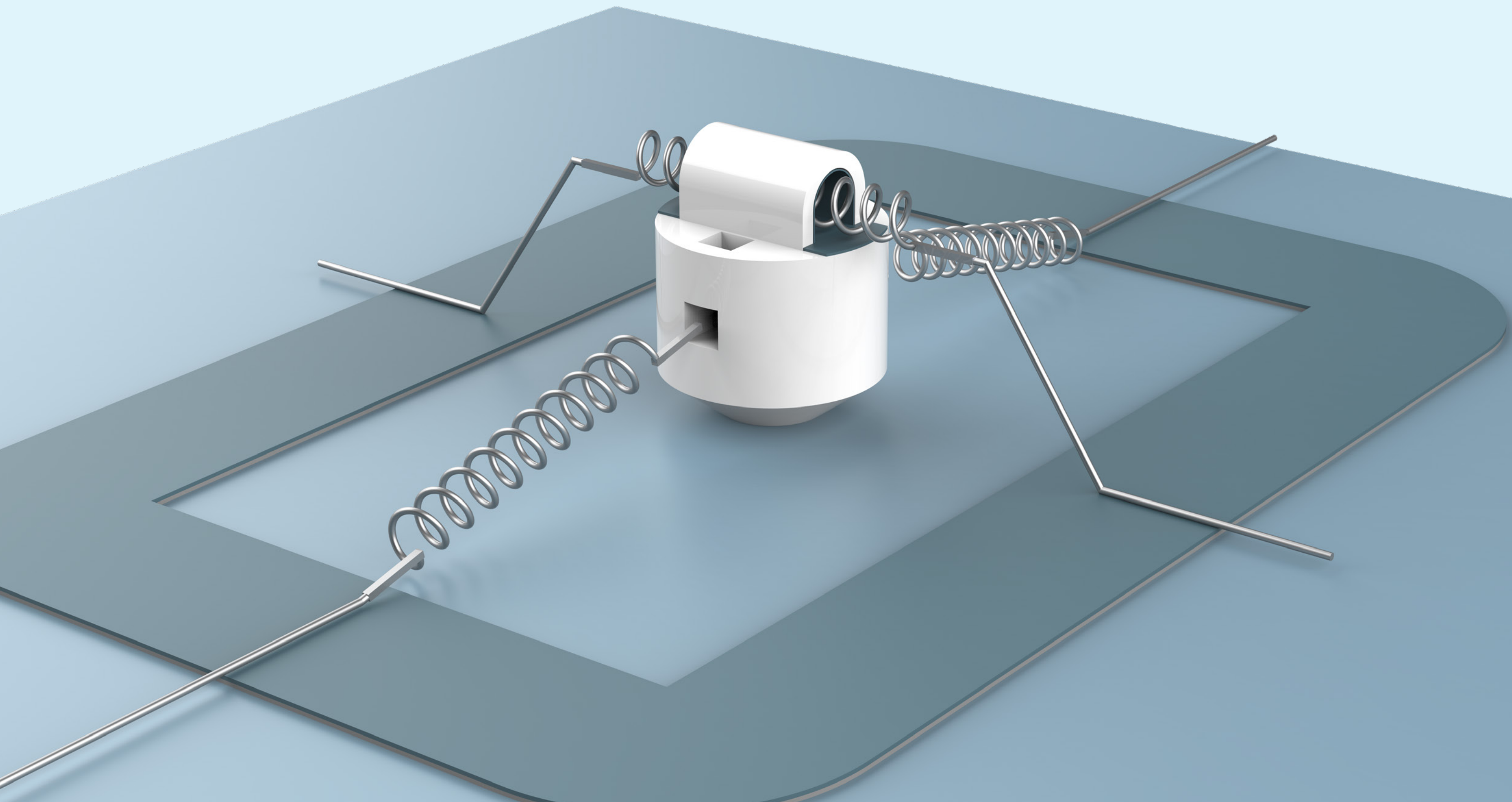
INTEGRATING SHAPE MEMORY MATERIALS INTO HAPTIC TECHNOLOGY

How can it be incorporated as an aid for the visually impaired?

Master Thesis | Preeti Sandhir | July 2021



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Executive Summary

There are approximately 285 million people worldwide living with a visual impairment and the rate of acquired blindness is expected to continue increasing. Assistive technology for them is progressively being developed in order to enable independent living. For the blind and visually impaired, the tactile sense is the primary source of understanding non-audible information. Therefore, haptic technology is being incorporated more in assistive devices meant for situations in which one cannot rely on sight to manipulate objects and conduct various activities.

An issue with currently available haptic solutions is that they typically use electromechanical systems that are heavy with large, obtrusive forms, produce sounds that hinder their usability and sometimes even provide unpleasant haptic feedback. A way to mitigate these problems is by incorporating soft, flexible and lightweight smart materials as actuators into these systems. Shape memory materials are a specific category of smart materials that have the ability to recover their original shapes from a deformation when certain stimuli are applied. They have the potential to bring hedonic characteristics to haptic technology such as providing organic sensations. Consequently, the haptic assistive devices become effective and comfortable interventions for the visually impaired.

This project demonstrates how these materials can successfully be incorporated to produce different types of tactile feedback as a form of an assistive-wearable and enriching the lives of the blind and visually impaired.

Abbreviations

AF- Austenite Finish Temperature
BVI- Blind or Visually Impaired
FDM- Fused Deposition Modeling
PLA- Polylactic acid
SMA- Shape Memory Alloys
SHM- Social human communication
SMC- Shape Memory Composites
SME- Shape Memory Effect
SMH- Shape Memory Hybrids
SMM- Shape Memory Material
SMP- Shape Memory Polymers
TPDT- Two-Point Discrimination Threshold
TPU- Thermoplastic polyurethane

Terminology

Austenite finish temperature- the temperature at which martensite to austenite transformation is completed when heating a shape memory alloy.

Bias force- A counter force to the force and movement of a shape memory material during actuation, which enables the setup to provide two-way actuation.

Effector- An object/material that provides haptic sensations to the skin due to its movement or shape change caused by an activate shape memory material.

Passive material- Materials in a setup which do not provide shape memory effects

Straight annealed wires- wires which already show the shape memory effect and return to a straight wire when heated above the austenite finish temperature.

Strain- A change in shape or size resulting from applied forces.

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1.
Introduction

1.1 The Project

This graduation project focuses on exploring how currently available shape memory materials (SMM) can be incorporated into haptic technology applications in order to improve the wellbeing and lifestyles of the blind and visually impaired. An overview of the project is presented in fig 1.1

Both haptic technology and shape memory materials are gaining popularity now with large, well-known companies exploring their applications. An example is the new Apple Pencil design which incorporates haptic feedback to allow users to 'feel' what is on the screen (Monckton, 2020). NASA is also exploring shape memory alloys for the development of tires that can handle the extreme terrain of Mars (Sands, 2020).

There is evidence that tactile sense in sensory substitution aids can be effective as methods of communication by providing information to sensory disabled individuals. This is especially since it is not localized to specific regions of the body, as is the other senses (Sorgini et al., 2017, Culbertson et al., 2018).

There is approximately 285 million people worldwide living with a visual impairment (He et al., 2020) and the rate of acquired blindness is expected to continue increasing (Bourne et al., 2017). Assistive technology are being progressively developed in order to enable them to live independent lives (Assistive Technologies Demand for Visually Impaired Market Forecast, Trend Analysis & Competition Tracking - Global Market Insights 2020 to 2026, 2020, Hwang et al., 2020). It is predicted that the demand for assistive technology for the blind and visually impaired market will have a large growth in the future (Assistive Technologies Demand, 2020) and it will be continuously expanding according to technological advancements (Hwang et al., 2020). This can be seen in fig 1.2, which presents the forecast of the demand for assistive technology.

Through my interaction with the visually impaired for previous projects, I have learnt that a majority of people use the basic aids available in the market such as the white cane, screen readers, magnifiers etc. although some of them are difficult to use to the fullest. For example, the general public tends to stand on the tactile tiles in train stations, leaving them unusable for the blind and visually impaired (refer to fig 1.3). Therefore, there is a need for development of new, relevant and effective methods of aids which are easily accessible to a majority of the target group.

There is a large opportunity to incorporate haptic technology in situations in which one cannot rely on sight in order to manipulate objects and complete tasks (Culbertson et al., 2018). Haptic technology is already starting to get incorporated more into assistive technologies, areas of relevance include workplace, education, leisure activities, daily activities and navigation. For example, a mobility service launched in Busan, South

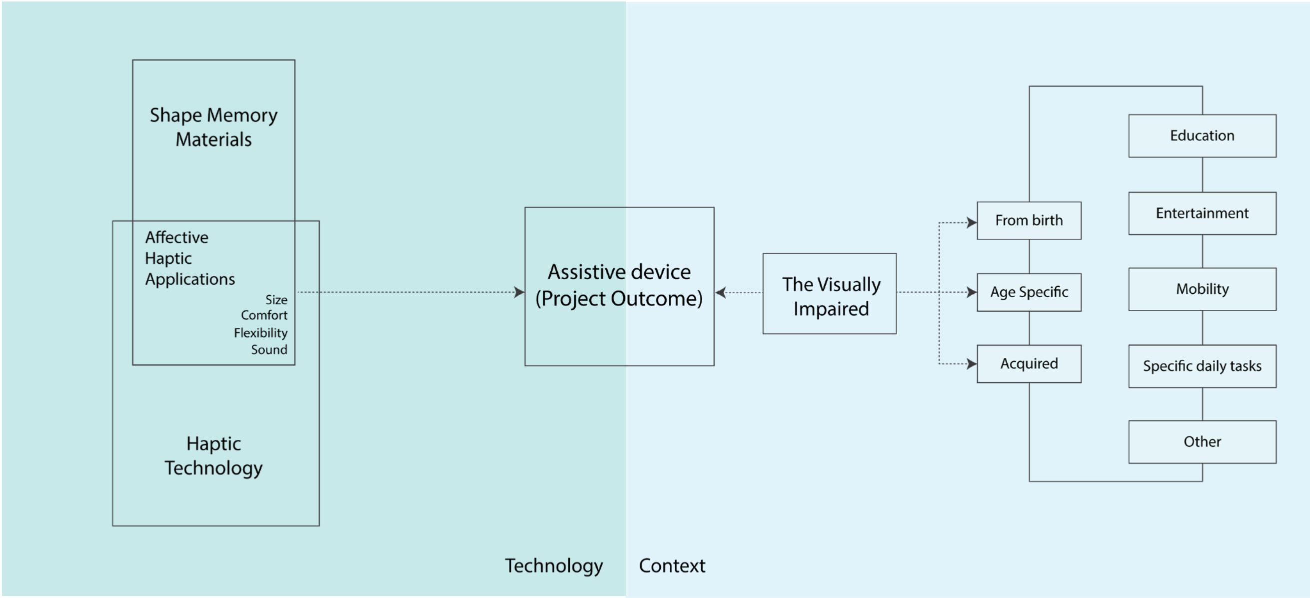


Fig 1.1- Overview of project

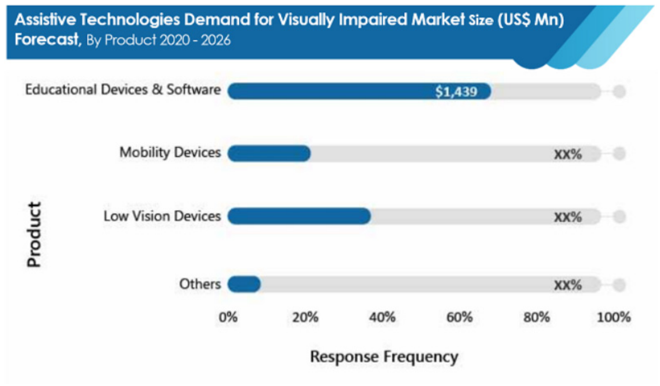


Fig 1.2- Forecast of assistive technology demand (Assistive Technologies Demand, 2020)

Fig 1.3- Obstructed tactile pavement in Rotterdam Central Station

Korea has placed a kiosk in a metro station with a Braille touch pad which can transform into a tactile map for navigation aid (Strother, 2021). .

A problem with many currently available haptic solutions is that they are large, produce sounds that hinder their usability and sometimes produce unpleasant haptic feedback. New types of actuators made from smart materials are starting to be incorporated into these systems since they have the ability to be thin, flexible, light weight as well as effective (Cruz et al., 2018). A fascinating aspect is that different materials can be combined in such a way that specific properties can significantly change in a controlled fashion in response to an environment, for eg- "robotic fabric" (New Atlas, 2020). Shape memory materials have the potential to bring hedonic characteristics to haptic technology by providing organic sensations and hence make the haptic assistive devices both effective and comfortable interventions for the blind and visually impaired.

This graduation project is to select and evaluate shape memory materials integrated in haptic applications regarding their affective properties (those that could potentially influence emotions and attitudes) and as solutions for improving the wellbeing and lives of the blind and visually impaired. Through this study these technologies will be applied in the form of interactive assistive device (graspable, wearable or touchable). Taxonomy of the important elements of the project can be found in Appendix A.

1.2 The Approach

This project has three main aspects to it- shape memory materials, haptic technology and the context of the blind and visually impaired. As portrayed in fig 1.4, there are multiple approaches to the project according to which aspect to focus on first.

It was decided to initially focus on answering the question of how shape memory materials can produce haptic feedback. After which the opportunities of incorporation for the blind and visually impaired were to be looked into.

Since there are a large variety of shape memory materials currently available, it was important to understand these materials first, before selecting specific ones for further studying. A literature review was conducted to understand what values these smart materials bring to haptic application, how they are currently being incorporated and perception of the feedback. This lay out the foundation of the possibilities and limitations of the materials which became the first level of definition for the project. Parallel to this, the target area was looked into, understanding how haptics can be a form of aid for the blind and visually impaired, the current usage and new opportunities for haptic assistive devices.

Some of the materials were then explored and experimented with, in order to understand their properties, behaviour, and grasp how they can be used in design. This led to the selection of one shape memory material to move forward with along with a haptic technology format.

The selected material was then explored as actuators in combination with different passive materials for the selected haptic format. The most feasible and effective one was built into a demonstrator and tested with participants outside the target group. The insights gathered from these tests and discussions led to a new refined demonstrator.

This demonstrator was then tested with different blind and visually impaired people, to understand their perception of the haptic feedback and possible future applications.

The project ended with a demonstrator of how shape memory materials can be incorporated in haptic technology and future recommendations so that it can successfully become an assistive device for the blind and visually impaired.

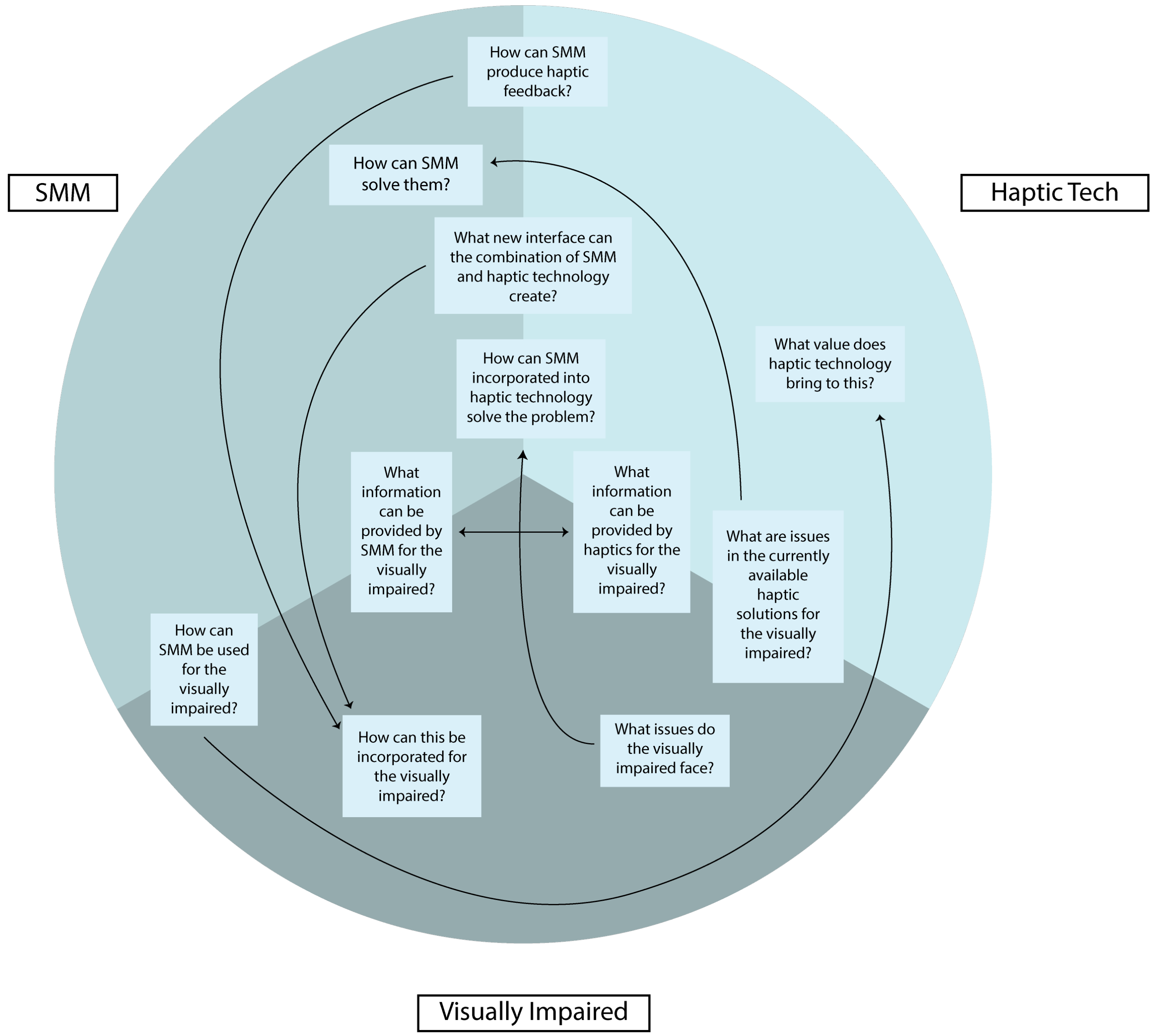


Fig 1.4- Project approach options

2.

Literature Review

2.1 Haptic Technology

The sense of touch or 'haptics' is an important method to explore, understand and interact with the world. Touch creates a sense of presence and is part of fundamental human behaviour to assure oneself in reality. It is means of not only exploration but also emotional connections. This sense is not localized to a specific region of the body, unlike the other senses (Culbertson et al., 2018) and hence has a large potential for a wide variety of applications. Haptic technology incorporates this as a form of communicating information. According to American Library Association- Center for the Future of Libraries haptic technology can be defined as "technology that incorporates tactile experience or feedback as a part of its user interface, creating a sense of touch through vibrations, motion or other forces" (Haptic Technology, 2018). It is based on the assumption that people generally respond well to tangible stimuli (Wójcik, 2019).

Haptic feedback has large potential in rendering abstract concepts as means of communication. Most commonly, they are being used as methods to notify users of events, identify current state or contents such as vibrations for a phone notification. There is also potential of communicating more intelligible information by becoming a language of itself (Enriquez et al., 2006). This will be explained further in chapter 3.

For haptic perception, two main types of sensory afferents are important- the mechanoreceptive and the proprioceptive types which provide information via the skin and muscles respectively. Each receptor type specializes in certain information functions such as curvature, corners or forces parallel to the skin (M. A. Hersh & Johnson, 2008). There is also a variation in the discrimination of different stimuli on the skin throughout the body. A measurement called the Two Point Discrimination Threshold (TPDT) is used to show the distance two pressure points should be in order for them to distinguishable (Velázquez, 2010). Fig 2.1 shows the TPDT of different parts of the body. For example the TPDT of the forearm is 40 mm while for the finger tips it is 2.54. This should be considered when designing haptic based devices especially like wearable tactile displays.

An important aspect to take into consideration is that touch perception isn't veridical. This means that it is not always perceived as it actually is. For instance the perceived distance between touches on a skin surface is larger on places of high acuity or tactile sensitivity than those with lower acuity. This effect is known as Weber's illusion (Longo & Haggard, 2011). For example the distance on a finger will be perceived as larger than the same distance on the hand. It was also seen that there is a difference in tactile perception according to orientation as well. For example vertical distance on the back should be larger than horizontal in order to be distinguishable yet there is a tendency for spatial distortion. Other influences on tactile perception include intensity and grouping of the sensations.

An issue with largely available haptic solutions is that they typically use electromechanical systems that are heavy with large, obtrusive forms and produce sounds that hinder their usability. An example of this is the Skin Drag Display (fig 2.2). The device aims at moving a small physical tactor across the skin (Ion, A. et al, 2015). The supportive mechanism is quite bulk. Many haptic systems also produce sensations which are often not very pleasant (Cruz et al., 2018, Muthukumarana et al., 2020, Biswas & Visell, 2019). One method to mitigate these problems is by incorporating soft, flexible and smart materials as actuators into these systems. Skin is mechanically soft and therefore in order to be ergonomically comfortable and have an improved mechanical transmission, the system should match the compliance of the skin (Biswas & Visell, 2019).

