicone in a 3D printed mold. The mold design follows the tutorial 'Mold Design CAD Tutorial' by Polygerinos et al. [2014] and has a length of about $60mm$. Its shape turned out to be very effective - the silicone actuators inflated with some air can reach a bend of over 90 degrees which is more than enough for the purpose of actuating some paperboard. Figure 3.10 shows

one actuator in two different degrees of bend. By having two actuators, one on each side, rotational movement is translated into linear movement. The effect is shown in figure 3.1
A special version of the basis connector has been designed which allows tying an actuator to it. Nylon thread is used here, again.
For the air supply, two motor pumps of *makeblock Air Pump Motor - DC 12V/370-02PM* are being used, one for each actuator. When energized, these pumps inflate the actuators, otherwise, they simply let air through them, allowing the actuators to deflate and return to their initial position. Controlling the motors electronically will be discussed in section 3.4.1 “Microcontroller”.

During usage, the biggest challenge of the pneumatic actuators is the friction on clothes at the neck. When set up properly, the actuators barely touch the fabric which is just enough to set the front plate in motion. This prototype is not intended to be used for a longer period of time, though, since even light body movement can cause a displacement of the actuators. In such case, repositioning by hand is required.

Over time, friction causes the pneumatic actuators to malfunction.

3.3.3 Rear Box

The rear box is behind the metamaterial component and is able to slide downwards. It is the last part of the three stacked squares which can extend the total surface in vision. The box has a dimension of $31mm \times 31mm \times 10mm$ with a wall thickness of $3mm$. It is designed using MakerCase[2] and inkscape[3]. The material used for the box are plywood of populus and acrylic glass which are cut using a laser cutter. The box from the front and from the back is shown in figure 3.11.
The box is designed to be glided downwards by releasing some string attached to it. For a final product, this should be done using electric motors, but for this prototype, it is done by hand.

The rear box consists of wood and glass.

[2]https://www.makercase.com/
[3]https://inkscape.org/

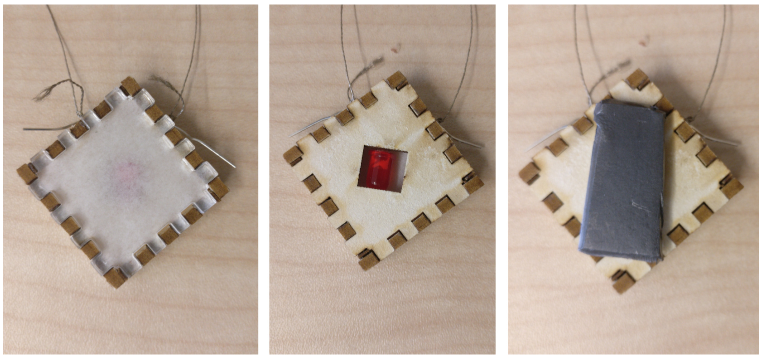


Figure 3.11: Left: Frontal view of the rear box. Center: Back view of the rear box. The hole for the LED can be seen. Right: Back view of the rear box with a chunk of lead attached.

Similar to the pneumatic actuators, friction causes a problem to the box when it is being guided downwards. This is solved by increasing its weight: A chunk of lead is attached to the back of the box and makes sure that the gravitational force is stronger than any friction.

LED

A LED is built into the rear box. Greaseproof paper is used to blur the light.

In the box, a standard red LED is planted. Because of wall thickness, the space in the box provides only a height of about $4mm$ which is insufficient for the LED in use. Therefore, a hole is carved behind the box. Greaseproof paper is used as a layer beneath the acrylic glass in order to blur the red source of light.
The feet of the LED go through the sides out of the box and is connected with some conductive thread. These not only pull the box physically, but also provide the electric connection to feed the LED. With 3 meters of total thread length (1.5 meters on each side), around 300Ω is reached.

3.4 Operation

Two of the three shape changing methods are performed manually, i.e. swapping the metamaterial component out and pulling at strings to glide the rear box downwards, and one of the two color changing methods is done automatically when ambient light becomes insufficient, i.e. glowing effect of phosphorescence. The remaining methods are controlled by the microcontroller Arduino Uno[4].

3.4.1 Microcontroller

The prototype is designed to be prototyping-friendly instead of wearer-friendly, meaning that the microcontroller is not portable and the wearer cannot move away from it. The arduino is connected to a laptop via USB and is also powered by that port.

In Appendix A "Breadboard Layout", the electric circuit of the necklace is shown. The microcontroller is programmed in such a way that it takes commands through the *Serial Monitor* of the *Arduino IDE*, providing the possibility to switch between the states *Off*, *Pulsating* and *On* for the LED. For the motor pumps, it expects a duration given in milliseconds. The controller then runs the motors for that duration with $5V$. Since the amount of air to be pumped into the pneumatic arms is very low, $5V$ for $400ms$ is enough for the actuators of this project. When the motors turn off again, they let the actuators deflate by themselves. This means that a state in which the actuators stay inflated is not part of this design.

Two pneumatic motor pumps and the LED are controlled through an Arduino.

3.4.2 Wizard of Oz Prototyping

Two out of five methods are still performed manually which is fine for the Wizard of Oz experiment in chapter 4 "User Study": The idea is to do so as if the electric motors to pull the rear box were actually implemented. The same

[4]https://www.arduino.cc/

goes for the SMAs built into the metamaterial component. As long as the alternative methodology is not noticed by viewers and its effect is the same, the outcome of such experiment will be the same, too.
However, due to the fragility of the connectors when swapping the metamaterial component in and out, and due to the impossibility to show the transition of its shape change when intervening by hand, this shape change method has been withdrawn from the experiment.

3.5 Defining States

Before we go to the next chapter, all the shapes and colors the necklace can turn into are summarized here. The following definition of 'state' will be used to define the states *Off*, *In Transition* and *On*.

Definition: *State of the Necklace*

State of the Necklace:
A time frame of three seconds in which the necklace *may* change its appearance.

Three possible states exist for an appearance change method: *Off*, *In Transition* and *On*.

Now, there are four different appearance changing methods. Each of these can potentially be either *Off*, *In Transition*, or *On*. *Off* stands for the initial position; it is the state before anything happens. Thus, nothing changes for three seconds. *On* refers to the state in which a method has reached its maximum; the appearance cannot be changed any further, e.g. the LED has reached its full brightness. This means that nothing changes anymore in the *On* state. *In Transition* is a state in which a method is being applied. At any given point during the transition, the method in use is moving towards the *On* or *Off* state, so the appearance of the necklace is changing constantly during these three seconds.
Therefore, *Off* is a state each method can be in. However, due to limitations in design, not all of the methods can take both *On* and *In Transition* aside from *Off*:
The moving rear box can be *In Transition* as well as *On* since the strings are pulled by hand. The moving front plate can only be *In Transition* since the pneumatic actuators automat-

ically start deflating when the pumps go off. The LED can gradually increase, decrease or hold at a certain brightness, enabling both *In Transition* and *On*. For the phosphorescence, *On* is possible by turning the lights off in the room. *In Transition* is a challenging state for this method: On the one hand, one can argue that the lights in the room can be dimmed in order to let the phosphorescence material glow stronger and stronger. On the other hand, human perception is different when repeated adaption to darkness and brightness is required in three seconds. *In Transition* has been neglected to be safe.
The possible states for each method are summarized in table 3.1.