Take-away

- Haptic technology can render abstract concepts as means of communication
- Touch perception is not always perceived as it actually is which needs to be taken into consideration when developing a device which is highly dependent on this sense.
- Many of the currently available haptic solutions are large, heavy and obtrusive and often produce unpleasant sensations

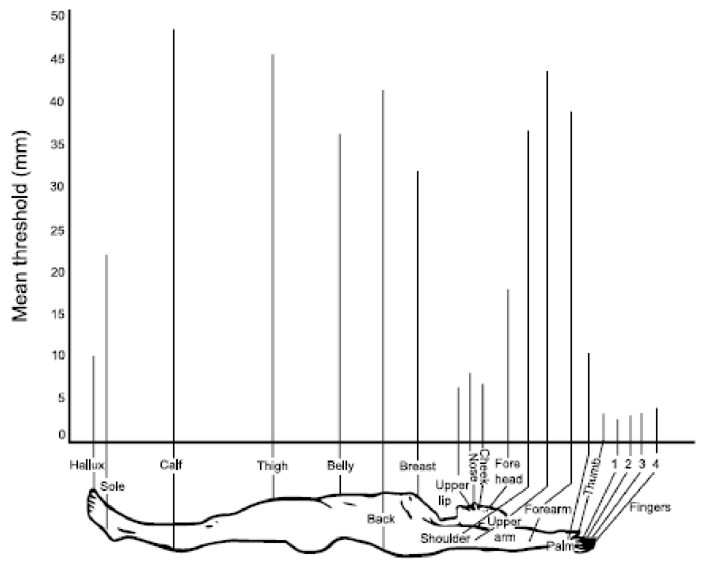


Fig 2.1- Two Point Discrimination Threshold (Velázquez, 2010)

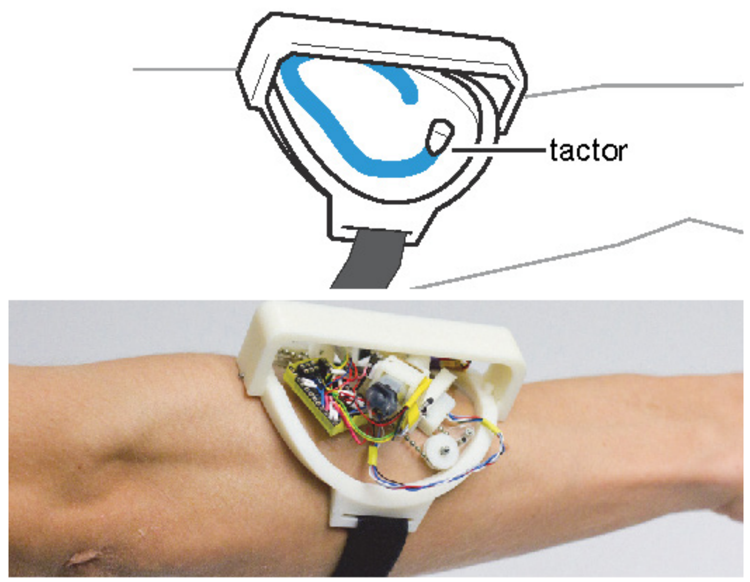


Fig 2.2- Skin Drag Display- a bulky supportive hardware for haptic wearables (Ion, A. et al, 2015).

2.2 Shape Memory Materials in Haptic Applications

Shape memory materials (SMM) are a specific category of smart materials that have the ability to recover their original shapes from a deformation when certain stimuli are applied. This ability is known as shape memory effect (SME). These materials are valuable to designers as they allow the development of shape shifting objects.

Although SME was found in 1932 in AuCd alloy, it only became more appealing in 1971 when NiTi alloy was studied (Huang, 2019). Now, a larger variety of SMMs are being incorporated into commercial use. Conventional materials have limitations in advanced functionalities like mechanical flexibility, transparency and size, so we see these smart materials replacing them in a large number of applications such as in haptic solutions. They have the potential to bring hedonic characteristics to haptic technology hence making them both effective and comfortable interventions.

Many types of external stimuli can change the shape of materials such as heat, light, moisture, magnetic field etc. These materials are of a large variety from the more traditional ones such as alloys and polymers to newly emerging types called hybrids (Huang et al., 2010).

In order to fully grasp how these technologies can be applied for improving the wellbeing and lifestyles of the blind and visually impaired, literature research was done to understand how shape memory materials are currently being incorporated into haptic technology. This not only provides insights into how shape memory materials bring value to haptic technology but also how different types of haptic feedback are perceived. The purpose of the literature review was to get familiar with current research and thinking which would highlight opportunities for further study for this application. The literature selected for this review was filtered according to the variety of applications, haptic feedback, format of materials and opportunities of incorporating as aids for the blind and visually impaired. An overview of the literature studied can be found in fig 2.3. The review had the limitation of studying work available and published in English.

For this study three types have been investigated for integration into haptic systems- shape memory alloys, shape memory polymers and fluids. Other haptic systems have also been looked into which have the potential of improvement with the help of shape memory alloys and have opportunities of enriching the lives of the blind and visually impaired.

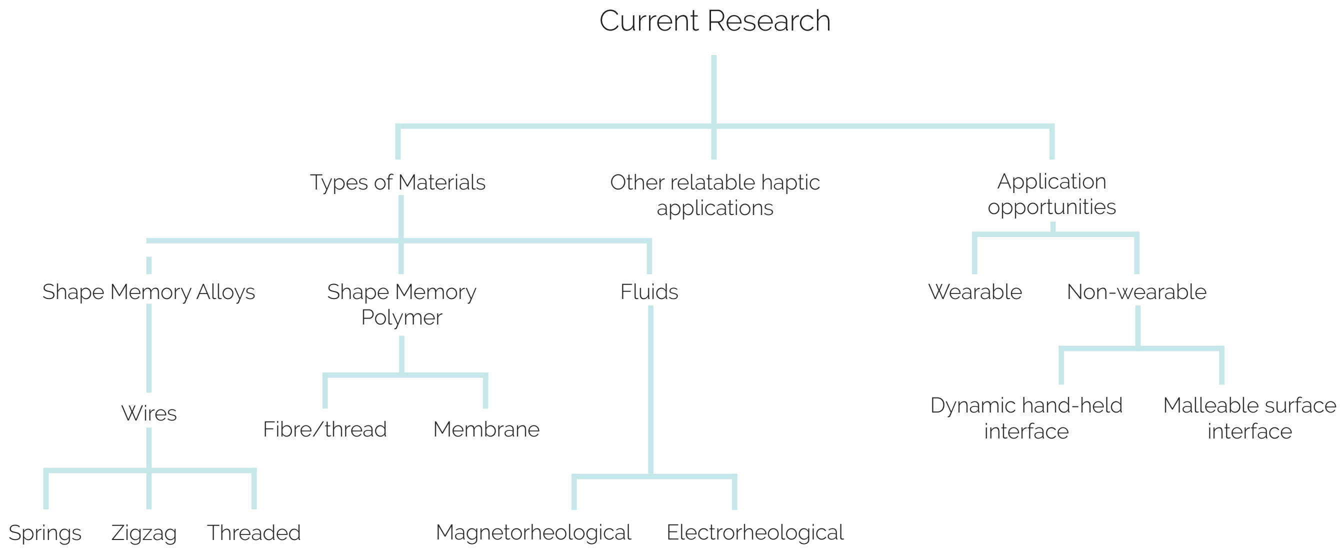


Fig 2.3 Overview of literature studied

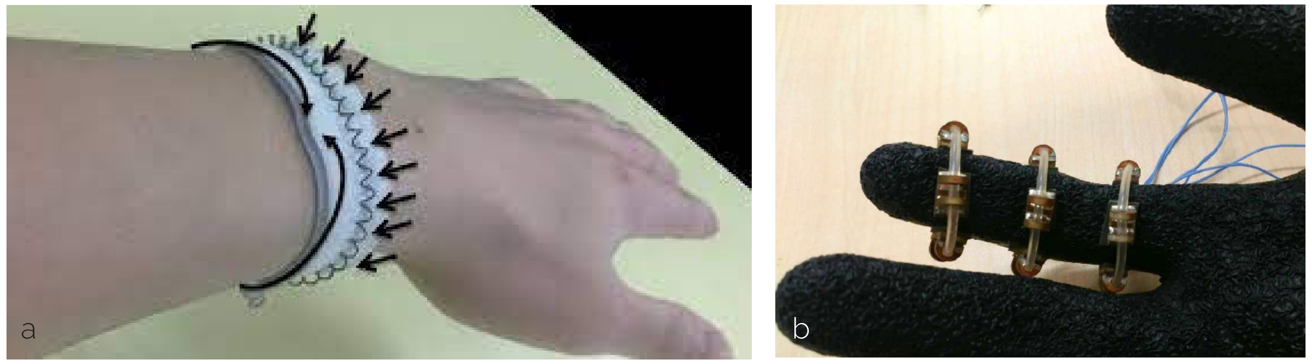


Fig 2.4- a HapticClench (Gupta et al., 2017). b Chernyshov et al. (2018)

2.2.1 Shape Memory Alloys

Shape memory alloys are one of the earliest and most familiar types of shape memory materials (Bengisu & Ferrara, 2018). They contract when their temperature is increased and expand when the stimulus is removed. They are attractive due to their high force-to-weight ratio, compactness and pliability (Mohd Jani et al., 2014). Currently, a majority of the haptic applications use Nickel-Titanium (Ni-Ti) alloys, potentially due to their affordability and reliability. The form and setup of the alloys though change in every application according to preferences of the type of haptic feedback, position on the body etc. Many shape memory alloys have been employed as actuators in order to create a more variety of sensations unlike the possibilities of the more commonly used vibrotactile simulations.

Haptic Applications

It is seen that shape memory alloys in the form of wires/springs can successfully be incorporated as means of actuators in both wearable and non wearable haptic systems. They can be programmed to provide a variety of different organic sensations according to their format, location on the body etc.

In the case of HapticClench (Gupta et al., 2017) it was seen that the wire in the form of springs provided good squeezing sensations. In this device, Flexinol- a commercially available Ni-Ti alloy – was tested in the form of both wires and springs attached to Velcro around the wrist (refer to fig 2.4a). The springs were found to have better contraction force and sensation and required less restorative force (which the squeezed skin could provide). The haptic sensations were tested in two formats- multi-clench and slow clench. It was seen that multiple points of squeezing could be identified easily yet locating of the exact point was difficult. Staggered pulses were more preferred as gradual slow progression than a continuous pulse.

Selection of the body location for wearables depends on how noticeable and identifiable the sensation should be, like in the HapticClench (Gupta et al., 2017) squeezing around the wrist was considered more subtle than around a finger. Although, Chernyshov et al. (2018) demonstrated that “finger augmentation devices”are great methods of providing haptic feedback because fingers and fingertips have a high concentration of nerve cells and nerve endings. The device consisted of a Ni-Ti wire kept in a silicon tube (Refer to fig 2.4b). By varying the electric current to the wire, it would expand and contract, therefore providing the sensation of pressure.

Springlets (Hamdan et al., 2019) also tested SMA in the form of springs in different parts of the body (refer to fig 2.5a). The wires behaved as skin actuators (by stretching the skin surface) or effector actuators (by moving an object against the skin) and could provide a large variety of haptic sensations. It was seen that the sensation of pinching was highly noticeable on the chest, pressing on the back and dragging on the wrist, upper arm, shoulder and neck. Generally, sensations were more noticeable when the user was sitting as compared to walking.

Along with body location, specific types of sensations are more identifiable than others (according to the SMA format). Touch me

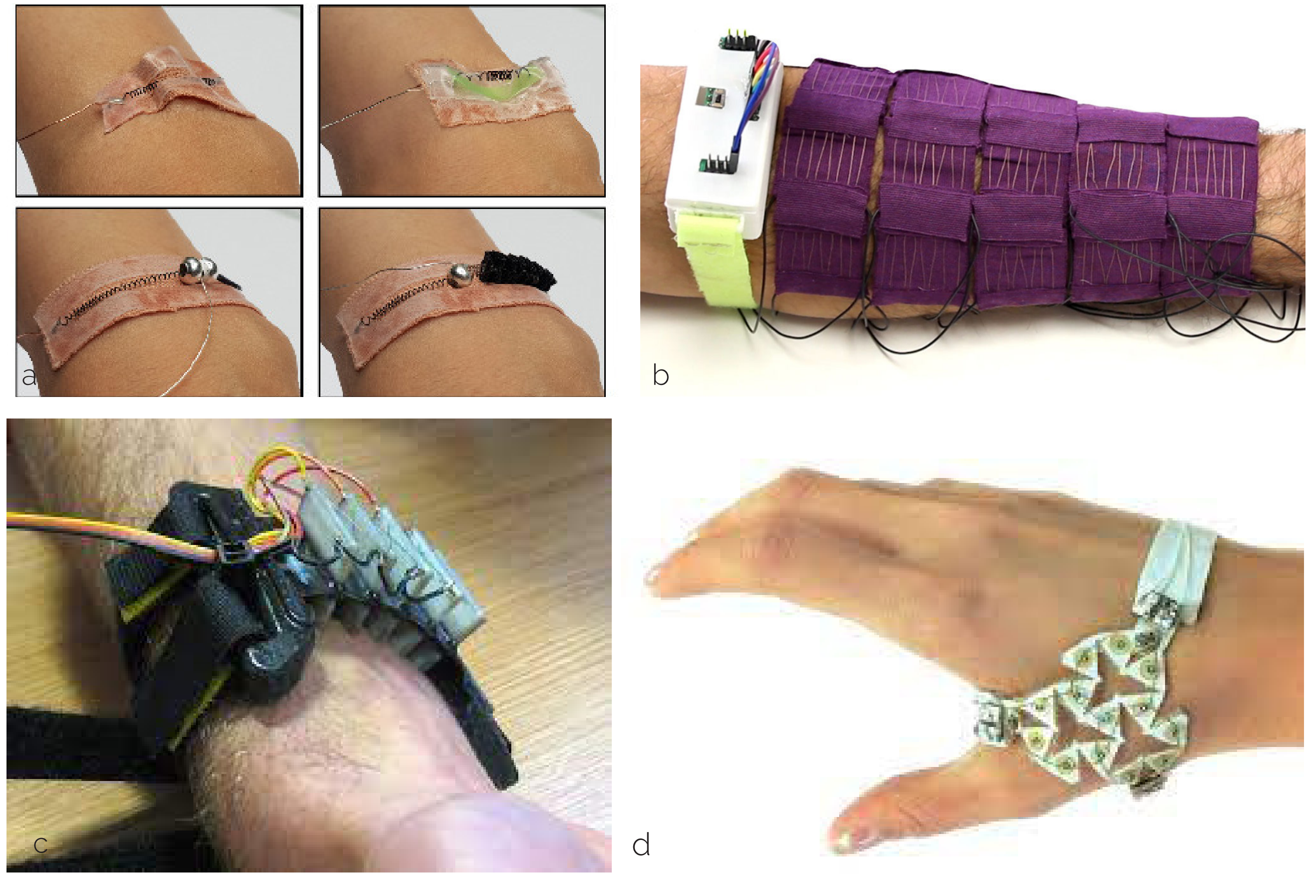


Fig 2.5-a Springlets (Hamdan et al., 2019), b Touch me Gently (Muthukumarana et al., c 2020 Tickler (Knoop & Rossiter, 2015), d Skin+ Cao et al. (2018)

Gently (Muthukumarana et al., 2020) was a wearable aimed at recreating eight different types of natural touch sensation namely- grabbing arm, grabbing wrist, 3 taps down the arm, 3 taps up the arm, encircling/rolling on arm and encircling/rolling on wrist. In this case, the alloys were in the form of a zigzag laid out between multiple layers of materials (meant for different purposes such as generating shear force on the skin, thermal dissipation or as insulation) as a plaster matrix on the arm (refer to fig 2.5b). Grabbing wrist, stroking up and encircling/rolling on wrist were the most identifiable sensations.

Gentle, unobtrusive means of communicating non-urgent information was achieved in the Tickler (Knoop & Rossiter, 2015). In this setup, the shape memory alloy wires were arranged between tactile bars which enabled the actuation to cause the specific bars to contract near the actuator and splay out against the skin. The sensation created by this device was stroking, although it could potentially provide more sensations such as pinching, pulling apart etc (refer to fig 2.5c).

Alloys can be combined with different materials which would affect their behaviour such as a passive shape memory material. In the master thesis project of Stolk, L. (2017), a shape morphing composite was created by combining Nitinol with silicon, field's metal and silicon rubber in order to create a hinge motion. The combination was required to create a compact automated composite with an effective heating method and capable of two-way movement. Cao et al. (2018) demonstrated in Skin+, how haptic feedback can be achieved by combining shape memory alloys and auxetic structures. The outcome was a thin, light weight, on-skin interface which provided squeezing sensations to the users. The device had three segments which contained one wire actuator each (refer to fig 2.5d). Although each segment was controlled individually, the physical connection between them would automatically move the other segments, thus leading to a haptic sensation.

Other combinations of SMAs with different materials are seen in a variety of non-wearable formats such as in the case of Surflex (Ishii, 2008). Surflex was a programmable

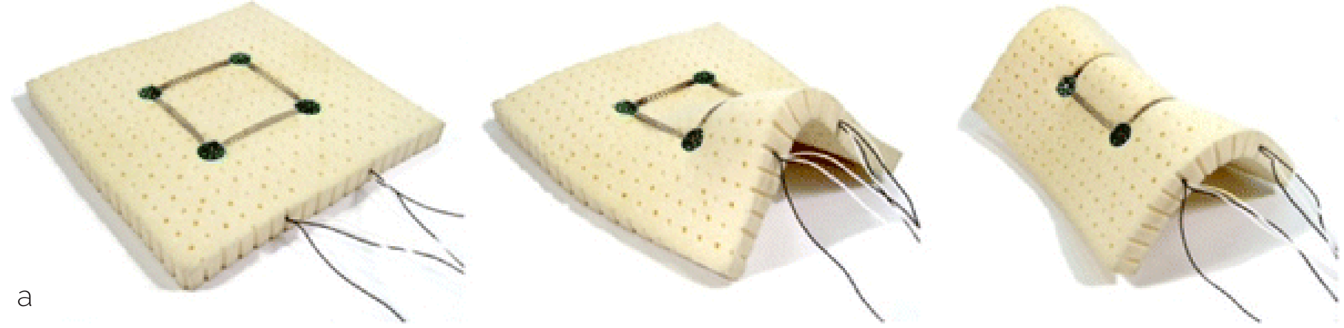
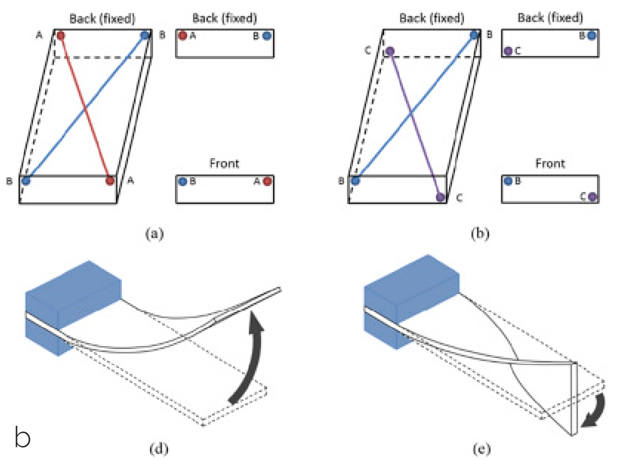
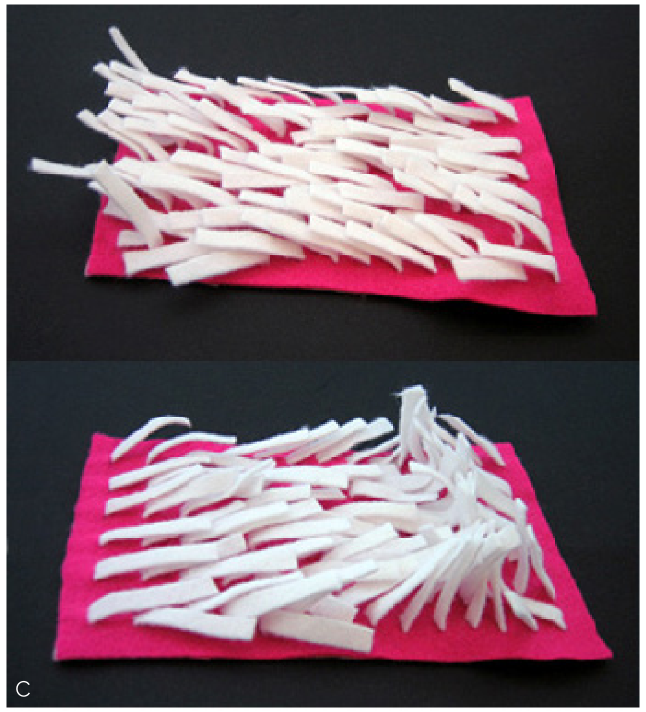


Fig 2.6a Surflex (Ishii, 2008), 2.6b, Rodrigue et al. (2015), 2.6c Sprout I/O (Coelho & Maes, 2008), 2.6d Lumen (Poupyrev et al., 2004)



surface combining active and passive shape memory materials. Ni-Ti wires were the active programmable shape memory materials while foam acted as the bias force once the alloy wires cooled down to a malleable martensite state (refer to fig 2.6a). By embedding eight alloy wires as sources of actuation into the system, a wider variety of movements could be achieved, along with adaptability to different needs.

Rodrigue et al. (2015) also created a smart soft composite capable of producing multiple modes of actuation with the help of shape memory alloys. The alloys were embedded in a rectangular polydimethylisiloxane matrix such that they could provide movements like bending, twisting and a combination of both in different directions (refer to fig 2.6b). The movement depended on which wires were activated.



Sprout I/O (Coelho & Maes, 2008) had a unique approach of creating a soft and kinetic membrane for means of both input and output by combining textiles and shape memory alloys. It was a haptic interface meant for both tactile and visual communication. This interface was made from shape memory alloy wires and felt composites with the alloy being placed on both sides of the felt for bi-state actuation (refer to fig 2.6c). This interface achieved creating a unique aesthetic and textural rich multi-sensory experience.

Another example of an interactive display that provided both physical and visual feedback was Lumen (Poupyrev et al., 2004). Users were able to interact with the display directly by forming shapes with their hands which would lead to a smooth physical motion of light guides (refer to fig 2.6d). The setup incorporated the characteristic of shape memory alloys of rapidly contracting when current is passed and returning to its original length when cooled. Each guide had an individual alloy attached to it and the device used capacitive sensing to detect touch applied by the user. This device is interesting because it is simple and easily scalable to become a large information display. An application proposed in the study was embedding into walls, furniture, ceilings etc. because it had the ability to be hidden when not in use.