Type	Method	Off	In Transition	On
Shape	Moving Rear Box	✓	✓	✓
Shape	Moving Front Plate	✓	✓	
Color	LED	✓	✓	✓
Color	Phosphorescence	✓		✓

Table 3.1: Possible states for each appearance changing method.

Although it is possible to perform multiple appearance changes simultaneously, we will only look at single changes to keep it simple. Multiple *In Transition* states of different methods simultaneously are discussed in section 5.2 "Future Work". There is, however, one exception. For the LED to be seen, i.e. *In Transition* or *On*, the rear box has to be *On*. Otherwise, the LED is hidden behind the metamaterial component.

Finally, we refer to the *In Transition* state as 'dynamic state' in contrast to the *On* and *Off* states as 'static states'.

Chapter 4

User Study

4.1 Pilot Studies

Two Pilot Studies have been conducted before going forward with the final user study. They were used to make sure the procedure is fine, to measure the time needed for one participant and to have a first indication that the results are usable and not random.

4.2 Research Questions

- What kind of emotions can be evoked as a *first impression* with the necklace prototype and its appearance changing methods?

- Is there any difference in intensity of evoked emotions if people perceive an appearance change in a passing-by situation or in a conversation?

4.3 Hypotheses

Definition: *Hypotheses of the User Study*

HYPOTHESES OF THE USER STUDY:
H_0: There is no difference in evoked emotions between the designed necklace and a normal necklace.

H_1: The designed necklace can evoke emotions such as desire, satisfaction or curiosity.

H_2: There is no difference in evoked emotions if people perceive an appearance change in a passing-by situation or in a conversation.

4.4 Experimental Design

There are seven possible states the necklace can be in.

Although we have four possible values for variable *method*, i.e. the four different appearance changing methods, and three possible values for *state*, i.e. *Off*, *In Transition* and *On*, the numbers cannot be simply multiplied to get the total number of conditions as not every method is able to be in each state. We therefore enumerate the possible states of table 3.1 from state A to state G and compile the table 4.1. Since only one method shall be applied at a time, the 'Off' column of table 3.1 can be united into a single instance, i.e. state A: *All Methods Off*.

Reference name	Method	State
A	All Methods	Off
B	Phosphorescence	On
C	LED	In Transition
D	LED	On
E	Moving Front Plate	In Transition
F	Moving Rear Box	In Transition
G	Moving Rear Box	On

Table 4.1: Enumeration of possible states of appearance changing methods.

4.4.1 Independent Variables

In this user study, two independent variables are defined, representing the parameters of this study:

1. The way of perceiving the appearance change:
   (a) Passing-by (PB). Participants have only the opportunity to look at the necklace for a short time.
   (b) Conversation (CS). Participants can look at the necklace anytime.
2. The seven new possible states constructed in table 4.1:
   A. All methods are in their initial position. Nothing happens for three seconds.
   B. All methods except for the Phosphorescence are in their initial position. The room is dark in order to let the phosphorescence material glow for three seconds.
   C. All methods except for the LED and Rear Box are in their initial position. The Box is lowered so the LED can pulsate for three seconds.
   D. All methods except for the LED and Rear Box are in their initial position. The Box is lowered and the LED stays on for three seconds.
   E. All methods except for the Front Plate are in their initial position. The Front Plate is lifted upwards during the three seconds.
   F. All methods except for the Rear Box are in their initial position. The Rear Box is lowered downwards during the three seconds.
   G. All methods except for the Rear Box are in their initial position. The Rear Box stays at the lowered position for three seconds.

4.4.2 Dependent Variables

The dependent variables are:

1. Perception of the appearance changing necklace
2. Interpretation of appearance changing methods (rated on 5-point Likert scales)

4.4.3 Experiment Type

The user study follows a split-plot design.

The study follows a split-plot design:
Since perceptual functions are required, there are greater individual differences. Hence, within-group is used to let participants go through each of the possible states of the second independent variable.
However, this can only be done once since a *second* cycle would stay in conflict with obtaining *first* impressions per definition as required by the research question. Consequently, between-group is used for the first independent variable of perceiving methods.

4.4.4 Randomizing

In order to guarantee a significant result for the within-group design, a Latin Square design is used to determine the order in which participants go through the states as shown in table 4.2.

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

Table 4.2: The order of going through the seven states follows the Latin Square Design.

The assignment of sequence to subject is done using the First Come First Serve principle: The ambiguity of who the next participant will be assures a random assignment. The perception methods, Passing-by (PB) and Conversation (CS), are alternated, resulting in an assignment as in table 4.3.

Subject	Sequence	Perception method
1	1	PB
2	2	CS
3	3	PB
4	4	CS
⋮	⋮	⋮
8	1	CD
9	2	PB
⋮	⋮	⋮

Table 4.3: There are 14 combinations of Sequences and Perception methods in total.

This means that any combination of sequence and perception method is tested exactly once after 14 subjects. In case the number of participants is not a multiple of 14, remaining participants were assigned to the combinations randomly.

14 participants are at least required for each condition to be tested at least once.

For simplification, a combination will be represented as {`Sequence`}-{`Perception method`}. For example, sequence number 4 with perception method Conversation would be DEFGABC-CS.

4.4.5 Measuring Emotions

To measure human emotion, PrEmo tool by Desmet [2003] was used. On a screen, it allows the subject to tap and play an animation of a character who expresses an emotion without using any words. He uses his body and face to express and even says things like 'hm-hm' or 'urgh!'. After seeing the character's feelings, the subject is asked if she feels the same way in respect to the situation she is currently in. She then rates it and circles a number according

Emotion is measured using animations and Likert scales.

to the following Likert scale:

0	-	I do not feel this
1	-	I feel this a little
2	-	I feel this somewhat
3	-	I do feel this
4	-	I do feel this strongly

14 of the animating characters are provided representing 14 different emotions. An overview of these emotions is compiled in table 4.4.

Positive emotions	Negative emotions
Desire	Aversion
Satisfaction	Dissatisfaction
Pride	Embarrassment
Hope	Anxiety
Joy	Sadness
Curiosity	Boredom
Admiration	Contempt

Table 4.4: PrEmo is able to measure seven positive and seven negative emotions. Desmet [2003].

4.4.6 Hardware Setup and Surrounding

- A table with two seats, one for the subject and one for the investigator, facing each other.
- Another table behind the subject to answer the questionnaire.
- An iPad displaying the 14 PrEmo characters.
- The necklace prototype worn by the investigator.
- A laptop for the investigator to control the necklace and to record sound.
- A quiet room, where the subject is able to observe the necklace and hear the animations of PrEmo without getting distracted.