Parkes (2009) presented different experiments of programmable kinetic forms in order to create and manipulate motion in response to computational and material input. The purpose of the study was to create an open-ended toolkit that could form into a 'kinetically transformable meshed textile interface". In the 'Bosu system', different formations were tested such as hinges, circular cinches and triangles. In these setups, nitinol was incorporated with flexible polypropylene sheets which had spring back capabilities. Eventually, a mesh of repeated trapezoids was created. Each module had only one embedded nitinol wire for actuation. The setup incorporated bendable polypropylene sheets laminated between a polyester fabric with the alloy wire threaded into it. This study was interesting to see how a setup like this can be applied to many different fields such as fashion design, architecture etc. with a wide variety of different uses. It didn't directly present applications with haptic feedback but has the potential of being incorporated as means of both wearable and non-wearable haptic interfaces.

The study successfully proved that SMA could provide noticeable and pleasant haptic sensation be it as a wearable or non-wearable device. It even identified a few haptic sensations which are considered to be more pleasant such as stroking and squeezing. It was also proven that it is beneficial if a composite is created from this material since the setups can be programmable and reversible by tapping into the physical properties of all the materials used. This study brought awareness to how attention should also be on attachment methods on the skin, in the case of wearables, since there were issues in some of the devices studied. A limitation of shape memory alloys that was brought to light was that there may be actuation delays, heat accumulation and a hysteresis behaviour (dependency on many aspects such as exposure time and temperature with persisting effects). Shape memory alloys in formats other than wires as means of actuation still have to be studied more.

Take-away

- SMAs can produce pleasant and noticeable haptic sensations
- Some sensations are more pleasant such as stroking and squeezing
- SMAs should be combined with other materials to aid properties such as reversibility
- SMAs have drawbacks of actuation delay and heat accumulation

2.2.2 Shape Memory Polymers

Shape memory polymers (SMP) are another well- known type of shape memory material. These materials have the potential of costing less than the shape memory alloys already available. They have the advantage of having lower densities and manufacturing temperatures and their shape can be easily programmed (Bengisu & Ferrara, 2018). Their material properties can also be more easily tailored through cross-linking (Garcia, 2014, p. 123). Limitations of shape memory polymers as compared to shape memory alloys are that they have lower application temperatures, strength and stiffness. They also produce lower actuation forces and respond slower (Bengisu & Ferrara, 2018).

Shape memory polymers are most commonly activated thermally. If the SMP is heated above its transition point (either the glass transition point or melting point according to the type of polymer), its shape can then be changed. The polymer should then be cooled below the transition temperature in order to retain this new shape. If it is reheated above the transition point, then it returns to the original shape.

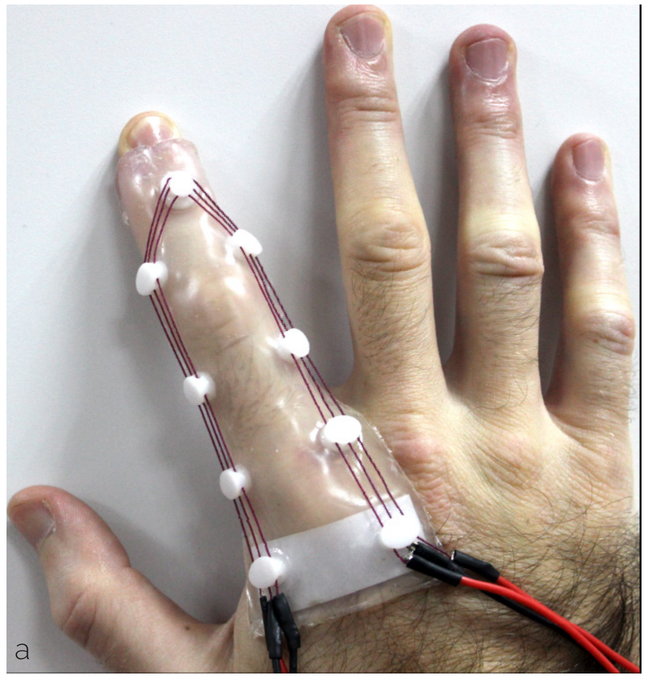
Haptic Applications

It has been seen that polymers can be incorporated as actuators for haptic application in two main formats- thread and membrane.

Chossat et al. (2019) used SMP in the form of fibre in order to produce a lateral skin stretch on a finger. In this setup, polymeric fibres were twisted and coiled with two Ni-Cr wires. In the device there were three actuators that would pull silicon rubber with the help of distal pins, creating the haptic stimuli (refer to fig 2.7a). The elasticity of both skin and the silicon acted as the bias force to the shape memory polymer.

Besse (2018) created a polymer actuator in the form of a thin membrane bonded with stretchable heating electrodes. Taxel motion was obtained by synchronizing the actuation from a common pneumatic source and local Joule heating (refer fig 2.7b). In this setup, the obtained force and displacement was good enough to discriminate each taxel individually. It was noticed that even though individual taxel actuation was possible, 'parasitive motion' was also observed. In terms of haptic perception, positive pressure or inflated up position was more pleasant than negative. A concern in this study was that polymer-based actuators could potentially degrade over time. This study did achieve demonstrating a refreshable display that was scalable and portable. This can serve many purposes such as learning, rehabilitation, navigation and mobility.

Although there are demonstrations of how SMP are used as actuators, there are limited studies done on this. This could be due to the limitation in how to activate these materials safely in close proximity to skin. The selection of incorporating shape memory alloys or shape memory polymers into



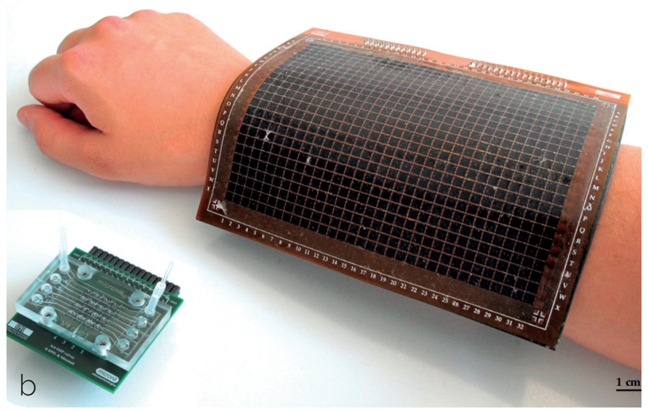


Fig 2.7-a Chossat et al. (2019), b, Besse (2018)

haptic technology is based on the specific requirements of the device as both materials have their own advantages.

Take-away

• Shapes of SMP can be easily programmed in the manufacturing process
• SMPs cost less and properties can be more easily tailored than SMAs
• SMPs in thread and thin membrane formats can be activated safely in close proximity to skin but there is lack of research for safely activating other formats
• SMP actuators can degrade over time
• Skin can successfully act as a bias force to the SMP motion
• For a touchable type of haptic system, positive pressure is more pleasant than negative

2.2.3 Electrorheological and Magnetorheological Fluids

Electrorheological and magnetorheological fluids are materials that have the capacity of changing rheological characteristics such as form, viscosity and rigidity in response to a stimulus (Bengisu & Ferrara, 2018).

The difference in both is in the stimuli to which they react. The rigid-plastic behaviour in both types is almost identical- polarization of suspended particles (insulated or magnetizable) lead to arrangement into rigid structures or chains which results in an increase in viscosity of the liquid. When the stimulus is removed, the viscosity drops leading the particles to return to a random state.

Haptic Applications

Some studies have been conducted to demonstrate how these fluids can be incorporated into haptic systems.

Mudpad (Jansen, 2010) was a multi-touch system with active tactile fluid-based feedback. This system incorporated magnetorheological fluids in which touch was detected by displacement of the fluid. This fluid has the advantage of switching from off to on and vice versa within 5 ms. By using an array of electromagnets, the system could provide localized feedback which was easily distinguishable for the users. This fluid- based system also had an advantage over more commonly available vibrotactile systems of providing continuous feedback sensation.

Another demonstration for incorporating magnetorheological fluids was provided by White (1998) who also created a force feedback device with no moving parts. The setup was a water-based non-toxic magnetorheological fluid in a bladder above a grid of 64 electromagnets (refer to fig 2.8 a). In this system, if the magnetic field remained constant then both hard and soft areas were created. If the field cycled at different frequencies, a vibrating texture or "exaggerated dynamic feedback" could be provided. This system has many potential applications including tactile displays, conveying information through finger painting and even entertainment.

Melli-Huber et al. (2003) presented the advantage of using electrorheological fluids in control knobs over mechanical components in order to encourage further developments of haptic interfaces for vehicular control. With the fluid, it is possible to decrease size, weight and power consumption while increasing force capability and degrees of freedom. As compared to magnetorheological fluids, this type of system requires a lot less power. It is also strong enough to resist hand motion. The fluid has the capability of being in a solid-like-state in the presence of electricity. This setup has the potential of combining functions of multiple instrument controls into one device, simplifying systems and providing information to the operator without requiring any visual attention.

Bose and Berkemeier (1999) also introduced an electrorheological fluid-based computer input haptic device with a simple mechanical construction. The function of the device was similar to a joystick with its movement being associated with movement on a computer screen. The electrorheological fluid had the requirements of high shear stress in an electric field, low base viscosity and good sedimentation stability of particles. When the electric current was applied there was a strong resistive force by the fluid against the movement of the stick. An application proposed in this study was a form of assistance to visually impaired people when working on a computer. With the help of the joystick the user could feel if the cursor entered the area he wishes to click on a screen.

Incorporation of the fluid as a compliant surface in passive tactile displays was demonstrated by Monkman (1992). This system depended on both compressive stress as well as applied electric field to work. If the fluid was allowed to flow freely between electrodes, then only in the vicinity of activated electrodes did the liquid harden (refer to fig 2.8 b). In this study, it was stated that if it is desired not to depend on applied pressure during exploration then the simple electrodes could be replaced by solid state valves and the fluid can be used as a hydraulic medium. This could widen the potential applications for this type of system.

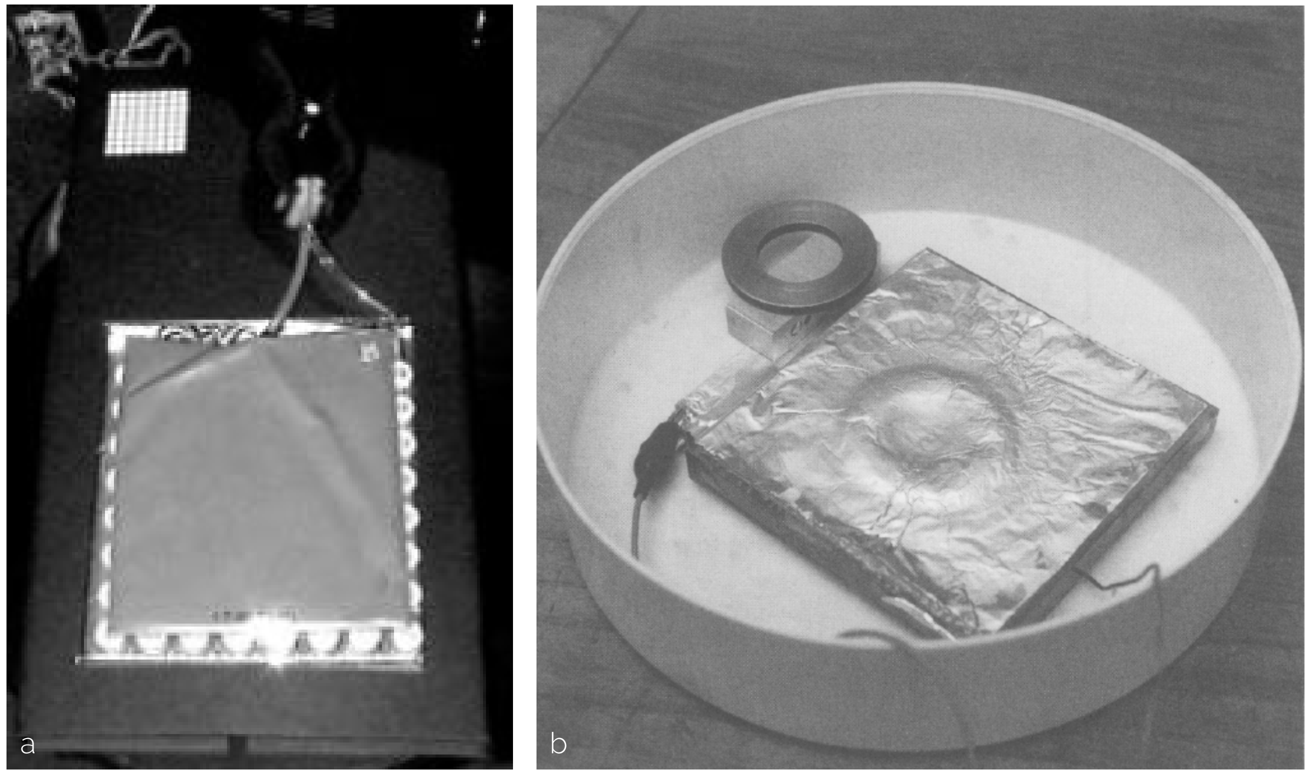


Fig 2.8-a water-based non-toxic magnetorheological fluid (White,1998). b Tactile display with electrorheological fluid (Monkman, 1992)

Take-away

• Electrorheological fluids require less power than magnetorheological fluids
• The fluids can be activated and deactivated very quickly
• The fluids provide continuous and dynamic feedback which is easily distinguishable by users
• The fluids require no moving parts and are capable of being applied to multifunction simple interfaces

2.3 Other Haptic Systems

A few other haptic devices were also studied. Although SMMs were not incorporated into these setups, they all provided interesting forms of haptic feedback and have the potential for improvement by the incorporation of smart materials. These devices also have opportunities of enriching the lives of the blind and visually impaired if further developed.

Similar to the multipurpose vehicular controls of Bose and Berkemeier (1999), the Haptic Chameleon (Michelitsch et al., 2004) also had the ability to provide multiple functions in one piece of instrument. It was a shape changing user interface that had the ability to convey information to and from the user. Users decided what the control did by changing the shape and could recognize the capabilities of the control through touch. The concept was demonstrated in both low and high-fidelity prototypes. The low-fidelity one had a grasp-ability aspect but was limited in terms of shape changing possibilities. It created a notion of surprise for users but they were able to adapt quickly to use it. The high-fidelity prototype had the limitation that it was only feel-able through thimbles so therefore had no grasping action. This prototype took longer to get used to because of the lack of actual 3d vision. This is important to take into consideration when designing a device meant to be intuitive.

Another form of direct and intuitive input devices was presented by Murakami and Nakajima (1994). The device was a cubical input device made of electrically conductive polyurethane foam. By deforming the shape of the cube, a user could intuitively manipulate a digital 3d shape. The deformation of the device was measured electrically in real time and represented digitally. The interesting aspect of this device is the free form manipulation as input. The user faced passive tactile feedback which the elastic material inherently generated. This helped the user feel the magnitude of deformation they are providing the input device.

The Bubblewrap (Bau et al., 2009) was a grid of electromagnetic actuators contained in a stretchable fabric. It created cells which could expand and contract individually. Electric current would cause an embedded coil to repel a magnet, leading to expansion of the specific cell. As a result of this movement, the setup could provide three types of haptic feedback- vibration, shape and firmness change. This setup has a wide variety of applications from active feedback dynamic passive feedback.

Super Cilia Skin (Raffle et al., 2003) was an interesting multi modal interactive membrane that presented information by changing the orientation of actuators also with the help of a magnetic field. In the device, the actuators were arranged in an array on a silicone membrane. They oscillated as a response to a magnetic field which in turn led to a deformation of the actuator angles on the top surface of the device. The elasticity of the membranes would pull the actuators eventually back to their original positions. The tactile feedback provided was subtle, described as 'butterfly kisses" but patterns could not be recognized tactilely. Although this setup was only tested as an output device there was a potential of incorporation as an input device as well. This study also presented the opportunities of applying this device to enhance children's learning and the benefits of physical experiences for long term memory.

Take-away

• There is a learning curve for new users which can be determined through type of interaction and haptic system category
• The support materials in the device can provide passive tactile feedback
• The capability of a device to produce perceivable haptic sensations does not ensure that patterns can be recognized tactilely

2.4 Material Comparison in Literature

The literature studied touched upon four types of shape memory materials- alloys, plastics, electrorheological and magnetorheological fluids. Although each material has similar characteristics, especially regarding its shape memory properties, their main physical properties may be different. For example elongation in alloys is much less than in polymers (6% compared to 50-600%).

Alloys have good mechanical properties like strength, corrosion and resistance. They are also advantageous because they have the ability to reverse completely to their original shape. The permanent shape for this material is created through thermal applications while for polymers it is done at the production stage. Their limitations include delays in actuation, overheating and persisting effects.

Shape memory polymers are lighter, more economical and easier to process. They also have high shape transformation, high recovery and soft touch. A disadvantage of this material is its weak recycling forces. Their triggering process is slow because it has low thermal conductivity as compared to alloys (<0.030W/m.K). It was also seen that they potentially wear down over time and have limited methods of providing the activating stimulus.

Electrorheological fluids are attractive materials because they have rapid, reversible and tunable transitions from fluid to solid state when an electric field is applied to it. They have long lives and are able to function in a wide range of temperatures (Mavroidis, 2002). Although they provide a lot of useful features their applications have been very limited. This is due to their behaviour being complex and nonlinear. They have relatively low attainable yield stress which results in the need for a large amount of fluid (Delivorias, 2004) and tends to be expensive. It also may need high voltage to control these devices and hence may have safety issues if the device is meant to be in close contact with human (Mavroidis, 2002). A This is being studied and experimented with more, though.

The rheological properties in magnetorheological fluids are also reversible and controllable when magnetic fields are applied to them. Their response time is slower than electrorheological fluids but still quite fast as compared to other materials. Only a small amount of the fluid is required to achieve a particular performance level. It is also not as sensitive to impurities as is in the case of electrorheological fluids. They also operate in a wide range of temperature. Limitations of the fluid are that magnetic fields are not easy to supply and often require bulky setups. There is also a difference in densities of particles and carrier liquid so therefore is in a high risk of sedimentation. It has also been seen that the fluid tends to thicken if subjected to high stress and shear rates over a long period of time (Delivorias, 2004).

2.5 Format Study

The purpose of this study was to see how shape memory materials can be incorporated into haptic technology and how they can be applied to improve the lives of the blind and visually impaired. Through the literature review, opportunities arose in two formats- wearables and non-wearables (refer to fig 2.9). Non-wearables can be of two types- graspable and touchable based on the interaction.

2.5.1 Wearables

Both shape memory alloys as wires and polymers as threads have been demonstrated to provide haptic feedback in the form of wearable devices. They are light weight and silent types of actuators that have the ability to be incorporated easily as non-obtrusive wearables. Some have the ability to even be incorporated with textiles. This could enable them to be subtle and not stand out as an assistive device.

When designing wearables, care needs to be given on how to ensure good contact with the skin. It was seen that sticky plasters were sometimes uncomfortable to wear. An interesting aspect is that the natural elasticity of skin is often good enough to provide bias forces to the device.

A wearable assistive device for the visually impaired opens new communication channels which are portable and mostly hands-free. Shape memory haptic wearable devices have a large variety of application from hidden navigation aids placed on the back to forms of muscle training. The study presented the human perception of different types of haptic feedback on different body parts. This lays out a foundation for further explorations

2.5.2 Non-wearables

Embedding actuation in the surface can allow for adaptable multi-modal movement in order to provide different types of information to the user. It can be incorporated into hand-held devices (graspable) or external tactile displays (touchable).

In the literature studied multiple formats of malleable surfaces were demonstrated. These can be in the form of subtle modes of guidance in a house environment such as the navigation carpets proposed by Sprout I/O (Coelho & Maes, 2008) or input/output devices for computer interactions from rheological fluids.

Shape memory materials in combination with meta-materials and auxetic structures are interesting in providing a wider variety of movement combinations. Another interesting direction is dynamic physical controls in more malleable formats in order to simplify interfaces.

2.6 Conclusion

There is a large potential of using shape memory materials to provide haptic feedback as aids for the blind and visually impaired. This literature review has successfully proven the capabilities of both technologies and possible applications for further study.

Four different types of shape memory materials were presented along with their benefits, limitations and haptic application examples. Some materials stood out more than others as having more opportunities for becoming assistive devices.

The rheological fluids have potential, especially as malleable surfaces and computer interfaces but still require further explorations regarding safety and size among other aspects. They are also comparatively expensive and thus will not be looked into further for this project. Shape memory polymers also have a lot of potential of being incorporated into all the directions mentioned in this paper for the blind and visually impaired.

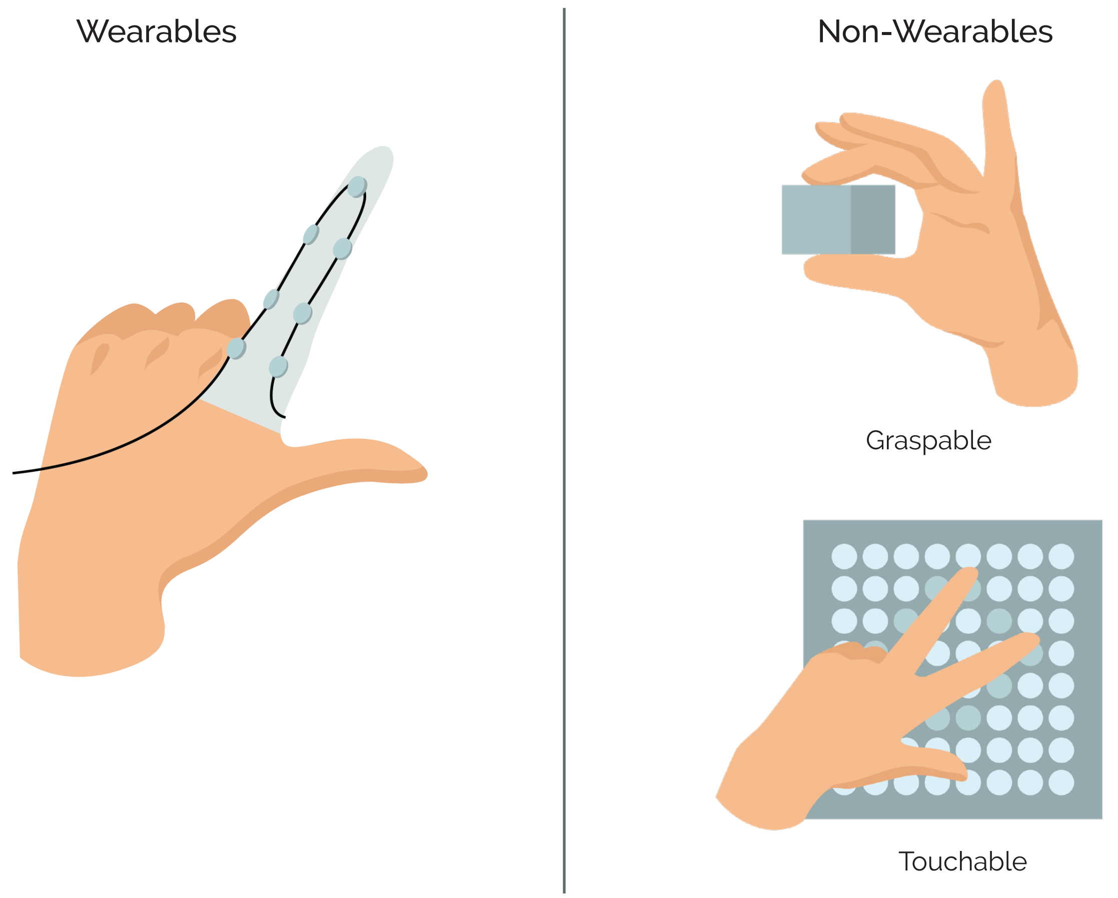


Fig 2.9 Formats of Haptic Technology

Yet, they have a limitation of safe methods of applying the stimulus for formats other than fibre and membrane, when in close proximity to human skin. This makes it less attractive for further studying. It was seen that although shape memory alloys were only tested in the form of wires, they have the largest scope of applications. They have the ability to be incorporated as wearables, hand-held devices and malleable surface interfaces and thus have more opportunities for adaption into this project's context area. They can be more easily actuated as compared to shape memory polymers and their pleasant haptic sensation capabilities have been validated.

In conclusion, shape memory alloys have the most potential for further explorations but both polymers and alloys will be tested and compared based on their capabilities of incorporation into wearables, hand held devices and malleable surface interfaces. A summary of the formats of shape memory alloys along with their haptic feedback is presented in Appendix B.

Haptic feedback can communicate multiple types of information to the blind and visually impaired, this study provided a framework based on which selection of formats can be done.

Take-away

- Both SMA and SMP will be further explored
- The SMMs with be tested in both wearable and non wearable formats

3.
Blind and Visually Impaired

Visual impairment can be defined as having 20/40 or worse vision in the better eye even with eye glasses. Blindness is a severe vision impairment which is not correctable with eye glasses, contact lenses, medicine or surgery (Centers for Disease Control and Prevention, 2011). There are at least 2.2 billion people worldwide who suffer from visual impairment or blindness, according to The World Health Organization (WHO).

There are many forms of visual impairments depending on a variety of different aspects like the causes, age, parts of eye affected, experiences etc which need to be taken into consideration when developing aids/assistive devices for them. A main classification for the blind and visually impaired is whether it is congenital (from birth) or acquired. The dependency on assistive devices sometimes vary between both. Major causes for acquired BVI are blinding eye diseases such like cataract, age related macular degeneration, diabetic retinopathy and glaucoma (Centers for Disease Control and Prevention, 2011).

BVI can affect the quality of life, with people experiencing difficulty in doing simple daily life activities. There are a variety of different devices and services which have been developed in order to aid this group of people called aids and assistive technology.

3.1 Aids and Assistive Technology

"The social model of disability says that disability is caused by the way society is organized, rather than by a person's impairment or difference. When barriers are removed, disabled people can be independent and equal in society, with choice and control over their own lives."- UNICEF (2017)

According to the World Health Organization (2018), assistive technology aims at 'maintaining or improving an individual's function and independence, thereby promoting their wellbeing in an ever more visually centred world.' The blind and visually impaired need aids and tools to compensate and be able to function in society without continuously seeking help from others. As technology advances, the scope of assistive devices also expands. They aim at overcoming a variety of barriers such as physical, social, infrastructure and accessibility areas.

In order to gather insights into how assistive technology for BVI have changed over the years, a historical study was done on aids for this target group.

Around 1780, there was an attempt to train dogs as aids in a hospital for the blind in Paris. Incidentally, the first guide dog school for the blind was opened in Oldenburg by a German doctor- Dr Gerhard Stalling. Since then, many guide dog schools have opened around the

Fig 3.1 White cane on tactile pavement (Debczak, 2019)

world. Guide dogs are very valuable as a form of assistance to many BVI people even today (International Guide Dog Federation - History, n.d.).

The first type of assistive device for the BVI was an analog Braille writing machine in 1892 in the United States, although Braille as a system of reading and writing for the blind and visually impaired was invented in the 1820s (Britannica, 2019). The writing machine was developed to enable students to write with the same ease and speed as those using a regular type writer. A modified version of this device is still being used today.

1931 marked the widespread use of the white cane. Although it was claimed that the white cane was first invented in 1921 by James Brigg, who lost his eyesight after an accident. He painted his normal walking stick white, to make it more visible in traffic (De geschiedenis van de blindenstok, 2020).

From 1943 onwards prototypes of reading machines for the blind were being developed including a unique letter recognition device.

Tactile pavement is another aid which is still being incorporated today. It was first developed by Seiichi Miyake in 1965 in Japan and was laid out in the streets of Okayama in 1967. It soon spread around Japan first and then the world (Tactilepaving, 2020). Sometimes there is a difference in colour and contours according to where they are placed. There is a necessity for standardization of

Fig 3.2 A user with guide dog at RBC's talking ATM (Carleton University Disabilities Research Group, n.d.)

such type of aids around the world to prevent confusion. Fig 3.1 presents one form of tactile pavement.

In 1982, the first refreshable braille display was introduced which made it possible for the BVI to use computers (The Information Age Braille Technology Timeline, n.d.).

Specific types of automated teller machines called 'Talking ATM' became available on October 22, 1997 by the Royal Bank of Canada. These machines provide audible information either through headphones (refer to fig 3.2) or attached telephone handsets (Wikipedia contributors, 2020). These are particularly helpful for BVI users.

The development of electronically based technologies for BVI began more recently, around 50 years ago. We can see that many of the aids and assistive devices developed in the past are still being used today but attempts of improvement for them have been made. For example, braille display processors were very expensive. Developments in technology have brought about possibilities to overcome this such as using electric stimulus instead of physical bumps etc (Legends and Pioneers of Blindness Assistive Technology, Part 3 |

AccessWorld | American Foundation for the Blind, 2006).

With the digital age, different types of aids have come about. These range from text readers to machine learning features. These aids make use of technology but also allow the blind and visually impaired to work with other widely used non assistive technologies like smart phones. There is also a development of assistive aids to keep up with new modern needs. For example, Gobox and Webbox3 are aids that read out subtitles allowing the blind and visually impaired to watch foreign movies and tv shows. Large companies such as Apple and Netflix are also highly interested in ensuring that their products are accessible to a majority of users. In 2009, Apple created the VoiceOver screen reader for the iPhone. The phones were made to be easily connected to external assistive devices such as braille displays (New England Low Vision and Blindness, 2020). The well known over the top content platform Netlflix has features such as audio descriptions and closed captions to cater to their BVI users. The platform is also compatible with user's voice over devices (Desk, 2020).

Although there are a large variety of assistive technology available which are meant to enhance the lives of the BVI, access to these technologies is limited. There are a few reasons for this. Development of technology for accessibility is quite time consuming, only around 20% actually move forward to commercial use. Most of the formats of assistive technology are software/ digital based since it is the easiest and fastest to develop. Although these may not always be the best forms of accessibility. A lot of them also depend on other software and require standardization which could potentially hinder their efficiency. There are sometimes problems of privacy and correct storage/ usage of personal data. Assistive technology is also a comparatively small business and often does not attract big companies since they are drawn towards sales. Differences in policies and regulations in different countries also hinder the accessibility of these technologies.

There is a need for the technology to be advanced so that they are mass manufactured. According to Pawluk et al. (2015), there is a strong reluctance to becoming critically dependent on technology if it is expensive or slow to repair or replace. Also, not everyone is aware of what is available. From a user point of view, technology is not accessible by everyone.

Assistive technology has to be accepted by both users and healthcare professionals. The work processes to support new technology require a lot of resources and money. There is a learning curve to incorporate new aids and assistive technology. Ideally if everything -products, software etc- are made accessible from birth, it will be useful for everyone. There may even be a reduced requirement of specific assistive devices and aids, and those which are still needed can become available to the market quicker. This being said, it was mentioned by multiple people in the target group interviewed for this project, that they are willing to spend a long time training themselves to use a device if it is useful to their lives (refer to section 9.1).

Some of the aids and assistive devices currently available are also stigmatized for example due to their alarming visual styles. They tend to strengthen any stigma surrounding their users, so much so that at times people are discouraged to continue using the device. One visually impaired woman, interviewed during a previous project, mentioned she feels people see her as a handicapped and incapable of doing things independently when she uses her white cane. She then tends to not use it unless absolutely necessary, although she did mention that this may be as a result of 'self-stigma' because of her cultural background. Two people interviewed for this project, one blind and the other visually impaired, mentioned that it is dangerous if surrounding people are not aware that they have an impairment so it is good that some aids such as the white cane have become internationally recognized symbols of blindness and visual impairment. The interviews conducted for this project are explained further in section 9.1.

There are therefore opportunities for the development of new types of aids which either do not stand out as assistive devices or are inclusive and usable by everyone. Many of the aids currently available target very specific activities such as walking or reading. Since there is a large spectrum of needs and requirements, another opportunity is in the development of free, open ended devices, which users can adapt to their own requirements. This needs to be taken into consideration in order to develop an effective assistive device.

3.2 Haptics for the Blind and Visually Impaired

Assistive technologies for BVI open up new methods of communication through combination of other senses such as hearing and touch. It is important though, that these devices don't hinder the individual's dependence on the other sense. For BVI, touch is the primary source of understanding non-audible information. In the research of Jansson (2008) a comparison of the types of information which can be communicated by both vision and touch was presented as follows:

Tasks both vision and haptics can perform:

• Find edges separating 3D surfaces.
• Locate objects in relation to observer within arms' reach
• Perceive the size of objects that are not too large
• Perceive the form of not too complicated and large objects
• Perceive the texture of surfaces (sometimes haptics is better than vision)

Tasks where haptics lags much behind vision or cannot perform the task at all:

• Provide an overview of a scene
• Perceive 3D space beyond arm's reach
• Perceive colours
• Perceive edges in a 2D picture (with no embossment)

Tasks where vision lags behind haptics:

• Perceive the weight of objects (even if vision has capacity to do this in some contexts where the objects are handled by other people)
• Perceive the hardness of surfaces
• Perceive the temperature of surfaces

A big difference is the capabilities of attaining a quick overview of a scene through vision which is more time consuming in touch. It is possible to provide spatial information haptically as in the case of the white canes as well as a 'haptic glance' through short contact with an object but these are of course limited as compared to vision. It is also sometimes possible to directly translate visual forms into tactile forms if the shape isn't too complicated. Haptic solutions are therefore designed with these parameters in mind.

When designing a haptic device for BVI, it is also important to take into consideration the diversity of population in terms of medical condition, preferences, experiences etc. A one size fits all approach for assistive devices are not effective. For example for people who are blind as a result of diabetes, have a lack of sensitivity in their fingertips and toes and hence can't use solutions with haptic feedback based in those locations (Pawluk et al., 2015). During the testing phase of the project, it was noticed that a participant with a visual impairment due to diabetes had limited sensations on the inner part of the forearm. (refer to chapter 9). Another aspect which should be taken into consideration when designing a haptic assistive device is the individual's familiarity with both technology and their dependency on the sense of touch. Those people who have already experienced technology as a whole and exploring through touch tend to accept haptic technology easier. For example, Braille is one well known haptic aid and those people who are used to Braille tend to adapt to other haptic devices quickly. An issue is that only 10% of the BVI population use Braille (Pawluk et al., 2015).

There are many types of haptic assistive devices currently available. Braille is one such system which incorporates the sense of touch to provide information to users. Traditionally, it incorporates embossed paper but now refreshable braille displays are available.

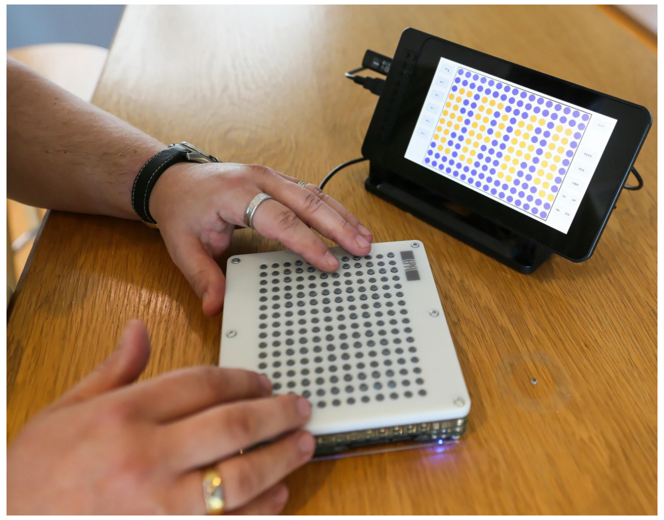


Fig 3.3 Tactile displays with moving pins (Coldewey, 2017)

These displays use piezoelectric technology but have limited reach because they are expensive and usually large in size. There are studies being done in order to develop the technology to overcome these limitations though.

Tactile displays are another form of haptic assistive devices. Tactile rendering for most of these types of displays are usually done with the help of moving pins or vibrations (refer to fig 3.3). Force feedback haptic displays are also forms of tactile displays coming up. According to Otaduy et al. (2013) "force feedback is used to identify and manipulate digital representations of objects that have no tangible physical presence in a virtual world created with a computer screen." One such device is the DualPanto (Schneider et al., 2018). It is a force feedback device that enables blind users to continuously track moving objects in virtual environments like sports games (refer to fig 3.4). Unfortunately, these devices are difficult to use to determine 3D shapes without vision (Pawluk et al., 2015) and therefore are not widely incorporated into assistive devices for the blind and visually impaired.

Tactile feedback is also used to provide information regarding navigation both indoors and outdoors. Commonly, this leads to a system using both Global Positioning System (GPS) and a Braille display. Another method is linking GPS to vibration motors positioned on the body. Fig 3.5 presents a trial kiosk in Busan, South Korea, which is inclusive to the blind and visually impaired. It consists of a

Fig 3.4 DualPanto- force feedback device for tracking movement (Schneider et al., 2018)

Fig 3.5 (New Smart Tech Helps Visually Impaired South Koreans Increase Mobility > PR/IR | (Dot Incorporation), 2021)

Fig 3.6 White cane with ball at the end (MaxiAids, n.d.)

Fig 3.7 haptic technology opportunities for the visually impaired

Braille touch pad which can transform into a tactile map.

White canes are the most common forms of haptic mobility aids. These devices help in sweeping the environment to detect obstacles, providing information of texture change and sometimes facilitating echolocation of objects not reachable directly by the cane. During interviews conducted for this project (refer to section 9.1), it was discussed how some members prefer the white canes with the ball at the end. The advantage is that there is better feedback when rolling rather than tapping (refer to fig 3.6). A disadvantage is that sometimes people aren't aware of their presence because there is no tapping sound. It is also possible to use the white canes in echolocation, where one can hear how large a room is by tapping the cane on the ground. As mentioned earlier, these products along with many other forms of assistive haptic devices have very specific visual characteristics which make them stand out as aids and strengthen stigmas surrounding their users.

It can be seen that haptic technology has been successfully incorporated as means of assistance for the BVI. There are opportunities to develop assistive haptic devices in a variety of different areas. Fig 3.6 highlights a few opportunities based off the desk research conducted. One area which is currently being looked into more is haptic communication.

Haptic communication is a non-verbal format of communication which is dependent on touch (Haptic Communication, 2018). As mentioned earlier in this report, there is potential of communicating more intelligible information to users than through the most commonly used methods of notification. Communication through touch can support expressive and more nuanced information and therefore can become its own language.

Lahtinen (2008) explained how a variety of information can be conveyed onto a body by touch. Single messages conveyed in such a manner is called haptices. A hapteme is a grammatical variable in the touch such as direction of movement, pressure, speed, frequency etc. This concept was reflected in an experiment conducted by Lahtinen in which photos of aeroplanes were expressed to visually impaired participants. This was done through drawing shapes on the back with one or two hands (refer to image 3.8). Haptices can be adapted from body movement, activities, written language, sign language, visual drawings, sounds etc and hence have a large potential for means of communication.

Simple tactile symbols were presented at The SUITCEYES: Living through Touch symposium by Myrthe Plaisier (2021) which can also be conveyed to the users via touch on their back (refer to fig 3.9) At the same symposium, Sándor Darányi (2021) introduced the term 'haptograms' which stands for tangible ideas. It was a tactile symbol drawn over a touchscreen conveyed eventually to the skin. The sensations were produced with the help of a matrix of vibrotactile actuators on the back. The haptogram vocabulary currently has 155 concepts which enables sentence and word construction. A limitation in this means of communication is the need for a person with the knowledge of the tactile symbols to provide the information and hence there is a dependency on someone else. It does, however, give rise to opportunities of providing different types of information to the blind and visually impaired with the help of touch.

Take-away

- There are opportunities in the development of inclusive devices which are usable by everyone
- If products stand out as assistive device there can be stigmas surrounding them
- There are opportunities in adaptable devices which can cater to individual needs
- There is a learning curve for using new technologies which need to be taken into consideration in their development
- Haptic devices for BVI should be designed taking into consideration the added value they have over vision
- There are opportunities of providing a variety of information to the BVI through haptics

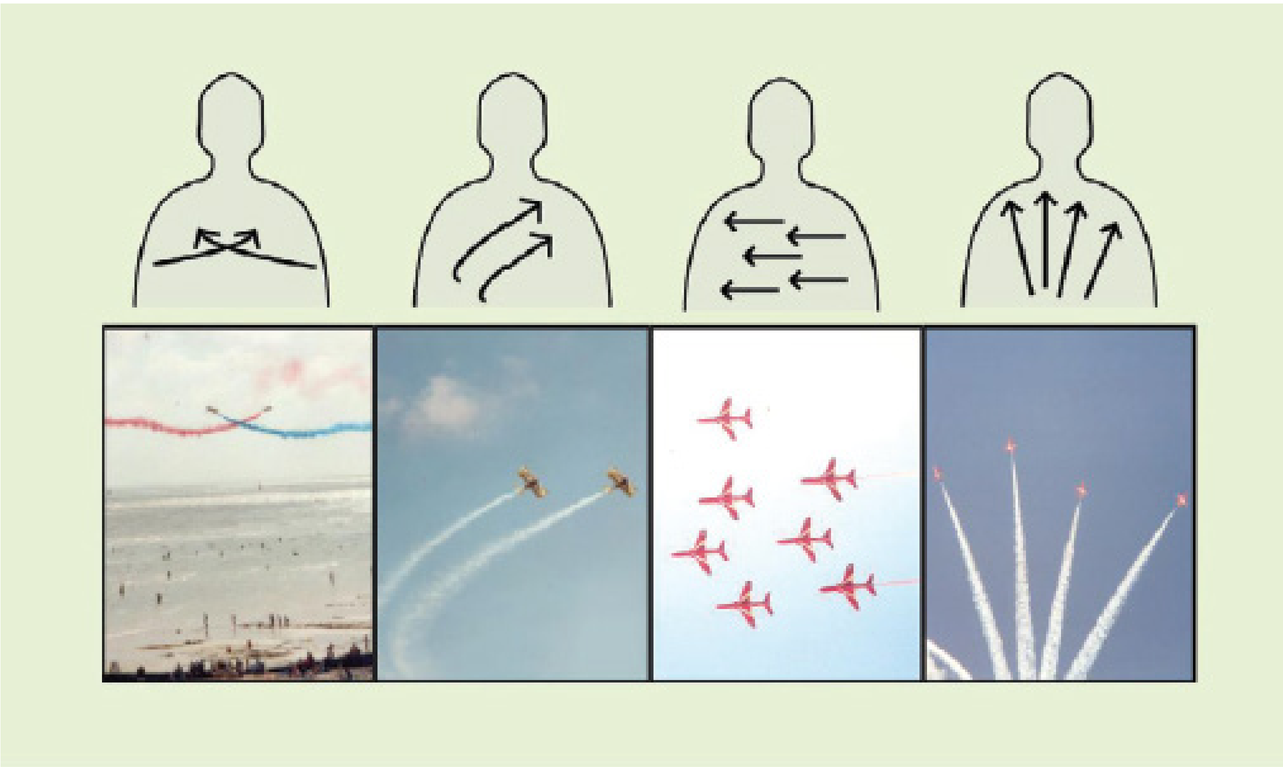


Fig 3.8 Experiment conducted by Lahtinen: drawing shapes on the back with one or two hands

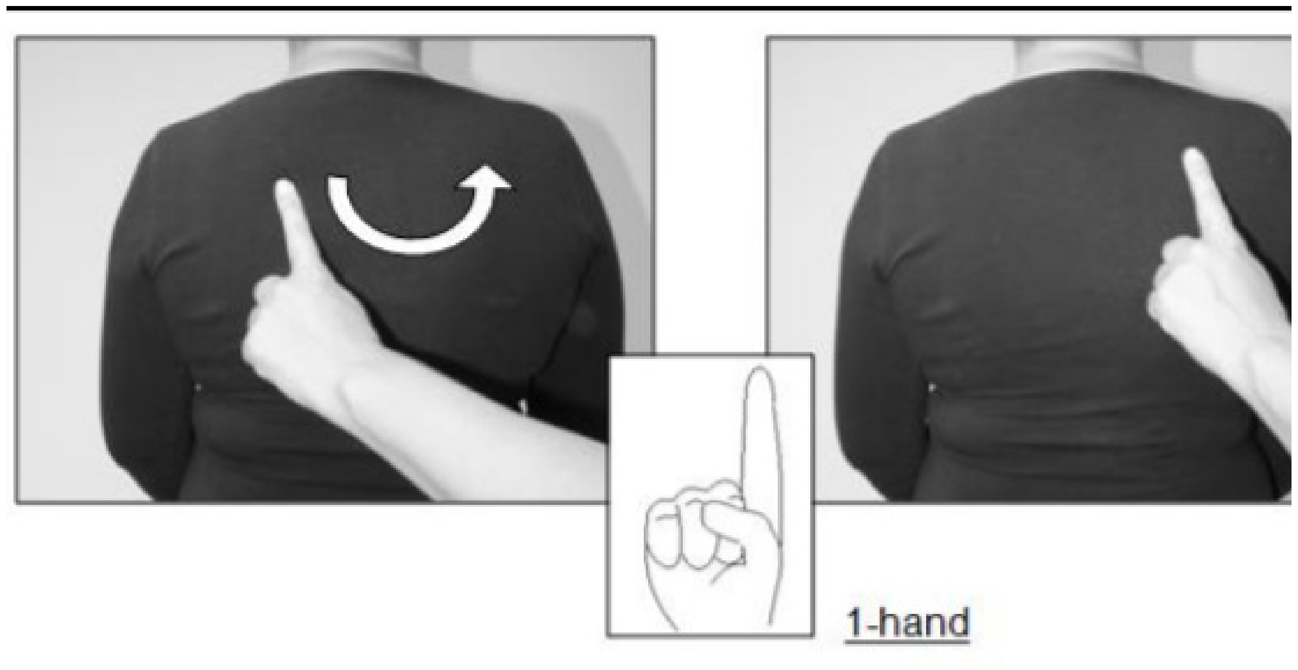


Fig 3.9 Conveying messages through simple tactile symbols

4.
List of Requirements

Research was conducted on what haptic technology is, how shape memory materials can be incorporated into it and what makes a product a successful aid for the visually impaired. Through evaluating this research, a set of design requirements were formulated to ensure that the demonstrator can provided perceivable tactile sensations and can successfully be used by the blind and visually impaired. The design requirements are of two types (demands and wishes) based upon the necessity of the project's final demonstrator to meet them.