- Light switches of the room in close proximity to the investigator to allow him to control brightness in the room.
- Snacks to combat any fatigue of participants.

4.4.7 Experimental Procedure

The experiment involves one investigator and one participant at a time, for up to 30 minutes.
First of all, all relevant components including the questionnaire and the experiment setup were prepared. The investigator was sitting at his seat wearing the necklace prototype before the participant came in. At this point, randomization and assignment of sequences to participants was already done beforehand to ensure a smooth user study.

As soon as the participant entered the room, she was asked to take a seat and to sign the Informed Consent Form, attached in Appendix B "Questionnaire of the User Study". If she approved, audio was recorded throughout the whole experiment. The participant was asked to answer the first page of the questionnaire which involves questions about personal data such as age and sex. For the second page, the two alternating phases of the experiment was explained next:

Participants were instructed about the procedure and what they were supposed to do.

1. Observing one of the seven states (from A to G) of the necklace: When demonstrating the states with a period of three seconds, the investigator explicitly announced the beginning and the end of each state. Also, a state was repeated on participant's demand. Naming the states 'A', 'B', ..., 'G' on the questionnaire is also intended. This assures that participants do not know what to expect since states are not named after the component in use. The participant then goes to the next phase. If she did not notice anything, that is also a valid first impression.
2. Rating each of the emotions on a separate sheet of paper with regard to the observed state using PrEmo: If

During the rating process, the next state was prepared.

the participant belonged to the group simulating the Passing-by (PB) perception method, she was asked to turn around and then rate the emotions on the table behind her. To prevent any confusion on why this is necessary, she was told that the next state was being prepared in the meantime. For participants belonging to the group simulating the Conversational (CS) perception method, nothing was told. During rating, they were able to take another look at the necklace which was being prepared for the next state. However, all participants were told to watch the corresponding animation each time before circling a number on the Likert scale.

Before showing the first state, the participant was asked if she understood what to do. If she did, seven Iterations of the above phases were performed. The order of these states was discussed in section 4.4.4 "Randomizing". Explanations to each of the states were presented in section 4.4.1 "Independent Variables".
After rating 14 emotions to each of the 7 states (98 ratings in total), the participant was asked to answer the last page of the questionnaire. This page involves questions about the overall opinion of the presented necklace and questions about personal habits and practices of the usage of necklaces in general.

At the end, the investigator thanked the participant and prepared the questionnaire for the next participant.

4.5 Participants

17 participants; most of them were familiar with conventional necklaces.

Over the course of three days, 17 participants, 10 female and 7 male, took part in this study. They aged from 18 to 28 with an average age of 22.88 and with a standard deviation of 2.87. 12 of the 17 participants stated that they wear necklaces at least sometimes. Consequently, many participants were able to relate to their own experiences with necklaces. 4 participants wear them often or almost always, while 5 participants never wear necklaces.

No participant stated to have any significant visual or auditory restrictions, so the study was conducted as planned.

4.6 Results

Unfortunately, in one case, a participant did not give a rating to one of the 98 ratings. To prevent any inconsistency, data of this participant was not considered in the analysis. Ignoring this case, 8 participants were assigned to the PB group and 8 to the CS group while the combinations DEFGABC-PB and DEFGABC-CS were randomly chosen to be tested a second time, as there are only 7 sequences in each group.

For consistency reasons, one data set had to be ignored.

4.6.1 Statistical Tests

Since the data does not follow a normal distribution, non-parametric statistical tests were used. To compare the two groups CS and PB, the Mann-Whitney U test is performed. For the statistical analysis in the groups, the Chi-squared test, the Friedman test and the Wilcoxon signed-rank test were executed for each emotion.

Four statistical tests are performed.

Chi-Squared Test

The Chi-squared test is able to check if there is a significant difference between the observed ratings and the expected ratings. In this case, to comply with the null hypothesis of the user study, we expected the participants to rate a state exactly the same way as if she saw a normal necklace. A normal necklace is represented by state A: All appearance changing methods are in their initial position and nothing happens for three seconds. It can be said that for each of the states B, C, D, E, F and G, we expected the same ratings as A. Consequently, the Hypotheses for the Chi-squared test are:

The Chi-squared test requires expected values to perform.

Definition:
Hypotheses for the Chi-Squared Test

HYPOTHESES FOR THE CHI-SQUARED TEST:
For emotion e and state S:

H_0: There is no significant difference in ratings between the given state S and state A.

H_1: There is a significant difference in ratings between the given state S and state A.

The Chi-squared test runs a total of 2 groups $\times 14$ emotions $\times(7-1)$ states $= 168$ times.
First, for each of the 5 possible values (from 0: 'I do not feel this' to 4: 'I do feel this strongly') in each of the 98 ratings, the frequency of how many times the value was picked by the participants is counted. This raises the problem that the expected count of value 4: 'I do feel this strongly' is 0 most of the time, resulting in a division by 0 for the χ^2 value. With a large enough sample size, this is not a problem as an expected value of 0 should never be the case. However, to circumvent this current situation, we simply add 0 to χ^2 if the expected value is 0 and leave the degree of freedom at 4. This ensures that Type I errors will not occur, i.e. rejecting H_0 although H_0 is true. So, in this configuration, the Chi-squared test may not find all significant differences, but if it finds one, it is not wrong.

In order to definitely avoid Type I errors, calculation of the χ^2 value is adapted.

The level of significance alpha is 0.05 and the critical value is 9.488. An excerpt of the p-values between state A and another state for each emotion, once for PB and once for CS, can be found in table C.1 and table C.2. If a p-value of emotion e in a comparison between state A and state S is below α, then H_0 has to be rejected and H_1 has to be accepted: There is a significant difference in ratings between state A and state S for emotion e.

Friedman Test

The Friedman test checks for an emotion if there is a significant difference in the distribution of ratings over all the states in general. The Hypotheses are:

> **HYPOTHESES FOR THE FRIEDMAN TEST:**
> For emotion e:
>
> H_0: There is no significant difference in ratings between the states of the necklace.
>
> H_1: There is a significant difference in ratings between the states of the necklace.

Definition:
Hypotheses for the Friedman Test

The Friedman test runs a total of 2 groups $\times 14$ emotions $= 28$ times.
The level of significance alpha is 0.05. The p-values calculated through the Friedman test can also be found in the appendix, table C.3. For a p-value of emotion e below α, H_0 has to be rejected. Thus, for emotion e, there is a significant difference in ratings between the states of the necklace.

Wilcoxon Signed-Rank Test

The Wilcoxon signed-rank test goes further and does a pairwise comparison of the Friedman test:

> **HYPOTHESES FOR THE WILCOXON SIGNED-RANK TEST:**
> For emotion e and state S and state T:
>
> H_0: There is no significant difference in ratings between the two given states of the necklace.
>
> H_1: There is a significant difference in ratings between the two given states of the necklace.