Demands

Performance

1. The technology should be able to convey information to the blind and visually impaired
2. The device should not depend on vision to operate
3. Should provide noticeable haptic sensation
4. The haptic sensation should be pleasant for the user
5. Movement should be reproducible (complete motion without error at least 5 times)
6. Shouldn't generate an uncomfortable amount of heat i.e. >45˚C (Ungar & Stroud, 2010)

Operation

7. Should be operational with electrical power
8. Should be operational at room temperature (27˚c)
9. There should be controllable actuation (can be changed midway)
10. Response time should be less than 5 seconds (from applying stimulus)
11. Device should be reusable
12. Should be safe to use in close proximity to skin

Material

13. It should incorporate shape memory materials
14. The materials used should not irritate the skin

Wishes

1. Comparatively simple to manufacture
2. Capable of quick movement
3. Should be easy to clean
4. Silent operation
5. Multi-modal actuations
6. Subtle/hidden actuators
7. Incorporable into multiple applications
8. Materials should not be very expensive and difficult to procure
9. Easy to setup

5. Exploration

In order to understand how these smart materials behave as well as how one can design with them, they were tinkered with in different formats. This not only aided the material selection process but also gave rise to opportunities for incorporation.

5.1 Shape Memory Alloy Exploration

Flexmet NiTiCu wires of diameter 0.5 mm and Flexmet NiTi wires of diameter 0.008 mm were tested. These wires were already straight annealed (even if they are deformed, when stimuli is applied they would become a straight wire) but could be trained to a different shape.

The training process requires the wires to be fixed in the new shape and then cured at 500˚C for 45 mins in a ceramic oven. After taking them out of the oven, they are quenched straight away in cool water for fast cooling as well as removing oxide layers which surround the samples.

The method of fixing the wire in a new shape can be seen in fig 5.1. According to the required shape, nuts and bolts can be used. It is important to keep them tightly secured, in order for them to cleanly recover their shapes and exert force (a requirement to produce haptic feedback). This became evident during some of the experiments. It can be seen in fig 5.2, that SMA wires programmed to form a spring, recovered the wrong shape when heat was applied to it. This was due to them not being securely fixed before placing them in the oven.

NiTi wires are more difficult to control and secure in place as compared to the ones with copper as they are less flexible. The 0.008 mm had the added challenge of being more susceptible to breakage when being secured.

The wires were trained as springs, flat springs and a 3d structure. After training the wires, shape recovery was tested by using both joule heating and hot water as the stimuli.(See fig 5.3). The transition temperature for the wires are between 30˚C and 60˚C. The power to heat up the 0.5 mm diameter wires sufficiently was 2A with 2 V output.

It was seen that the 0.5 mm wires had better shape recovery than the thinner ones. The wires trained to be a 3d shape had the weakest recovery. It is also necessary to have guides for good shape recovery of the wires. Quick shape recovery is possible with SMA wires using both electricity as well as hot water although the shape recovered is not always the clearest. Another disadvantage of SMAs is that overheating negatively affects its shape memory effect and it is difficult to train them into some shapes. More details of the SMA exploration can be found in Appendix C.

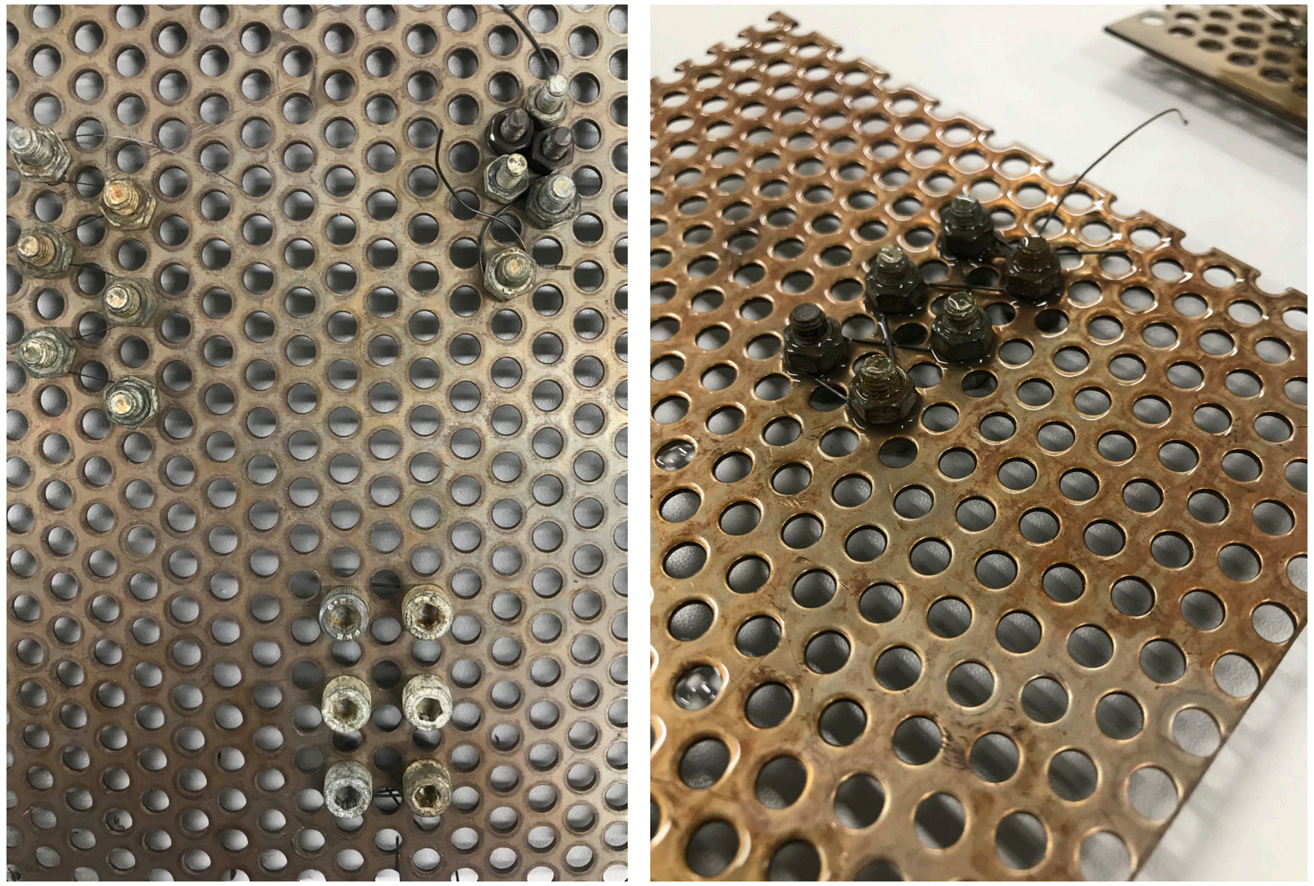


Fig 5.1 Fixing shape of the wires with the help of nuts and bolts

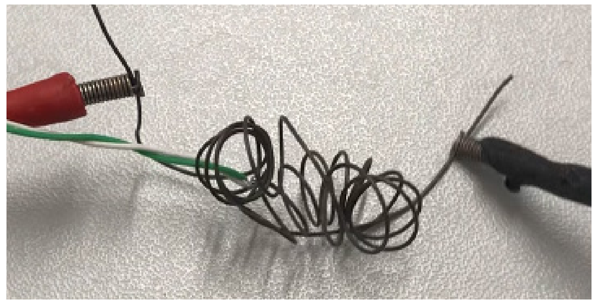


Fig 5.2 SMA springs recovering a distorted shape

Take-away

- SMA wires have to be securely fixed when being trained
- 3d forms of the SMA wires do not produce good shape recovery
- Quick shape recovery is possible with SMA
- Overheating of the SMA wires may negatively affect its SME

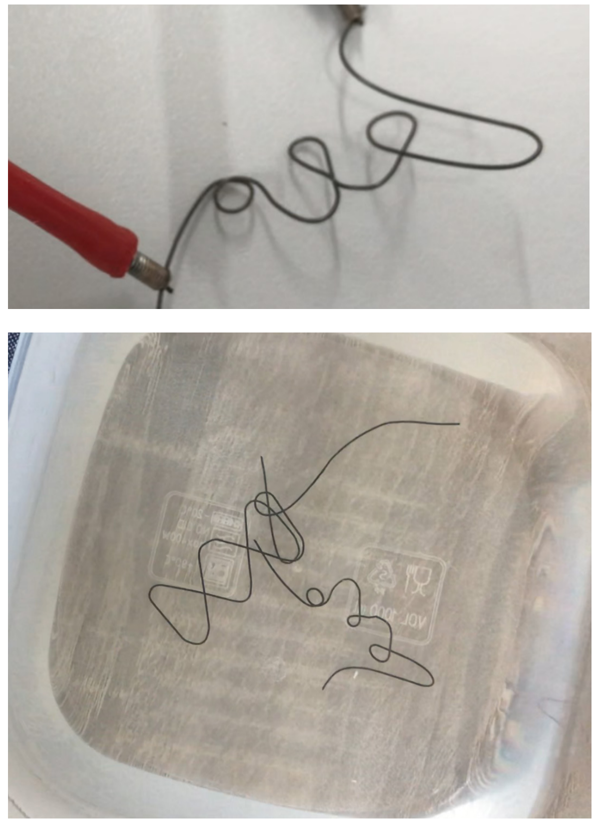


Fig 5.3 Heat as a stimuli through electricity and hot water

5.2 Shape Memory Polymer Exploration

Polylactic acid (PLA) is one of the most common materials used in fused deposition modeling (FDM) printing due to its low cost and high stiffness. This material has SME when exposed to heat as a stimulus.

Different PLA structures, 3d printed using Ultimaker 2+, were tested to understand this material's shape memory properties (see fig 5.4). The structures included a flat format (with different scoring details), flat springs and wave springs (see fig 5.5). The shape in which they are printed is the trained shape they would return to after they are deformed and then thermally activated.

Since the glass transition temperature of PLA is between 55˚C and 60˚C, by submerging in boiling hot water, the material becomes pliable and its shape can be deformed. If the material is allowed to cool, it retains the new shape. By submerging it in hot water again, the material returns to its original printed shape. Refer to fig 5.6 for the process.

The speed at which the original shape is recovered depends on the structure and level of deformation. It was noticed that details such as the scoring had minimal impact on the speed and steps of shape recovery. Self-bending was very noticeable in the flat structures, where over time the recovered shape was slightly altered from the one it was originally printed in (refer to fig 5.7).

Therefore the materials slowly deformed throughout the testing phase. It was also difficult to control the recovery motion as was seen in the case of the flat spring (refer to fig 5.8) which had the tendency to curl and expand unevenly.

Changing different printing settings also had an impact on the shape memory effects of the materials. For example low infill density affects activation time, and thicker materials have more accurate shape recovery and less self bending.

The materials were also tested with bias forces such as lycra and a rubber band (refer to fig 5.9) which proved to be too strong for the PLA to change its shape. Attempts were also made to activate the materials using electricity as a source of heat. NiCr and copper wires were entwined around PLA in the form of a flat sheet and a wire which was not effective in providing heat to the materials. Refer to Appendix D for more of the SMP explorations.

Generally, PLA had better and clearer shape recovery than SMAs. Even texture recovery was possible in PLA. Another benefit of PLA is being able to 3d print a variety of different structures. A large disadvantage of PLA is the limitation of activation stimulus which is safe to use in close proximity to the skin.

Take-away

- SMP have clear shape recovery
- Capable of a variety of different shapes
- Some structure details can influence its SME properties
- Capabilities of shape recovery may reduce over a period of time
- Activating stimuli may not be safe to use in close proximity to the skin

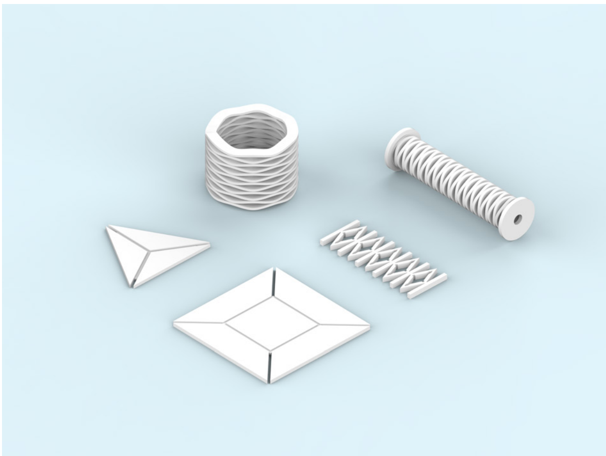


Fig 5.4 Overview of 3d printed PLA components

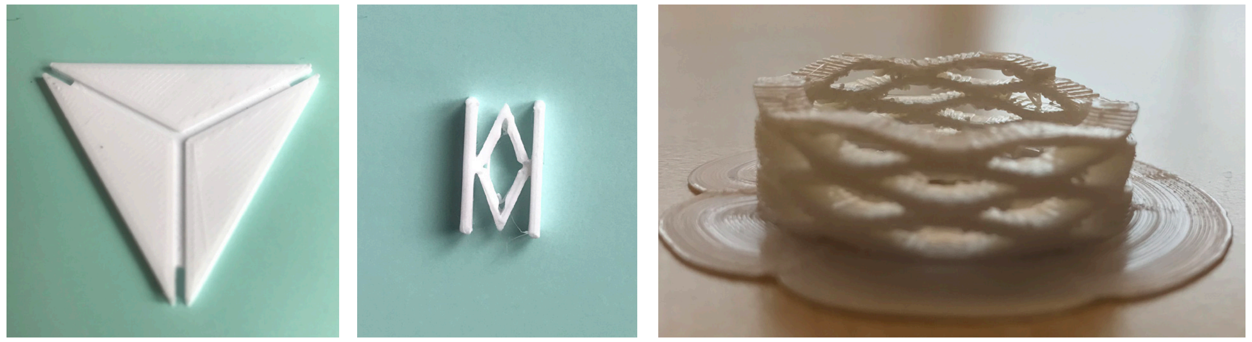


Fig 5.5 SMP in different formats- from left to right- Flat with one sided scoring, flat springs and wave springs

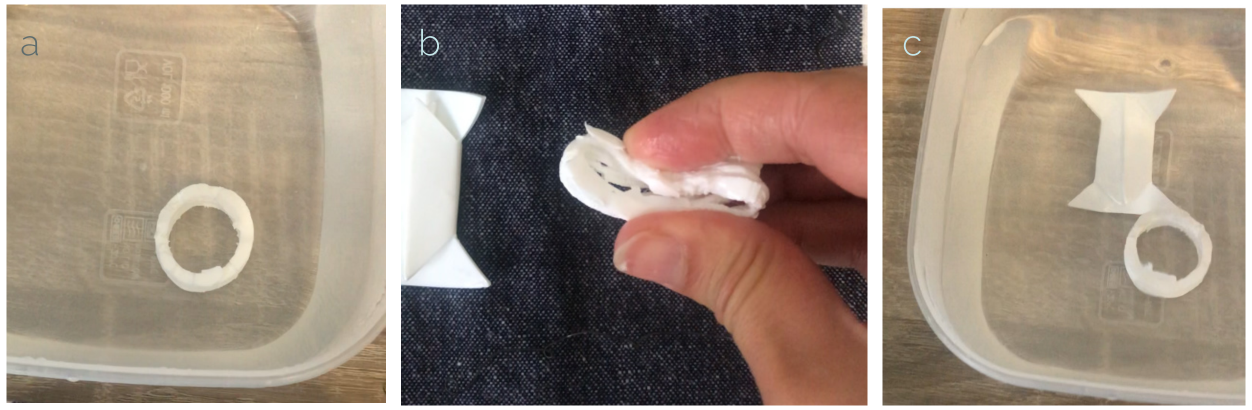


Fig 5.6 Activation process. a- Submerge SMP structure in boiling water b- Remove structure, deform and allow to cool. c- Re- submerge in hot water

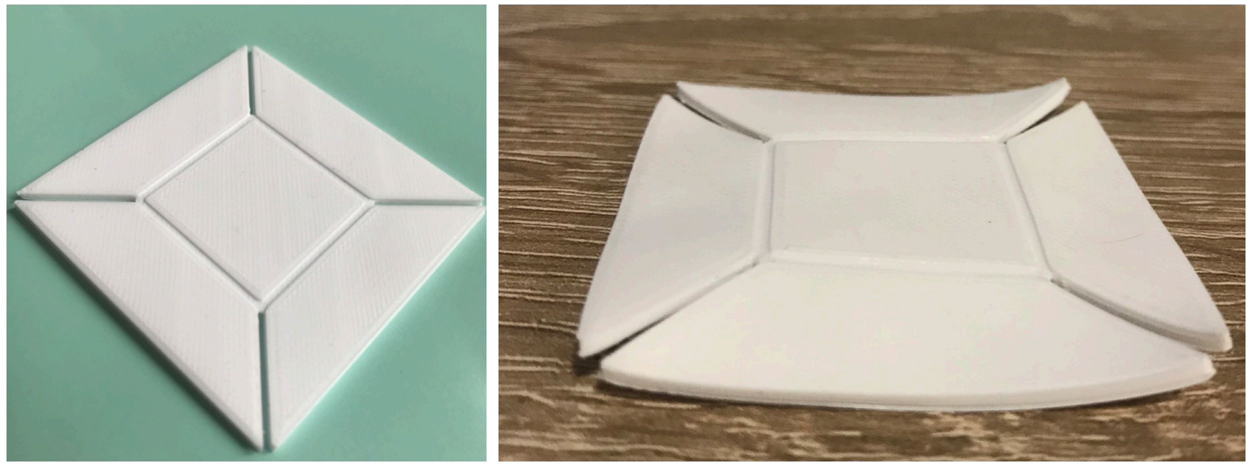


Fig 5.7 Self-bending - from left to right- original print, after 5 tests

Fig 5.8 Tendency to curl unevenly

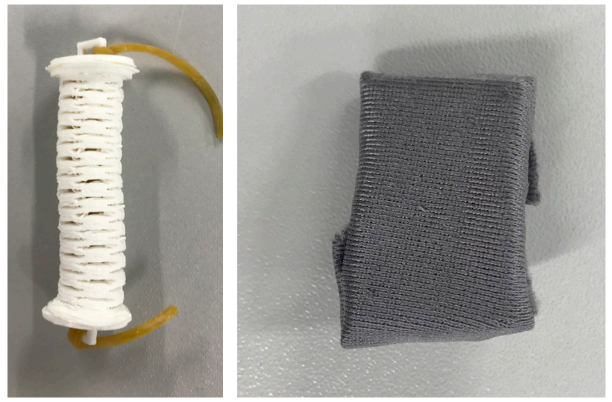


Fig 5.9 Elastic band and lycra as bias force

5.3 Selection

The shape memory materials were compared using a Harris Profile (refer to table 5.1) based off the literature reviewed and tests conducted.

Shape memory alloys were selected in combination with passive materials for further explorations in this project. They had the most potential for a safe incorporation into haptic applications.

The literature studied provided haptic application opportunities in two formats- wearable and non wearable. They were both compared in terms of the value SMMs bring to them over other types of technologies available.

Wearable devices were chosen since it involves a more intimate interaction and shape memory materials provide soft, quiet and light modes of actuations capable of organic sensations.

Wearable assistive devices allow for hands free interactions. These type of devices often open new means of communication through other senses for sensory challenged individuals. Wearable devices are of a large variety based on the type of technology used and its location on the body.