Definition:
Hypotheses for the Wilcoxon Signed-Rank Test

The Wilcoxon signed-rank test runs a total of 2 groups $\times 14$ emotions $\times \binom{7}{2}$ pairwise comparisons $= 588$ times.
The level of significance alpha is 0.05. Only the 64 p-values with $p < 0.05$ has been attached as table C.4. For each entry of the table with group g, emotion e, first state S and second state T, the rating distribution of participants in group g to an emotion e between the states S and T is statistically significant. For these entries, H_0 has to be rejected and H_1

accepted.

Mann-Whitney U Test

The Mann-Whitney U test looks for a significant difference between the two groups PB and CS for each emotion and each state:

Definition: *Hypotheses for the Mann-Whitney U Test*

HYPOTHESES FOR THE MANN-WHITNEY U TEST:
For emotion e and state S:

H_0: There is no significant difference in ratings between the two groups PB and CS.

H_1: There is a significant difference in ratings between the two groups PB and CS.

The Mann-Whitney U test runs a total of 14 emotions $\times 7$ states $= 98$ times.
The level of significance alpha is 0.05. The p-values are listed in table C.5. If a p-value is below α for a state S and emotion e, H_0 has to be rejected; there is a significant difference in ratings between the two groups PB and CS for state S and emotion e.

4.6.2 Observations

With all the p-values in appendix C "Cumulative Data and Calculated P-Values of Statistical Tests", following information has been extracted:

1. Most of the significant differences are found in the PB group.
2. The Mann-Whitney U test found exactly one statistically significant difference between the two groups: For state A with emotion *contempt*.

3. In the PB group, Chi-squared test, Friedman test and Wilcoxon signed-rank test all agree that, compared to state A, there is a significant difference for
   (a) state B (phosphorescence) in the emotions *admiration*, *dissatisfaction* and *boredom*.
   (b) state C (pulsating LED) in the emotions *dissatisfaction* and *boredom*.
   (c) state E (front plate being lifted) in the emotions *dissatisfaction*, *boredom* and *contempt*.
   (d) state F (rear box being lowered) in the emotions *dissatisfaction*, *boredom* and *contempt*.
4. According to Wilcoxon, in the PB group, any static state, i.e. one of $\{A, D, G\}$, has significant differences with
   (a) state C (pulsating LED) in emotion *desire* and *boredom*.
   (b) state E (front plate being lifted) in emotion *satisfaction*, *admiration* and *boredom*.
   (c) state F (rear box being lowered) in emotion *boredom*.
5. In group PB, the static states $\{A, G\}$ have significant differences with any dynamic state, i.e. one of $\{B, C, E, F\}$, in emotion *curiosity* (except for the pair F and G) according to the Wilcoxon test.
6. In the PB group, when comparing any static state, i.e. one of $\{A, D, G\}$, with any dynamic state, i.e. one of $\{B, C, E, F\}$, there is a significant difference in the emotion *boredom* according to the Wilcoxon test, except for the comparison of B (phosphorescence) and D (constant LED).
7. In any group for any emotion, there are no significant Wilcoxon-differences between any two static states.
8. There are no significant differences between the shape change methods.
9. In group PB, there is one weak significant difference ($p \approx 0.0455$) between the color change methods, states B (phosphorescence) and C (pulsating LED), for emotion *satisfaction*.

10. There are significant differences between shape and color changing methods for:

    (a) In group PB, between state B (phosphorescence) and E (front plate being lifted) for emotion *pride*. $p \approx 0.0253$.

    (b) In group PB, between state B (phosphorescence) and F (rear box being lowered) for emotion *contempt*. $p \approx 0.0455$.

    (c) In gruop CS, between state E (front plate being lifted) and C (pulsating LED) for emotion *admiration*. $p \approx 0.0384$.

    (d) In gruop CS, between state E (front plate being lifted) and B (phosphorescence) for emotion *anxiety*. $p \approx 0.0394$.

4.6.3 Discussion

Passing-By vs Conversational Perception Method

Regarding observations 1 and 2:
First of all, it is interesting to see that there are actually differences between the groups at all. This was not expected before conducting the study. When looking at the raw data of table C.6, participants from group PB tend to be more emotional in several cases, especially in emotion *contempt* with a significant difference calculated through the Mann-Whitney U test.
The difference of the two groups was that participants from PB were hindered to look at the necklace while it was being prepared for the next state. One can argue that there is a learning curve even for emotional impressions - which would suggest that the longer people look at the necklace, the less emotional impact it has when its appearance changes.

The CS method seem to have less emotional impact than the PB method.

Static vs Dynamic States

Regarding observations 3, 4 and 5:
In comparison to state A, which represents a normal necklace, dynamic states seem to be less dissatisfactory and boring according to the raw data. It looks like that this is confirmed by the three executed tests.
Depending on the dynamic state, the data point to the direction that dynamic states are able to evoke emotions such as *desire*, *satisfaction*, *admiration* and *curiosity*. They are less *boring* and evoke less *contempt* in comparison to static states.

All tests confirm that there are differences between static and dynamic states.

Regarding observations 6 and 7:
In contrast, static states do not seem to differ that much. They all have significant differences compared to the dynamic states and are also to be considered very *boring* according to the raw data.

With *curiosity*, *admiration* and *desire*, dynamic states seem to be good at catching someone's attention which is plausible. *Satisfaction*, however, is interesting as it is not an emotion usually evoked by seeking attention.

Shape vs Color Changing Methods

Regarding observations 8 to 10:
The two shape changing methods are quite similar in their effect of moving a square piece. One can understand that there are no significant differences between them. This seems to be a little bit different with color changes: Although barely below the significance alpha value, phosphorescence and LED have a significant difference in *satisfaction*.
When comparing shape and color change, there are significant differences here and there: For group PB, state B (phosphorescence) differs from shape changes in *pride* and *contempt*, and for group CS, state E (front plate being lifted) differs from color changes in *admiration* and *anxiety*.

LED and phosphorescence seem to differ in *satisfaction*.

It would be definitely interesting if the same differences of shape and color changes applied to both groups. However, since this is not the case and the p-values are also not that convincing, this aspect has to be taken with a grain of salt. Out of the four observations, 10a has the lowest p-value of 0.0253 and is therefore most convincing suggesting that the front plate being lifted tends to evoke more of *pride* than the phosphorescence.

4.7 Conclusion

H_0 is rejected due to the differences observed.

H_1 is accepted due to the dynamic states being significantly different than static states.

The null Hypothesis of the conducted user study can definitely be rejected which states that there was no difference in evoked emotions between the designed necklace and a normal necklace. Significant differences have been observed between static and dynamic states.
Emotions such as *desire*, *satisfaction* and *curiosity* seem to be evoked easily. H_1 should therefore be accepted. *Pride* and *admiration* often lack the ratings 'I do feel this strongly' on the Likert scale, but for dynamic states, some positive shifts can be seen compared to the other states. It can be noted that, apart from the evoked positive emotions, there seem to be much less negative emotions with appearance changes, such as *boredom* and *dissatisfaction*.

There are, of course, more than these 14 emotions measured through PrEmo, so we cannot say for sure that a particular appearance changing method is best suited at evoking a certain emotion. It could be very well the case that other emotions not evaluated in this study are evoked with much more intensity and that these 14 emotions are simply side effects and by-products of the actual emotions.

H_2 is also rejected due to the differences observed between the gruops.

Interestingly, though, H_2 has to be rejected. There seems to be a difference in the effects depending on how appearance changing necklaces are perceived and presented. Not the kind of emotions, but rather their intensity seem to differ. This would greatly influence possible use-case scenarios.

4.7.1 Use-Case Scenarios

A very concrete use-case scenario with regard to passing-by cases would be conducting a presentation. There are cases where people stare at the slides and never look at the presenter herself. If she wants to grab everyone's attention to articulate and transmit other information outside the slides, some jewelry with the size of a necklace that can change its appearance subtly would be perfect. The evoked emotions would also fit to the act of giving a presentation: Increased satisfaction, curiosity and admiration while decreasing boredom, dissatisfaction and contempt.

Holding a presentation is one possible use-case scenario.

For a conversational situation, such necklace could be used to remind a person of something important or, if we stay at the emotional aspect, it can adapt its appearance based on the level of agreement to the opinion of the person one is talking to.

One of the most common answers as suggestions for use-case scenarios in the questionnaire were parties and (fashion) events, including a variety of situations in which people appear differently than on casual days: Cosplay, shows - either as a performer or as a viewer - and even in movies as actors.

Such necklace can, of course, be worn as personal style, to simply express oneself or to attract people. It has to be noted that there are also situations in which people cannot express by themselves, so that they have to rely on smart wearable devices to communicate with surrounding people. Brainstorming further on this idea, pets could also wear such necklace to somehow express an intent.

Chapter 5

Summary and Future Work

The last chapter summarizes the thesis and the contribution of its results. In the end, ideas of future work to improve the necklace and proceeding studies for further investigation are presented.

5.1 Summary and Contributions

This thesis investigated the emotional effects of an appearance changing necklace. As research so far rather neglected user experiences about design and focused on the engineering side, Väänänen-Vainio-Mattila et al. [2015], the thesis put focus on the core idea of traditional jewelry which is appearance and nonverbal communication. Emotions are part of the nonverbal communication and was therefore measured in a user study using the jewelry prototype. Based on results of the emotions, possible use-case scenarios were proposed.

The thesis put focus on the traditional aspect of jewelry.

The main question with the constructed necklace regarding emotions was: What kind of emotions can be evoked with an appearance changing jewelry compared to a traditional jewelry?

Different methods of changing appearance were defined. The two categories are shape change and color change. For each type, two technically different methods were implemented into the necklace. For the first category, a moving plate through pneumatic actuators and a moving box by pulling and releasing strings through electric motors were designed. The actual electric motors were replaced through Wizard of Oz prototyping for the latter one. Phosphorescence and LEDs are the methods to change color. The third shape change method was dropped from the user study because of technical reasons.

A necklace that can have seven different states was designed and constructed.

Seven different states the necklace can be in were defined. They were categorized into static and dynamic states. A satic state refers to a period of time in which nothing happens with the necklace, whereas in a dynamic state, the appearance changes over the time frame.

A user study was conducted in which participants were divided into two groups: Passing-by and Conversation.

In the user study, the seven states were presented one after another to the participants. To obtain their very first impression of the necklace, they were not told what to expect. Participants were divided into two groups. One simulating the passing-by situation, in which they were hindered to look at the necklace during preparation of the next state, and another group simulating the conversational situation, in which participants were free to look at the necklace anytime. To measure human emotion, PrEmo by Desmet [2003] was used.

Different tests revealed that there were actually significant differences in the result.

Four tests were performed on the data from the user study: Chi-squared test, Friedman test, Wilcoxon signed-rank test and the Mann-Whitney U test. The analysis of the tests together with the raw data revealed that appearance changing methods tend to evoke emotions such as *desire*, *satisfaction* and *curiosity*. They seem to be drastically less *boring*, *dissatisfactory* and *contemptible*.

The two groups did not differ that much in the kind of emotions evoked, but rather in their intensity. As such, most significant differences were found in the data by the passing-by group.

Based on these findings, some use-case scenarios were ideated: From using the necklace in a presentation to letting a pet wear such necklace.

In conclusion, the contribution of this thesis lies, on the one hand, in the construction and making a necklace smart with appearance changing capabilities. On the other hand, the contribution lies in the investigation on emotional effects of such jewelry by conducting a user study. Instead of designing a smart jewelry for a certain interaction, this thesis considers first what a smart jewelry is capable of as knowing the effects thoroughly is important before choosing an interaction. This might animate future researchers to investigate their targeted device in its potential entirely before using and trying it in interactions.

5.2 Future Work

The necklace at hand establishes a foundation for further research, for example, by increasing its complexity. Alternatively, interactions can be now tested based on the results of the conducted user study.

5.2.1 Increasing Complexity

More Components

Replacing the Wizard of Oz prototyping methods by actual working components is one suggestion. The rear box moving vertically can be supported by electric motors and the metamaterial component could use some SMAs.

Fixing these and adding more shape and color change methods as new modules are straightforward. However, the modularity of the necklace does not limit one of only focusing on appearance changing modules. Depending on the use-case, not only output components, but also input components can be considered which can sense the surroundings through e.g. microphones or biometric data collecting sensors.

The modularity of the necklace enables simply adding more components.

More Emotions

More emotions to measure can be added. Alternatively, relations between them can be investigated.

Only 14 emotions have been measured in the user study using a tool. Although they cover already a wide range of human expressions and give us an overview of what is possible and what not, a more detailed measurement could be performed. Simply adding more emotions to measure is possible, but investigating the reasons and relations between emotions would also be interesting: Does one find a state curious because it is interesting or, actually, because it is very unattractive?

Combining Multiple States

Besides adding more components or finding relations between emotions, (dynamic) states can be combined. When input components are added, they could be connected over a network and provide some interaction:

- What happens if a moving component points to a direction and an LED is blinking restlessly over a course of three seconds?
- What information can be transmitted not on the emotional level, but as actual messages?

Such combination drastically increases the complexity and maybe makes user studies hard to conduct. If thoroughly conducted, results would definitely be interesting, though.

5.2.2 Interaction Testing

User studies to specific interactions can be conducted.

Specific testing of interactions would be the final step. With a more comprehensive knowledge of effects through the appearance changing necklace, user studies to interactions mentioned in section 4.7.1 "Use-Case Scenarios" can be conducted. In the case of holding a presentation, it can be investigated if such necklace can influence how well the audience is able to understand and follow the presentation.

A provocative, yet interesting interaction might be a job interview. An appearance changing jewelry would probably impact the impression of the employer, be it in a pleasant or in an unpleasant way. But regardless of the interaction, reasons for why a necklace specifically would fit rather than other jewelries should be found.