5.4 Additional Design Requirements

After exploring the capabilites of the materials selection was done for the material to be incorporated as means of haptic feedback and the product category. This lay out the base for additional design requirements to ensure that the demonstrator can become a successful wearable device. These are a list of demands which are to be added to the list of requirements previous mentioned in chapter 4.

1. It should be lightweight (<130 g)
2. It should be comfortable to wear for prolonged periods of time (at least 60 min continuously)
3. It should not be sensitive to motion
4. It should be simple to operate without external actuators and motors
5. It should operate without noise
6. The product should be able to function regardless of small changes in placement.
7. The user should be able to wear the device without it interfering in activities
8. The user should be able to wear and operate the product without experiencing discomfort or fatigue.
9. There should not be any sharp edges or corners
10. It should not limit the motion
11. It should not be very large and bulky
12. It should be compliant to the skin

Shape Memory Alloys

	- -	-	+	++
Demands				
Should provide noticeable haptic sensation			■	■
The haptic sensation should be pleasant for the user			■	
Movement should be reproducible (complete motion without error at least 5 times)			■	
Shouldn't generate an uncomfortable amount of heat (>48˚C)		■		
Should be operational with electrical power			■	■
There should be controllable actuation (can be changed midway)			■	
Should be safe to use in close proximity to skin		■		
Wishes				
Comparatively simple to manufacture			■	■
Capable of quick movement			■	■
Materials should not be very expensive			■	

Shape Memory Polymers

	- -	-	+	++
Demands				
Should provide noticeable haptic sensation			■	
The haptic sensation should be pleasant for the user			■	
Movement should be reproducible (complete motion without error at least 5 times)			■	
Shouldn't generate an uncomfortable amount of heat (>48˚C)			■	
Should be operational with electrical power		■		
There should be controllable actuation (can be changed midway)			■	
Should be safe to use in close proximity to skin		■		
Wishes				
Comparatively simple to manufacture			■	
Capable of quick movement			■	
Materials should not be very expensive			■	

Table 5.1 Harris profile for SMA (left) and SMP (right) refer to Appendix E for Magnetorheological and Electrorheological fluids

6.

Shape Memory Alloys

The shape memory effect was first discovered in SMAs, in AuCd and NiTI alloys in 1932 and 1971 respectively (Huang, 2019). Now a larger variety of shape memory alloys have been developed. The most common and commercially used ones are Nickel Titanium (NiTi) based, Copper (Cu) based and Iron (Fe) based.

NiTi based SMAs have a good biocompatibility and high performance. Cu based SMAs have lower costs and are easy to process. Fe based SMAs are the weakest types, mainly used for one time actuations.

The SME occurs in the alloys due to martensitic transformations. When SMAs are in the martensite phase, they can be bent without damage to the atomic structure. The bending leads to internal stresses by transformation in the crystalline structure of the alloy. When they are heated, this phase starts transforming into the austenite phase at the austenite start temperature. When it is cooled, the reverse transformation occurs (refer to fig 6.2). Shapes are set for the alloy in temperatures above the austenite start temperature. For Nitinol this setting temperature is between 500˚C and 550 ˚C. After the shape is set, the alloy must be cooled down. The transformation temperature for it ranges from -200˚C to 100˚C.

Hysteresis is the measure of the difference in transition temperatures between heating and cooling, that is generally when the material is transformed 50% to austenite when heated and to martensite when cooled (Mohd Jani et al., 2014). This property is important when the

Fig 6.1 Shape Memory Alloys (Ingpuls - Nitinol, Shape Memory Alloys, Products based on SMA, n.d.)

material is being incorporated into different applications. For example for a quicker actuator application, a small hysteresis is required. This property is also important when identifying the operating range of the application. The transition temperature and hysteresis depends on the composition of the material and its processing.

There is also differences in the physical and mechanical properties between the phases of the material. For example the martensite structure is softer and more malleable than the austenite structure.

When the alloys recover their original shape as a result of heat, the SME is called one-way shape memory effect. If the material has two predefined shapes- one at a high temperature and the other a low temperature then the transformation is called two-way shape memory effect.

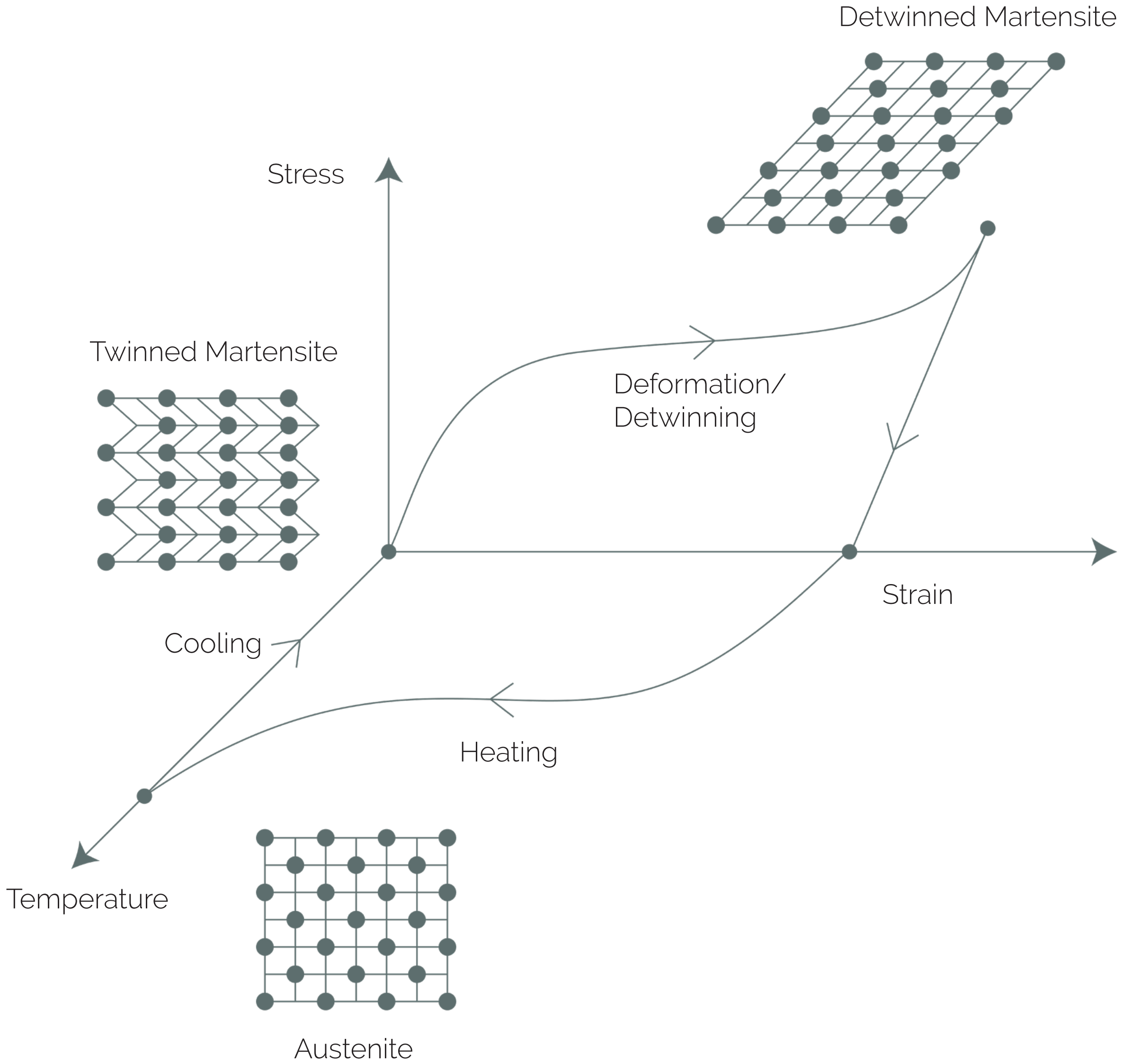


Fig 6.2 Shape Memory Alloys phase transformation

Pseudoelasticity or superelasticity occurs when no thermal activation is required for the material to return to its original shape. The martensitic transition happens due to applied stress. An example of this can be seen in fig 6.3, where this property of a shape memory alloy allows the spectacle to recover its original shape, even if it is deformed through accidental 'damage'.

Shape memory alloys are now being incorporated in a wide variety of applications in fields ranging from aerospace to medical instruments and civilian products. They are being incorporated in bridge structures because they have the capabilities to dampen vibrations. They are also used as actuators in aircraft and space vehicles because they are lighter and save more energy than the

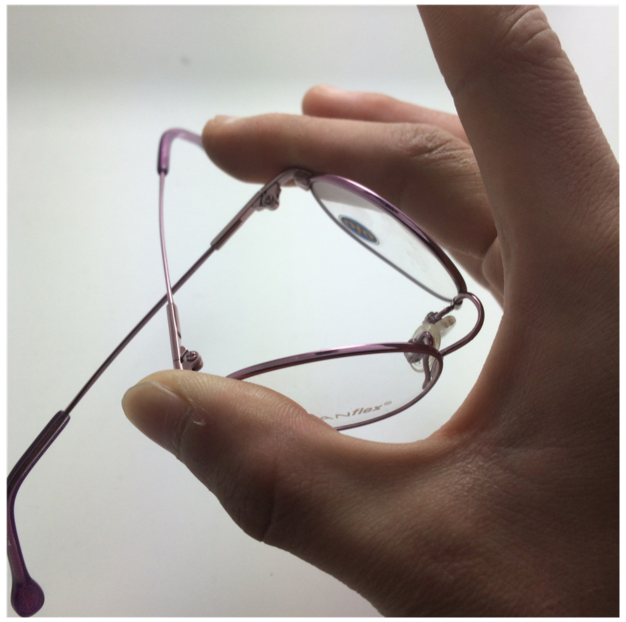


Fig 6.3 SMA spectacles (Design and Technology, n.d.)

commonly used actuators (Supriya, 2018).

Nitinol is the most widely used SMA. It is cheaper to produce and easier to handle than other SMAs. It also has the potential of recovering much higher deformations (up to 8%) compared to other metals. It can exert up to 600 million newtons per square meter, depending on the composition and dimensions.

They are well known for their incorporation into biomedical applications due to their high biocompatibility. Their mechanical behaviour is also more similar to biological tissue response as compared to other metals used in biomedical devices. A common application of this smart material is as stents. The stent treatments are meant to recover original blood flow when there are obstructions in a vessel. Nitinol ensures an easier navigation process to specific vessel due to their ability to self-expand (refer to fig 6.4).

A challenge when designing applications with SMA is that they have a relatively high heat capacity which leads to a narrow bandwidth. They also often have a very slow cooling process. Size and shape of the actuators have an impact on their response time. Another challenge is durability of these actuators. It is seen that overstraining the material would degrade its performance and those with a constant load higher than the recommended load have a reduction in strain with the number of cycles. The format of the alloy also has an impact. For example the recovery force and strain of SMA wire is better than SMA springs (Mohd Jani et al., 2014).

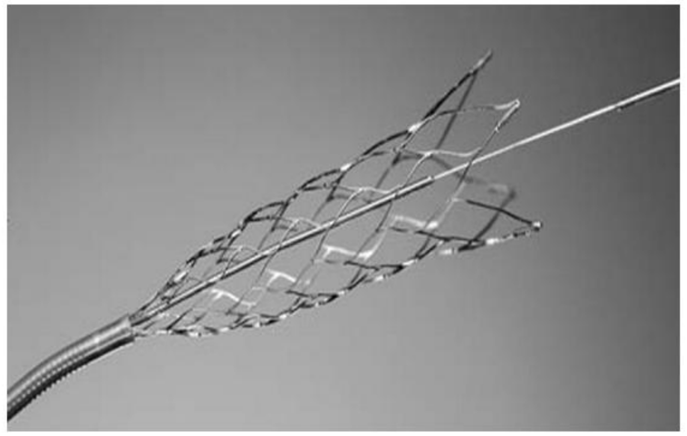



Fig 6.4 SMA stents

Fig 6.4 Hanabi lamp designed by Oki Sato using Nitinol (Bengisu & Ferrara, 2018)

7. Actuators

The material explorations, literature study and context dive gave rise to the opportunity of using shape memory alloys as means of communicating information through touch. It was also seen that in order to be able to provide perceivable haptic feedback, passive materials have to be combined with the shape memory material. The next step of the project consisted of creating a variety of actuators incorporated with SMA wires. The literature studied provided information about preferences in feedback as well as its noticeability on different locations of the body. A summary can be found in Appendix B. This became the foundation for further actuator explorations.

Straight annealed wires as well as wires in other programmed shapes such as springs were tested. The ideation sketches can be found in Appendix F.

7.1 Straight Annealed Wires

These wires are programmed to become straight when exposed to the stimuli. They are NiTiCu wires of diameter 0.5 mm from Flexmet with an austenite finish temperature (AF) of 65 ˚c.

It was seen that in actuators with a large amount of the SMA wire, such as in the cases of fig 7.1, the actuators were harder to control. These actuators were made using two 3d printed PLA components and the SMA wires entwining them together. When heat was supplied to the wires, the PLA components would slide unevenly. The movement itself was very minimal and the entire setup accumulated a lot of heat. It was realized at this point that in order to create an effective and controllable haptic interface, minimal amount of SMA wire should be used.

The next actuator can be seen in fig 7.2. This actuator was in the form of a wearable on the finger. The wire was attached to lycra in a zig zag manner. In this case, the sensation created when activated, was pressure against skin. Although this mechanism was easy to control, the feedback was very subtle.

Two types of sliding mechanisms can be seen in fig 7.3. In both cases, the wires provided no motion.

Another sliding mechanism (refer to fig 7.4) consisted of three PLA components, attached together with the help of brad pins, through which the wires were inserted. This mechanism had very quick and noticeable motion, Although it was seen that the motion with two PLA components were better than with three. This is explored further in section 7.3.

In fig 7.5, a SMA wire is placed in between two PLA components. In a closed position the wire takes the shape of the teeth features of the components. With the application of heat, the wires force the components apart, thus creating a sliding motion. This mechanism was explored further with different sized