Appendix A

Breadboard Layout

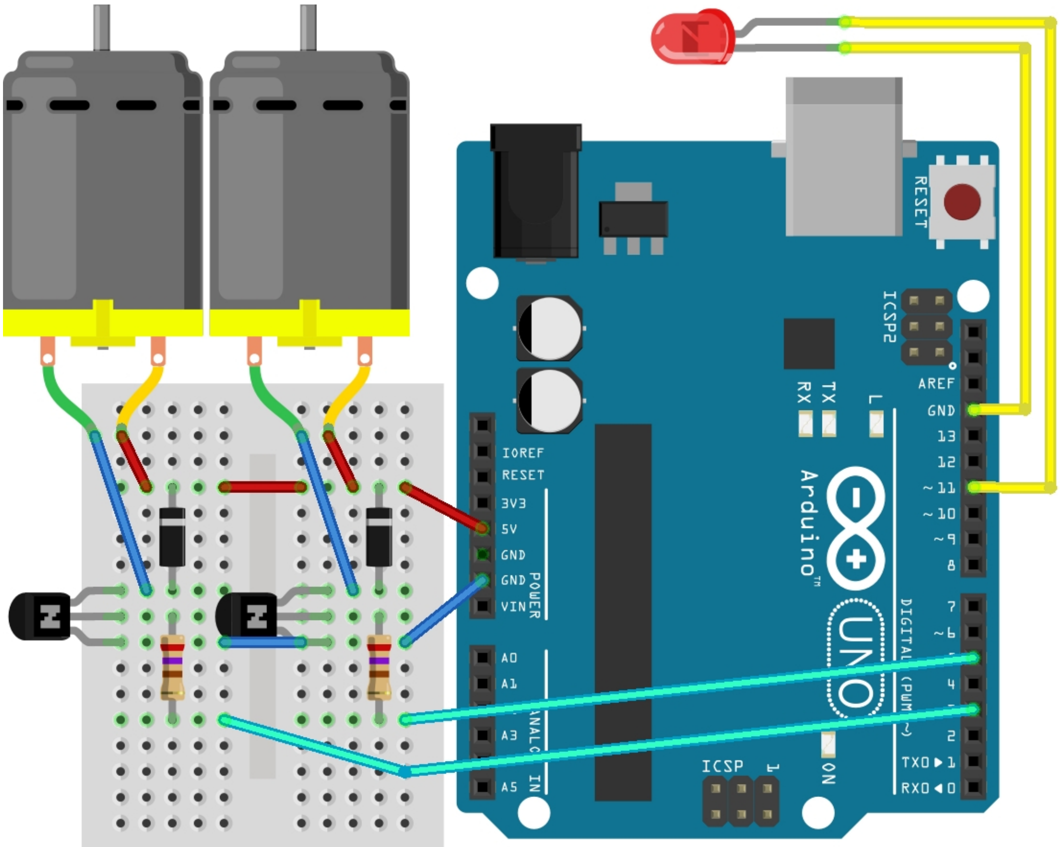


Figure A.1: Breadboard layout design with the motor pumps (actuator component) and the LED (rear box component). Made with *Fritzing.org*.

Appendix B

Questionnaire of the User Study

The following pages show the questionnaire with sequence FGABCDE for the conducted user study. After signing the Informed Consent Form, the first page was filled out immediately thereafter. The second page was filled out column by column after the according state was shown. The last page was filled out after all the states were presented in the user study.

Informed Consent Form

Evaluating emotions evoked by an appearance changing necklace

PRINCIPAL INVESTIGATOR Mitski Piekenbrock
Media Computing Group
RWTH Aachen University
Email: mitski.piekenbrock@rwth-aachen.de

Purpose of the study: The goal of this study is to understand the effect of appearance changing necklaces. Participants will be asked to observe the different appearance changing methods of the necklace. The questionnaire and the conversation during the study will be used in the analysis.

Procedure: Before the study, we will ask you to fill out a questionnaire with some information about yourself.

Participation in this study involves alternation between two phases. In the first phase, you will be asked to observe the appearance changing necklace. In the second phase, you will be asked to rate the method based on emotions. This study should take up to 30 minutes to complete.

After the study, we will ask some general questions about your habits and practices with respect to necklaces.

Risks/Discomfort: You may become fatigued during the course of your participation in the study. You will be given several opportunities to rest, and additional breaks are also possible. There are no other risks associated with participation in the study. Should completion of either the task or the questionnaire become distressing to you, it will be terminated immediately.

Benefits: The results of this study will be useful for finding out the impact of changing appearance in the fields of wearable devices as well as for investigating possible use-case scenarios of such necklace.

Alternatives to Participation: Participation in this study is voluntary. You are free to withdraw or discontinue the participation.

Cost and Compensation: Participation in this study will involve no cost to you. There will be snacks for you during and after the participation.

Confidentiality: All information collected during the study period will be kept strictly confidential. You will be identified through identification numbers. No publications or reports from this project will include identifying information on any participant. If you agree to join this study, please sign your name below.

_____ I have read and understood the information on this form.
_____ I have had the information on this form explained to me.

Participant's Name	Participant's Signature	Date
	Principal Investigator	Date

If you have any questions regarding this study, please contact Mitski Piekenbrock at email: mitski.piekenbrock@rwth-aachen.de

Experiment Questionnaire

Evaluating emotions evoked by an appearance changing necklace

Before the study, please answer the following questions.

Information about yourself:

1. How old are you? __________
2. What is your gender? ☐ male ☐ female ☐ n.a.
3. Do you have any sight restrictions except glasses? ☐ yes ☐ no
4. Are you color-blind? ☐ yes ☐ no

   If yes, referring to which color (Please fill in)? ________________________
5. Do you have any auditory restrictions? ☐ yes ☐ no

   If yes, please specify. ________________________

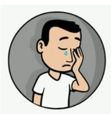
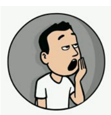
On the following page, you will see a table. Each column represents one state of the necklace (A, B, C, D, E, F, G; 7 in total) and each row one emotion (from a to n; 14 in total). You can see the characters expressing their feelings of each emotion on the screen next to you with their corresponding letter.

Please use the scale below and report if the feelings expressed by the characters correspond with your own feelings towards the state of the necklace.

0 - I do not feel this
1 - I feel this a little
2 - I feel this somewhat
3 - I do feel this
4 - I do feel this strongly

You will be asked to circle a number in each cell of the entire column after observation. Please watch the animations to the characters each time before you circle a number.

There is no right or wrong – take your time and give us your honest opinion. Have fun!

	F	G	A	B	C	D	E
a 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
b 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
c 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
d 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
e 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
f 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
g 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
h 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
i 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
j 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
k 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
l 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
m 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4
n 	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4	0 1 2 3 4

After the study, please answer the following questions.