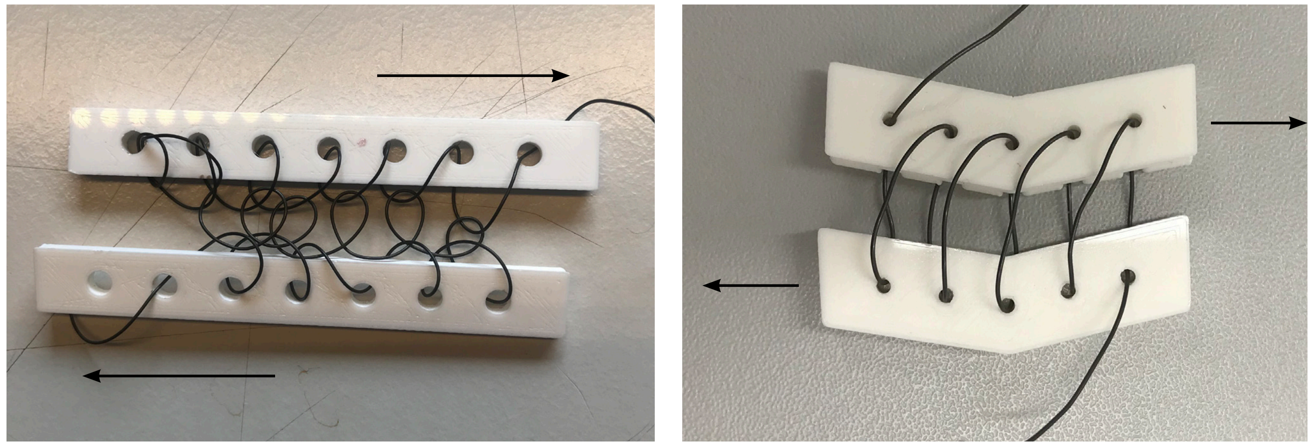


Fig 7.1 Actuators with large amount of SMA wire

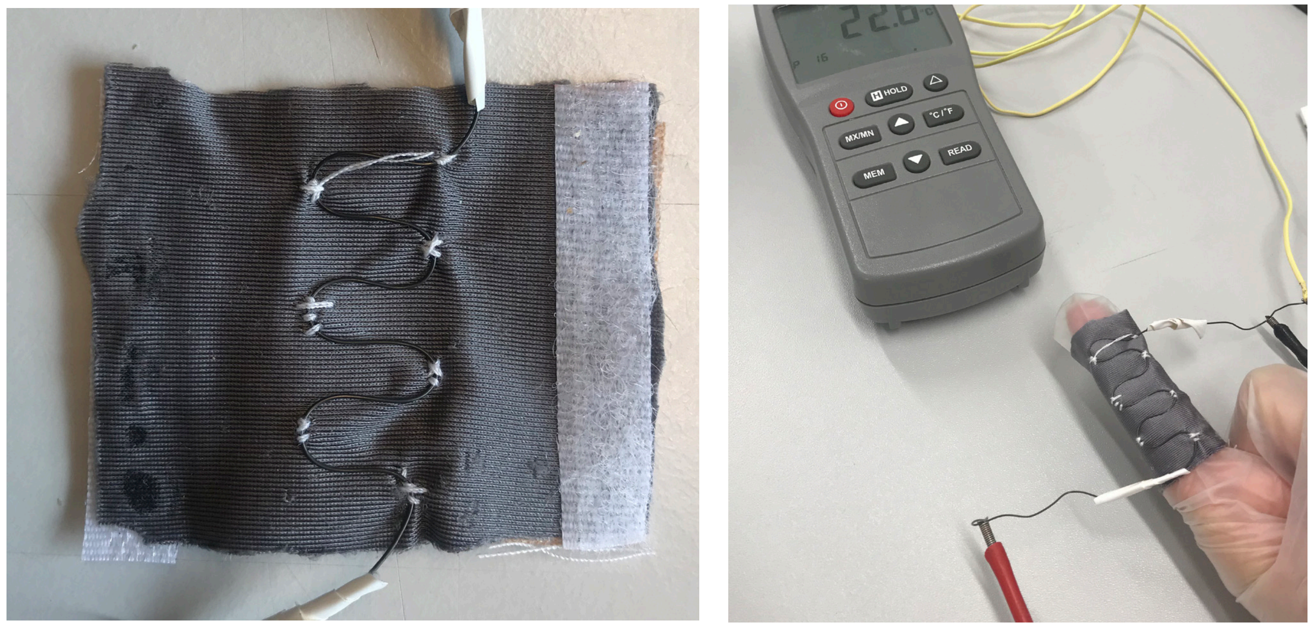


Fig 7.2 Finger mechanism creating subtle pressure on finger

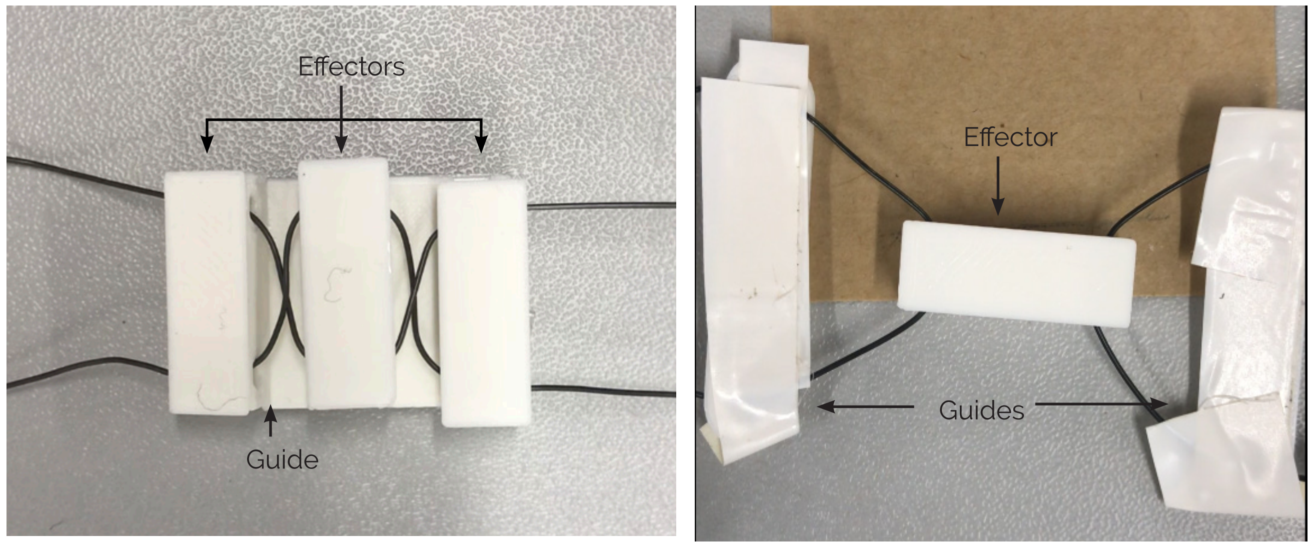


Fig 7.3 Slider mechanisms with no motion

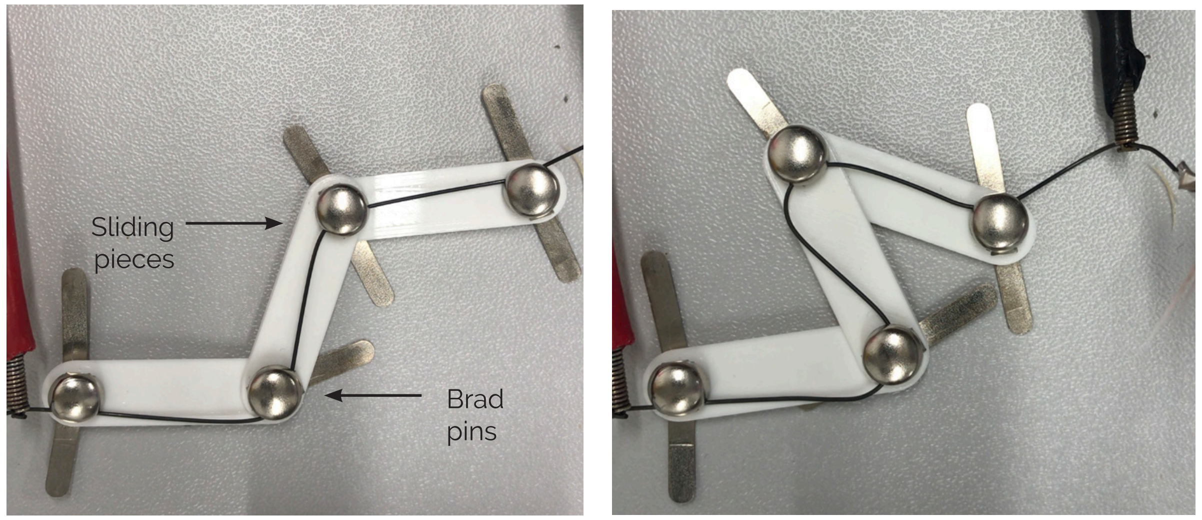


Fig 7.4 Slider mechanism with prominent motion

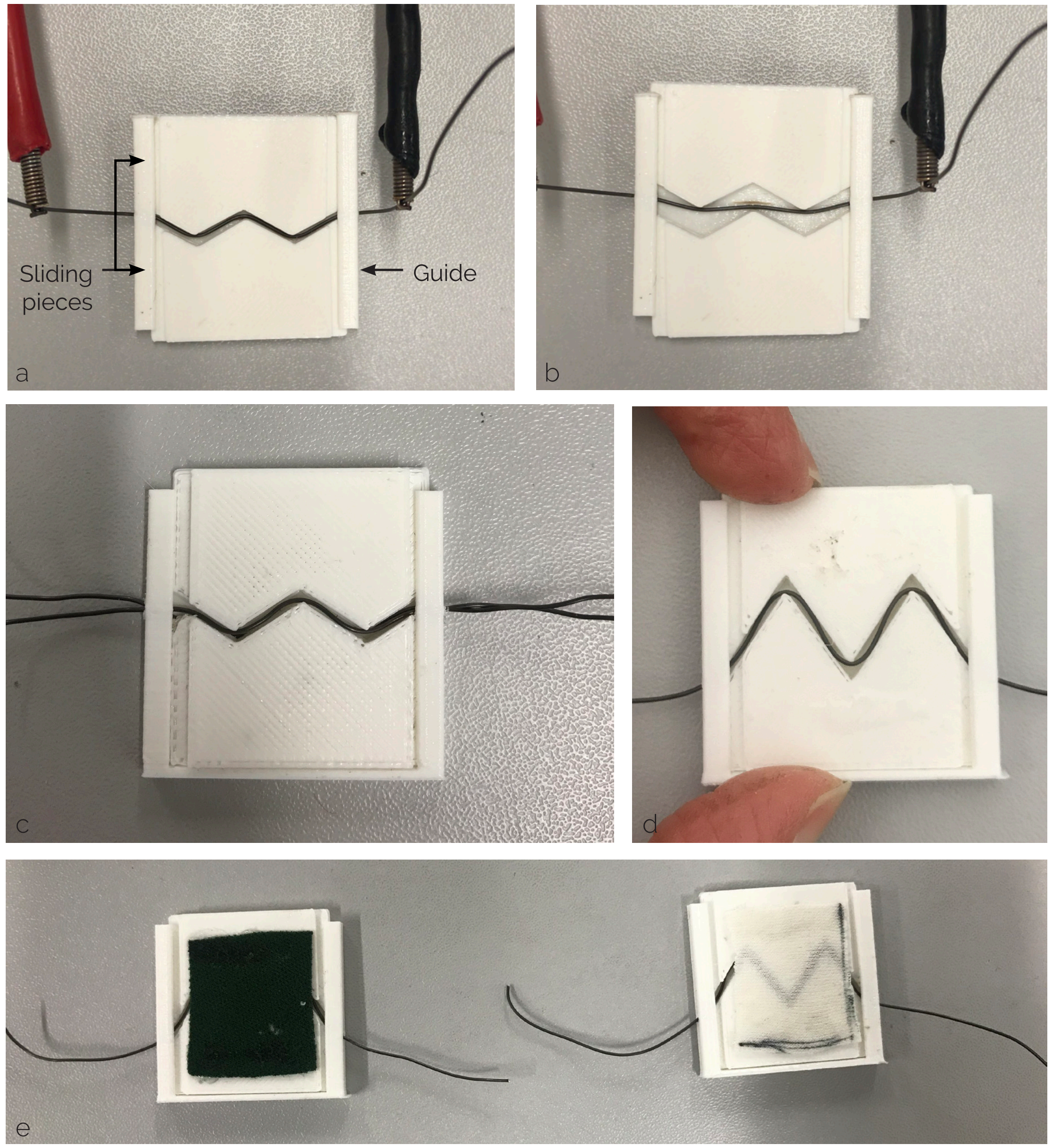


Fig 7.5 Actuator with two PLA components with teeth features a- closed position, b- after activation, c- dual wired, d- Steaper teeth, e- lycra and silicone rubber as bias forces

teeth and different types of bias forces. Two bias forces were used- lycra and silicone rubber. Double wires were also tested in order to provide quicker and more prominent motion, but proved to not have an impact on the motion.. Although this mechanism was easy to control with design changes to the 3d printed components, the movement was minimal.

7.2 Other Programmed Shapes

Flexmet SMA wires of diameter 0.5 mm (AF of 65 °c) in the form of springs were used in a few of the actuators.

In fig 7.6, the alloys were connected to four PLA components with the help of brad pins. With the application of heat, two brad pins were pulled together. This had the potential of creating sliding as well as pinching sensations.

SMA springs were also tested in a 3d printed TPU ring type structure (refer to fig 7.7). TPU is a flexible material which can be easily controlled with the help of SMM as well as had the potential of being a bias force. The structure was such that when the springs were activated, one side of the ring would contract. The motion was very prominent. The problem in this set up was that due to the size of the springs the wearable became very bulky.

A wire programmed to be a type of flat spring was also tested (refer to fig 7.8). When activated the wires moved a bead (effector). When the heat supply was cut, the bead would slide back slowly with the help of a silicone rubber sheet as the bias force. Although the motion was prominent, the wires were difficult to control, therefore each test provided different levels of displacement.

Some of the actuators were more effective than others. In order for the mechanism to be controllable, it is required to use a small amount of the SMA wire. The springs provided the most amount of motion, but the process of creating the springs could lead to the recovery of a distorted shape.. Amongst all the actuators the slider mechanism (fig 7.4) provided the largest amount of motion. An overview of the actuators is on the next page.

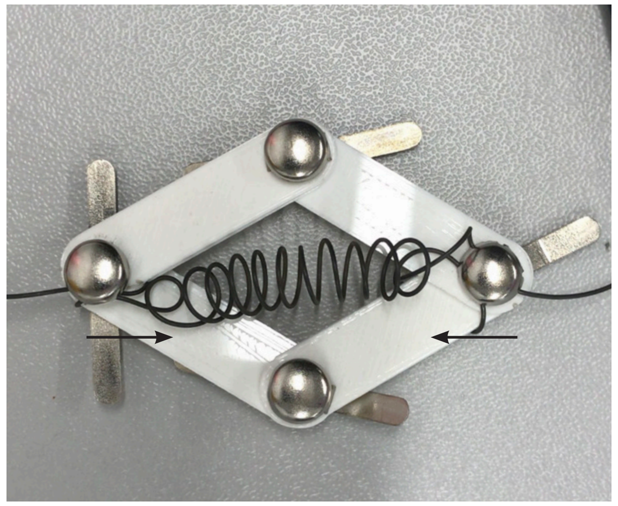


Fig 7.6 Actuator with SMA spring to create sliding and pinching sensations

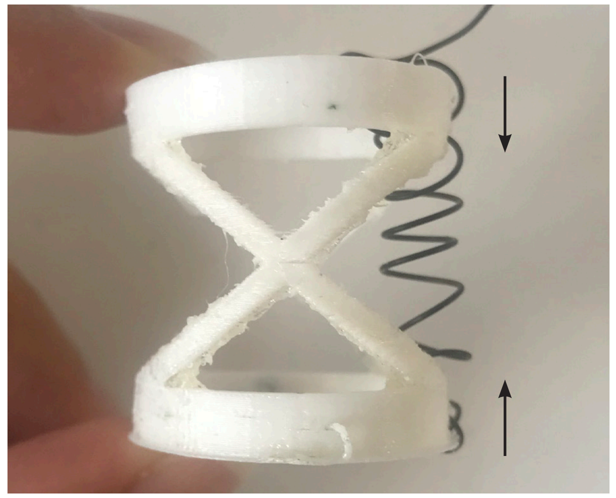


Fig 7.7 Ring structure with spring

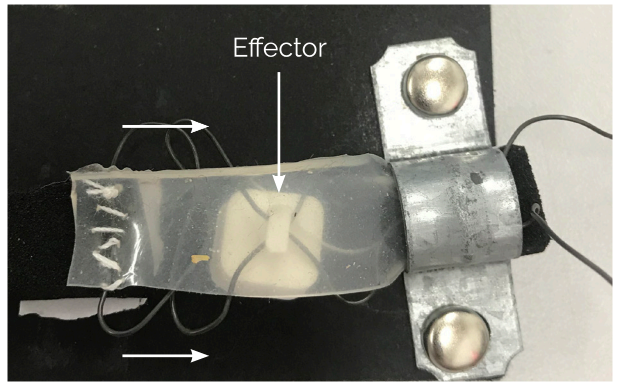
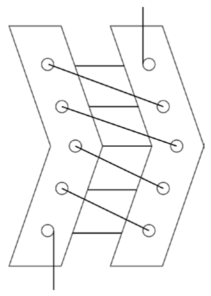
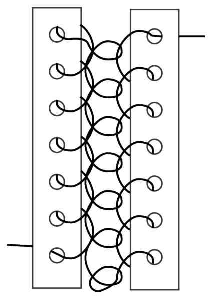
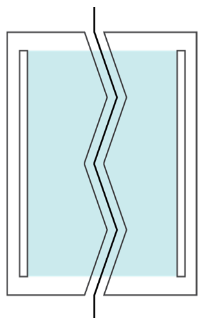
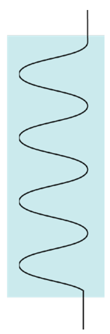
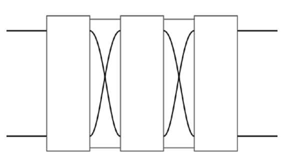
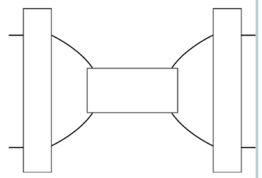
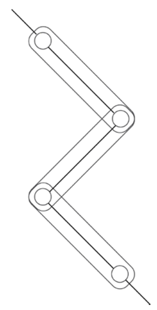
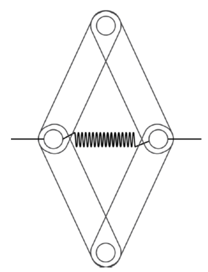
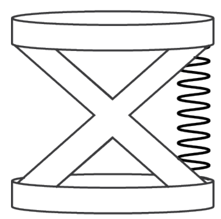
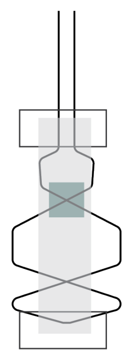


Fig 7.8 Mechanism with flat spring

Please scan the code to see a video compilation of the SMA actuators.

Actuators	Components	Motion	Pros	Cons
Straight annealed SMA wire				
	• 2 PLA pieces • 1 Long SMA wire	•Uneven slide •Uneven contraction		•Difficult to control
	• 2 PLA pieces • 1 Long SMA wire (mesh format)	• Uneven slide		•Difficult to control •Accumulated heat
	• 2 PLA teethed sliding pieces • 1 PLA guide piece • 1 SMA wire • (tested with lycra or silicone rubber as bias force)	• Slide	•Easy to control •Repeatable motion with bias force	•Subtle motion
	• Lycra • SMA wire (zigzag format)	• Pressure	• Easy to control	• Subtle motion/ sensation
	• 3 PLA sliding pieces • 1 PLA guide piece • 2 SMA wires	• No motion		• No motion

Actuators	Components	Motion	Pros	Cons
	• 1 PLA sliding piece • 2 PLA fixed pieces • 2 SMA wires	• No motion		• No motion
	• 3 PLA sliding pieces • Brad pins • 1 SMA wire	• Slide	• Quick and noticeable motion	
Other programmed SMA wires				
	• 4 PLA sliding pieces • Brad pins • 1 SMA spring	• Slide • Pinch	• Easy to control • Prominent motion	
	• TPU ring • 1 SMA spring	• Pinch	• Easy to control • Prominent motion • TPU acted like a bias force	• Bulky set up
	• 1 PLA bead • 1 SMA flat spring • Silicone rubber sheet (bias force)	• Slide	• Prominent motion	• Difficult to control

7.3 Selection of Mechanisms for Further Exploration

In order to provide a larger range of information, it is good if the actuators are capable of providing multiple distinguishable sensations.

Two methods of achieving multiple motion were looked into- simple single slider and multi motion of a single effector. In the case of the simple single slider, in order to achieve a large number of movements, the setup can consist of multiple of these mechanisms. In the case of the single effector, one point can be controlled in such a way that it is capable of a variety of movements.

7.3.1 Single Slider

This mechanism was inspired from the three component sliders (refer to fig 7.4). The structures were first tested without a bias force, in order to understand the behaviour of the wires when exposed to the stimulus. It was seen that the motion was the clearest with the reduced number of components. Further experiments were done using only two components.

The set up consisted of 3d printed PLA structures and Flexmet NiTiCu wires of 0.5 mm diameter. Different versions of the structures were constructed based on the programmed shape of the SMA wires and type of bias force.

The basic motion created in this set up was sliding. By changing the type of effector, different sensations could be created such as pinching and dragging. The point of the mechanism which is anchored also had an impact on the motion and feedback (refer to fig 7.9).

Different modes of bias forces in this mechanism were also compared, These were lycra, silicone rubber and a second SMA programmed wire (refer to fig 7.10).

The second SMA programmed wire had the quickest recovery motion therefore enabling it to produce repetitive and a larger range of motion. This mechanism consisted of one SMA wire programmed to be a V shape and the other programmed to be straight. These were attached to the mechanism through brad pins and insulating tape (refer to fig 7.10 c). An issue faced with this mechanism was that the wires were susceptible to twisting and changing their orientation. When activated, it attempts to recover its shape in a different plane than the structure. In order to fix this, a new set of structures were printed with guides and a single part printed hinge (refer to image to fig 7.10 d). Although this was less susceptible to the error, the wires could still twist in this setup.

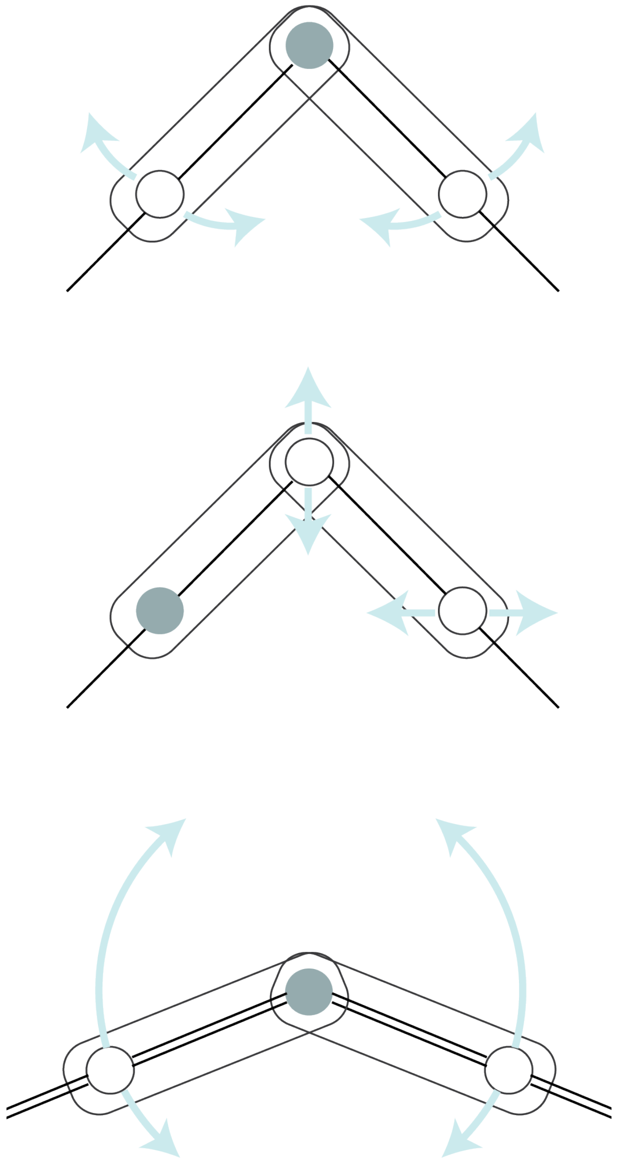


Fig 7.9 Impact of anchored position on motion

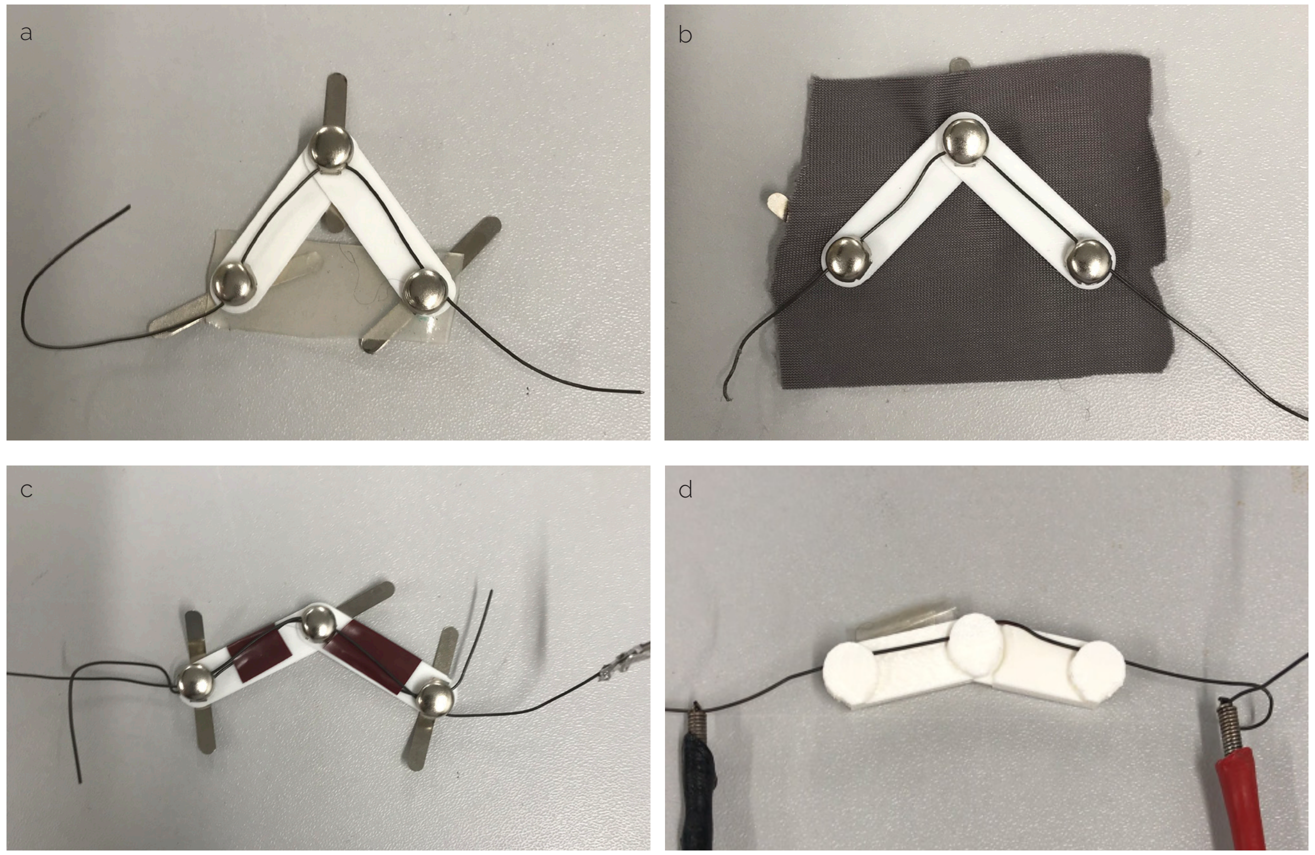


Fig 7.10 bias force explorations a- Silicone rubber, b- Lycra, c- SMA wire, d-single printed structure with guides

Benefits of this mechanism:

- Small structure
- Large and prominent motion
- Repetitive motion
- Quick actuation

Disadvantages of this mechanism:

- Susceptible to error due to misalignment
- Mechanism can get overheated since two wires are being activated and takes longer to cool down

Please scan the code to see a video compilation of the single slider explorations

7.3.2 Multi Motion of Single Effector

The aim of this mechanism was to achieve multiple types of movements of one effector along a plane. Three formats were tested.

Two formats consisted of four Flexmet NiTiCu wires of 0.5 mm diameter. In the first format, the wires were attached to a centre effector and fixed directly onto a ring (refer to fig 7.11a). In the second format, the wires were attached to a ring via lycra (refer to fig 7.11b). Each wire was activated individually in order to move the centre effector. Both formats failed to move the centre effector significantly.

The third format consisted of 4 programmed springs made from Flexmet NiTiCu wires of 0.5 mm diameter. The springs were programmed using a m6 bolt. The springs had around 12 coils and had 200% elongation. The mechanism was created on a sheet of lycra with one end of the springs being attached to the cloth and the other end to a centre effector (refer to fig 7.11c). Each wire was activated individually. This mechanism successfully moved the centre effector. The other springs had the possibilities to behave as a bias force to bring the effector back to the centre once the stimulus was removed. The springs were however difficult to control. It was important to fix one end of all the springs securely to the cloth to ensure the complete range in motion. During the tests, this was done by placing weights on the ends of the springs.