Information about your personal usage of necklaces:

1. How often do you wear necklaces? ☐ often ☐ sometimes ☐ never
    1. If you did, would you wear this particular necklace in the same way as other necklaces you wear? ☐ yes ☐ maybe ☐ no
    2. If you did, would you wear necklaces with similar capabilities, i.e. moving parts and changing color? ☐ yes ☐ maybe ☐ no
2. Which situations can you think of where one would wear such necklace? Please explain why. (optional)

3. If you have anything to note or comment, please write it down here.

Appendix C

Cumulative Data and Calculated P-Values of Statistical Tests

The following pages show the cumulative Likert data and the results of all statistical tests as p-values. The significance alpha is $\alpha = 0.05$, so any value below 0.05 is written in **blue**.

Emotion	A - B	A - C	A - D	A - E	A - F	A - G
desire	0.4337	0.1847	1.0000	0.7907	0.9513	0.8781
satisfaction	0.8266	0.3839	0.1273	0.3839	0.5303	0.7051
pride	0.8874	0.8139	1.0000	0.1788	0.8139	1.0000
hope	0.7051	0.9967	0.8836	0.9967	0.8836	1.0000
joy	0.3796	0.7725	0.9953	0.3195	0.1257	0.9735
curiosity	0.1648	0.1870	0.7358	0.3839	0.3232	0.8836
admiration	**0.0005**	0.1046	0.9554	0.4530	0.2397	0.8836
aversion	0.7051	0.6151	0.6151	0.9735	0.9735	0.6151
dissatisfaction	**0.0285**	**0.0174**	0.6747	**0.0021**	**0.0174**	0.6747
embarrassment	0.9513	0.4337	0.9513	0.8781	0.3084	0.3084
anxiety	1.0000	0.8836	0.7358	1.0000	0.8836	0.6151
sadness	0.9967	1.0000	0.9554	0.6151	0.6151	0.6151
boredom	**0.0008**	**0.0295**	**0.0497**	**0.0000**	**0.0010**	0.8266
contempt	0.6005	**0.0022**	**0.0156**	**0.0022**	**0.0022**	0.8698

Table C.1: Passing-by (PB) p-values of the Chi-squared test between state A and another state for each emotion.

Emotion	A - B	A - C	A - D	A - E	A - F	A - G
desire	0.3732	0.9098	0.9098	0.9928	0.6298	0.8118
satisfaction	0.8557	0.8118	0.6747	0.7358	0.2548	0.8118
pride	0.5578	0.5249	0.9098	0.9953	0.9384	0.7907
hope	0.9554	0.8836	1.0000	0.6151	0.9554	0.7051
joy	0.9554	0.4779	0.1648	0.0857	**0.0328**	0.7968
curiosity	0.4530	0.1546	0.6446	0.0916	0.7968	0.6446
admiration	0.8836	0.6151	0.7968	0.0571	0.7968	0.3232
aversion	0.8836	0.2706	0.9098	0.7051	1.0000	0.7051
dissatisfaction	**0.0289**	0.8781	0.6990	0.7358	0.2674	0.6990
embarrassment	0.8836	0.7051	0.9735	0.7051	0.7051	0.7051
anxiety	1.0000	1.0000	0.9967	0.8266	0.8836	0.9554
sadness	0.8836	0.8836	0.8836	0.6151	0.8836	0.7051
boredom	**0.0098**	0.6151	0.0916	0.0533	0.1193	0.8557
contempt	0.9976	0.9976	0.8139	0.2592	0.6834	0.8874

Table C.2: Conversation (CS) p-values of the Chi-squared test between state A and another state for each emotion.

Emotion	PB	CS
desire	**0.0141**	0.5479
satisfaction	**0.0003**	0.265
pride	**0.0251**	0.559
hope	0.4306	0.523
joy	**0.0096**	0.0675
curiosity	**0.0043**	**0.0289**
admiration	**0.0015**	**0.0485**
aversion	0.1751	0.9709
dissatisfaction	**0.0181**	0.8818
embarrassment	0.2806	0.6652
anxiety	0.3315	0.0514
sadness	0.0609	0.293
boredom	**0.0016**	0.0916
contempt	**0.026**	0.7829

Table C.3: p-values of the Friedman test to each emotion and each gruop.

Group	Emotion	State 1	State 2	p-value
PB	desire	A	C	0.0384
PB	desire	C	D	0.0384
PB	desire	C	G	0.0244
PB	satisfaction	A	C	0.0158
PB	satisfaction	A	E	0.0264
PB	satisfaction	A	F	0.0256
PB	satisfaction	B	C	0.0455
PB	satisfaction	C	D	0.0339
PB	satisfaction	C	G	0.0256
PB	satisfaction	D	E	0.0384
PB	satisfaction	E	G	0.0264
PB	satisfaction	F	G	0.0256
PB	pride	A	E	0.0339
PB	pride	B	E	0.0253
PB	pride	E	G	0.0339
PB	joy	A	B	0.0256
PB	joy	A	E	0.0152
PB	joy	B	G	0.0260
PB	joy	E	G	0.0272
PB	curiosity	A	B	0.0097
PB	curiosity	A	C	0.0152
PB	curiosity	A	E	0.0169
PB	curiosity	A	F	0.0434
PB	curiosity	B	G	0.0412
PB	curiosity	C	G	0.0384
PB	curiosity	E	G	0.0394
PB	admiration	A	B	0.0196
PB	admiration	A	C	0.0384
PB	admiration	A	E	0.0256
PB	admiration	B	G	0.0114
PB	admiration	C	G	0.0231
PB	admiration	D	E	0.0384
PB	admiration	E	G	0.0260
PB	dissatisfaction	A	B	0.0231
PB	dissatisfaction	A	C	0.0235
PB	dissatisfaction	A	E	0.0412
PB	dissatisfaction	A	F	0.0374
PB	boredom	A	B	0.0339
PB	boredom	A	C	0.0339
PB	boredom	A	E	0.0196
PB	boredom	A	F	0.0384
PB	boredom	B	G	0.0473
PB	boredom	C	D	0.0384
PB	boredom	C	G	0.0256
PB	boredom	D	E	0.0384
PB	boredom	D	F	0.0394
PB	boredom	E	G	0.0422
PB	boredom	F	G	0.0394
PB	contempt	A	E	0.0384
PB	contempt	A	F	0.0384
PB	contempt	B	F	0.0455
PB	contempt	F	G	0.0384
CS	joy	A	C	0.0412
CS	joy	A	E	0.0264
CS	curiosity	A	B	0.0339
CS	curiosity	A	C	0.0384
CS	curiosity	A	E	0.0164
CS	curiosity	D	E	0.0455
CS	admiration	A	E	0.0152
CS	admiration	C	E	0.0384
CS	admiration	D	E	0.0196
CS	anxiety	B	E	0.0394
CS	boredom	A	E	0.0339
CS	boredom	E	G	0.0394

Table C.4: All 64 out of 588 p-values of the Wilcoxon signed-rank test with $p < 0.05$.

Emotion	A	B	C	D	E	F	G
desire	0.7234	0.8641	0.1468	0.1184	0.9558	0.6587	0.4806
satisfaction	0.2954	0.9559	0.1108	1.0000	0.4150	0.2015	0.3335
pride	0.2673	0.4055	0.9490	0.2673	0.8668	0.2821	0.5371
hope	0.9447	0.9517	0.9534	0.8473	0.6833	0.6719	0.5371
joy	0.5223	0.1308	0.9561	1.0000	0.7467	0.4109	0.6838
curiosity	0.9449	0.3280	0.8277	0.7850	0.5889	0.1692	0.7802
admiration	0.9449	0.3234	0.3801	0.9100	0.7884	0.9121	0.1556
aversion	0.9447	1.0000	0.0746	0.1709	0.6535	0.9449	0.0760
dissatisfaction	0.2675	0.2382	0.9447	0.8668	0.3686	0.2954	0.3227
embarrassment	0.9490	0.3936	1.0000	1.0000	0.5874	0.3816	0.0746
anxiety	0.9447	0.9447	0.5874	0.5613	0.1307	0.6800	0.3816
sadness	0.8358	0.8557	0.6997	1.0000	1.0000	0.3816	0.3816
boredom	0.8699	0.8577	0.8193	0.0549	0.4875	0.6800	0.5167
contempt	**0.0156**	0.4278	0.5371	0.7485	0.1213	0.1085	0.2681

Table C.5: p-values of the Mann-Whitney U test between the gruops PB and CS for each emotion and each state.

PB	A					B					C					D					E					F					G				
	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
desire	5	2	1	0	0	3	4	0	1	0	1	4	2	1	0	5	2	1	0	0	4	1	2	1	0	4	1	1	2	0	6	2	0	0	0
satisfaction	6	2	0	0	0	3	2	2	1	0	1	2	4	1	0	2	5	1	0	0	1	2	3	2	0	2	1	3	2	0	7	0	1	0	0
pride	7	1	0	0	0	6	2	0	0	0	5	2	1	0	0	7	1	0	0	0	3	3	2	0	0	5	2	0	1	0	7	1	0	0	0
hope	6	1	1	0	0	5	2	0	1	0	5	1	1	1	0	5	2	1	0	0	5	1	1	1	0	5	0	1	2	0	6	1	1	0	0
joy	5	1	0	2	0	1	2	1	2	2	2	1	3	2	0	4	1	1	2	0	1	2	2	1	2	1	3	2	2	0	5	1	1	1	0
curiosity	6	0	0	2	0	0	3	2	1	2	1	2	3	0	2	3	1	2	1	1	1	1	1	2	3	1	0	4	3	0	4	2	0	1	1
admiration	6	1	0	1	0	1	5	0	1	1	2	3	0	2	1	4	1	2	1	0	2	2	1	1	2	3	3	0	1	1	7	0	0	1	0
aversion	6	0	2	0	0	7	1	0	0	0	8	0	0	0	0	8	0	0	0	0	6	1	1	0	0	6	1	1	0	0	8	0	0	0	0
dissatisfaction	2	2	3	1	0	6	1	1	0	0	6	2	0	0	0	3	3	2	0	0	7	0	1	0	0	6	2	0	0	0	3	3	1	1	0
embarrassment	5	2	1	0	0	6	1	1	0	0	7	0	0	1	0	6	1	1	0	0	6	2	0	0	0	8	0	0	0	0	8	0	0	0	0
anxiety	6	1	1	0	0	6	1	1	0	0	7	1	0	0	0	6	2	0	0	0	6	1	1	0	0	5	2	1	0	0	8	0	0	0	0
sadness	6	2	0	0	0	5	2	1	0	0	6	2	0	0	0	7	1	0	0	0	8	0	0	0	0	8	0	0	0	0	8	0	0	0	0
boredom	1	4	2	1	0	5	2	0	1	0	4	3	1	0	0	3	0	3	2	0	6	0	2	0	0	5	2	1	0	0	1	2	3	1	1
contempt	2	4	2	0	0	4	3	1	0	0	7	1	0	0	0	6	1	0	0	1	7	1	0	0	0	7	1	0	0	0	3	3	1	1	0

CS	A					B					C					D					E					F					G				
	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
desire	4	3	1	0	0	5	0	0	3	0	4	3	0	1	0	2	3	1	1	1	3	3	1	1	0	3	1	2	1	1	5	1	1	0	1
satisfaction	4	3	1	0	0	4	1	1	2	0	5	1	1	1	0	4	1	2	1	0	2	3	2	0	1	4	1	3	0	0	5	2	0	1	0
pride	5	2	1	0	0	5	0	2	1	0	6	0	0	2	0	5	2	0	0	1	4	2	1	1	0	3	2	1	1	1	6	1	0	1	0
hope	6	0	2	0	0	5	1	1	1	0	4	3	1	0	0	6	0	2	0	0	4	2	0	2	0	5	2	1	0	0	7	1	0	0	0
joy	6	1	1	0	0	4	1	1	2	0	3	0	2	3	0	3	2	3	0	0	1	3	1	2	1	3	1	4	0	0	4	1	2	1	0
curiosity	6	0	1	0	1	2	3	0	2	1	2	1	3	1	1	3	0	2	2	1	0	3	2	1	2	4	1	1	2	0	3	3	0	1	1
admiration	6	1	0	1	0	5	0	1	1	1	4	2	1	0	1	4	1	1	2	0	1	2	1	3	1	4	0	3	1	0	4	1	0	3	0
aversion	6	1	1	0	0	7	0	1	0	0	5	3	0	0	0	6	0	1	1	0	5	2	0	0	1	6	1	1	0	0	5	2	0	1	0
dissatisfaction	5	1	1	0	1	3	4	1	0	0	6	1	1	0	0	4	2	1	1	0	5	2	1	0	0	4	3	1	0	0	6	0	1	1	0
embarrassment	6	0	0	2	0	4	3	0	1	0	7	0	0	0	1	6	1	0	1	0	7	1	0	0	0	7	0	1	0	0	5	0	3	0	0
anxiety	6	2	0	0	0	6	2	0	0	0	6	2	0	0	0	5	2	0	1	0	3	2	1	1	1	4	3	0	1	0	7	1	0	0	0
sadness	6	0	1	1	0	5	1	1	0	1	7	0	1	0	0	7	0	1	0	0	8	0	0	0	0	7	0	0	1	0	7	1	0	0	0
boredom	3	1	3	1	0	4	4	0	0	0	4	2	1	1	0	6	2	0	0	0	7	1	0	0	0	4	3	0	1	0	3	1	2	2	0
contempt	7	1	0	0	0	6	1	1	0	0	6	1	0	1	0	5	2	0	1	0	4	3	0	1	0	4	2	2	0	0	6	0	2	0	0

Table C.6: Cumulative Likert values. An entry indicates how many participants rated an emotion (left) to a state (top) with a certain Likert value (0 to 4, below state) in group PB or CS.

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