The mechanism also had the capabilities of creating a large range of motion depending on the sequence of wires activated. For example in fig 7.12, if wires A and B were activated at the same time, the effector would move diagonally.

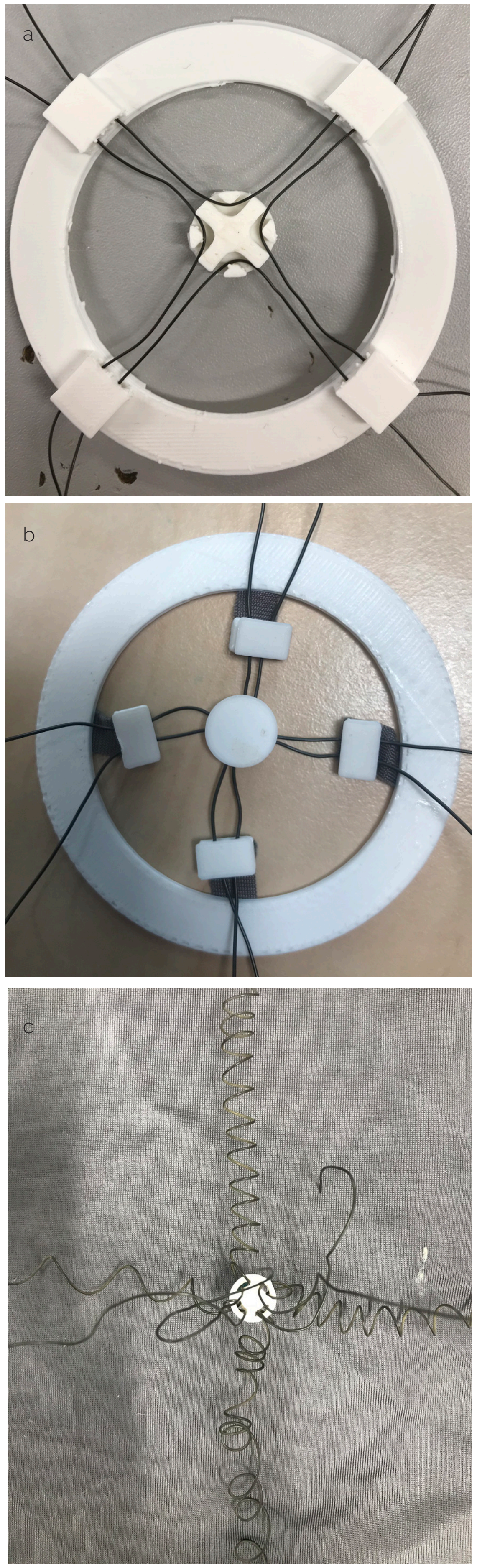


Fig 7.11 Multi motion demonstrator a- wires attached to ring, b-wires attracted to lycra, c- springs attached to effector

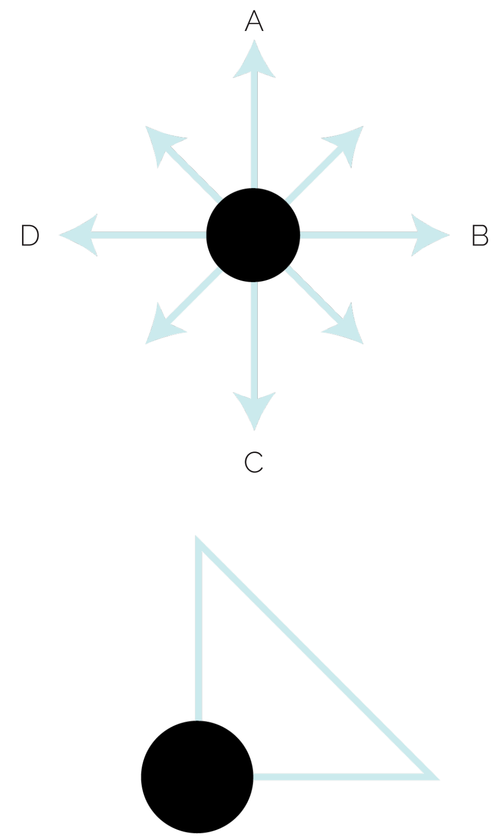


Fig 7.12- Multi motion of effector

Benefits of this mechanism:

- Prominent motion
- Repetitive motion
- Quick actuation
- Large range in motion

Disadvantages of this mechanism

- Mechanism can get overheated since multiple wires are being activated and takes longer to cool down
- The springs were difficult to control and both the cloth and one end of each spring needed to be fixed securely.

7.3.3 Selection

Both mechanisms were compared using the weighted objective method (refer to Appendix G) Although both were rated very closely, the single effector multi motion mechanism was less susceptible to error and therefore could reproduce the same motion multiple times. There is also an opportunity to simplify the manufacturing process for this actuator if the springs are procured from suppliers. It also had an opportunity of providing a larger variety of motion. This mechanism was therefore chosen for further development.

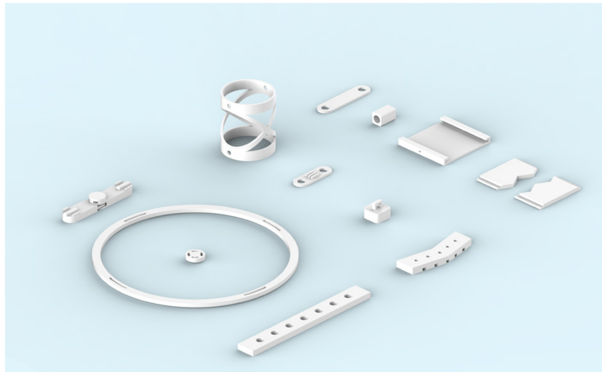


Fig 7.13 Overview of 3d printed components

Please scan the code to see a video compilation of the single effector multi motion explorations

8.

Demonstrator

8.1 Passive materials

The smooth functioning of the demonstrator is not only dependent on the active material i.e. the SMA spring but also the passive materials supporting it. It is important that the materials selected do not interfere with the movement of the shape memory alloys. The passive materials in this demonstrator are the effector, the heat barrier components and structural support.

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The setup was tested first on a silicone rubber sheet of 0.3 mm thickness and then lycra. It was seen that both the materials did not hinder the movement of the effector.

Temperatures above 48˚C is considered to be uncomfortable for the skin (Ungar & Stroud, 2010). The austenite finishing temperature of the SMA wires is 90˚C, hence there was a need for a heat barrier layer between the wires and the skin. According to Hamdan et al. (2019), kinesiology tape can be used as a heat barrier material. This was tested on the skin using one SMA spring (refer to fig 8.1) which concluded that the tape alone was not enough to block temperatures of 90˚C. It was then tested in combination with the silicone rubber sheet which proved to be very effective.

The demonstrator was then tested sandwiched between two sheets of silicone rubber (refer to fig 8.2a). The purpose of the second silicone sheet was to ensure that the effector stayed positioned against the skin. The second layer did hinder some of the movement of the effector. It had the tendency to drag the sheet with it rather than moving just on the surface.

The demonstrator was then tested between a silicone rubber layer and lycra (refer to fig 8.2b). The lycra ended up getting entangled in the spring therefore hindering the motion. Lycra sleeves for each spring were also tested, but it was decided that the least intrusive format would be to have just the heat barrier layer between the active material and the skin and nothing on the other side of the SMA wires.

The size and shape of the effector also has an impact on the perception of the haptic feedback created by the demonstrator. Different sizes of effectors were 3d printed in PLA and tested (refer to fig 8.3).

Fig 8.1 Testing heat barrier properties of kinesiology tape

The dimensions were as follows:
Effector 1: Dia 18 mm, height: 8 mm
Effector 2: Dia 14 mm, height 7.8 mm
Effector 3: Dia 14 mm, height 6.2 mm
Effector 4: Tapered tip with Dia 5.6 mm, height 20.2 mm

The sensation created by the motion of effector 3 was very subtle, this could be predicted due to the small height and tendency of misaligning itself away from the skin. Effector 1 although with a similar high as effector 2, also provided a subtle sensation. The large diameter was seen to be a cause of this, since the pressure exerted on the skin by the effector increases with the decrease in surface area of contact. The increased thickness of the heat barrier i.e. silicone rubber and kinesiology tape, also affected the perception of the effector's motion. In order to counter this, effector 4 was used. It had a tapered edge and a larger height to ensure that it is in constant contact with the skin. There were still some errors of misalignment with the effector due to the flexibility of the springs.

The springs require a semi rigid material to provide structural support to the entire demonstrator. This allows them to solely

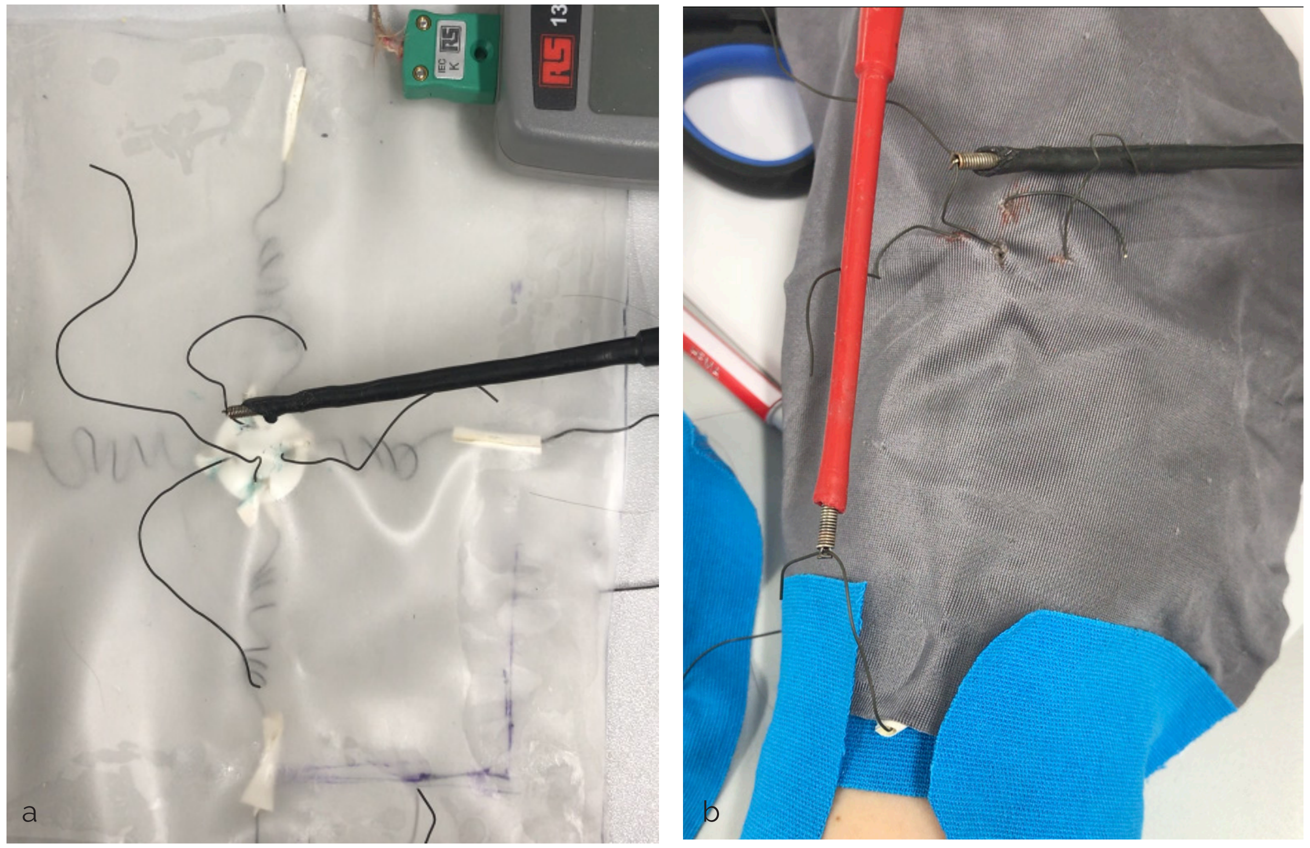


Fig 8.2 a- sandwiched between two silicone rubber sheets, b- sandwiched between one silicone rubber sheet and lycra.

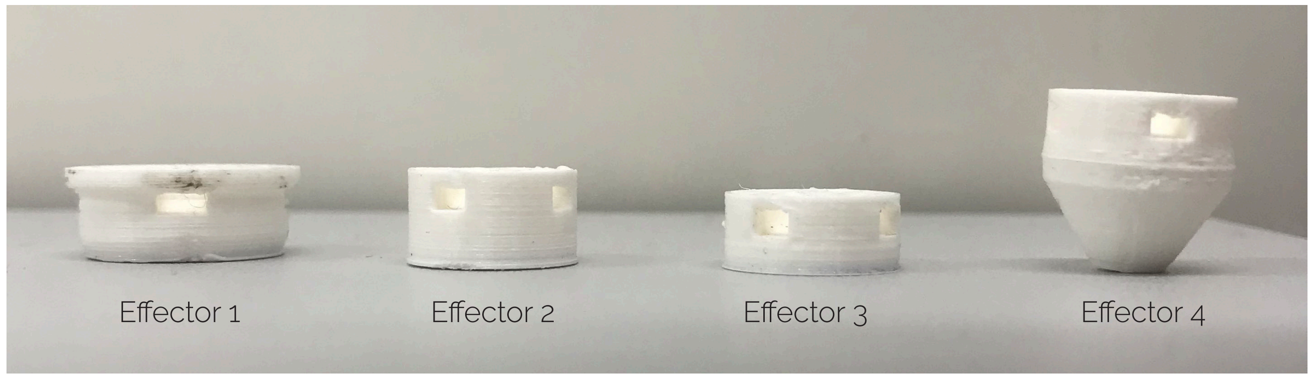


Fig 8.3 Different sized effectors tested

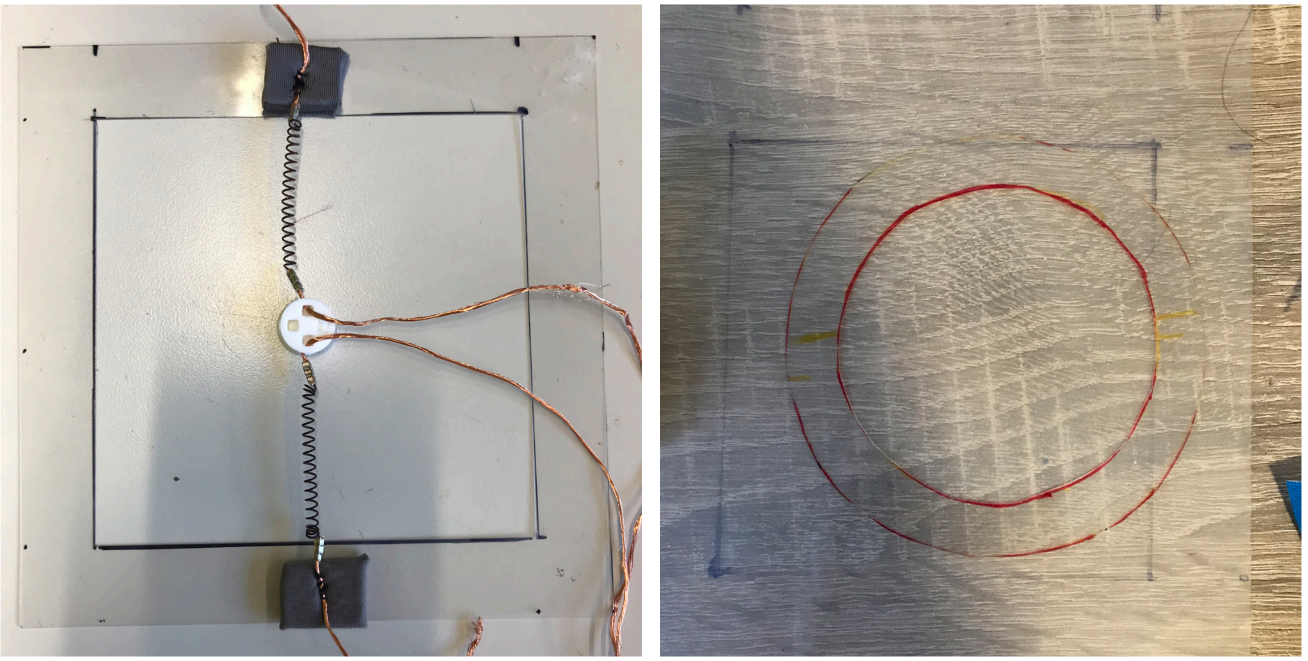


Fig 8.3 Square and circular PVC sheet structure for support

move the effector and not the other passive materials. Polyvinyl chloride (PVC) sheets were tested as they are flexible (can take the shape of the body location the demonstrator is placed on) yet rigid. The form of the sheet also had an impact. Both a circular and square frame were tested (refer to fig 8.3). The circular format provided enough support to enable the demonstrator to work smoothly as well as allowed the setup to be smaller and hence was taken forward into the final prototype build.

8.2 Active materials

In the material testing phase of the project, multiple springs of different dimensions were created and tested. The process of programming SMA wire to be springs are as follows:

The wires are wound around bolts and fixed with the help of nuts as can be seen in fig 8.4. They are then programmed to 'remember' the shape by treating them in a ceramic oven at 500˚C. After 45 minutes, they are removed from the oven, immersed in water and then can be removed from the bolts.

It is recommended to create extra SMA springs because the process of creating SMA springs is sometimes susceptible to error, especially if the wires aren't tightly fastened.

Fig 8.4 Programming SMA wires to become springs with the help of nuts and bolts.

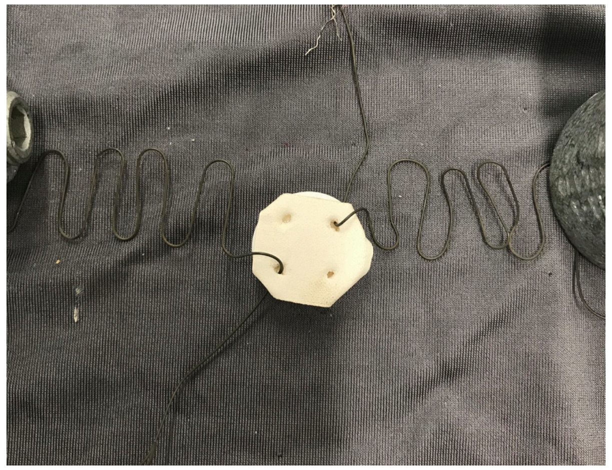


Fig 8.5. SMA programmed to be flat springs were tested with the effector

Another aspect was the comparison of NiTiCu and NiTi wires. NiTi wires were more difficult to control and fasten tightly in the creation process but springs made from this material were more rigid than those made with copper (Cu). Less flexibility of the springs is ideal for the demonstrator in order to ensure that

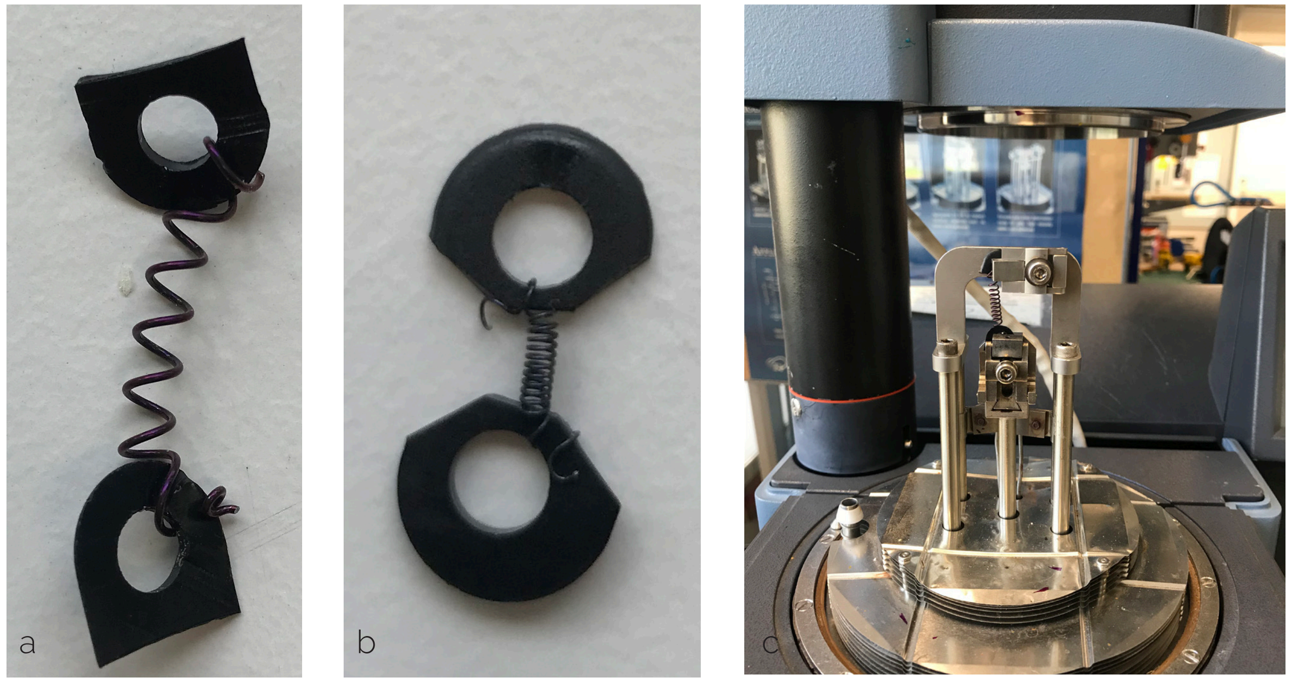


Fig 8.5. a- spring 1, b- spring 2, c- sample clamped in Q800 DMA machine

the effector is always positioned in contact against the skin.

SMA wires programmed to be flat springs were are also tested but proved to be inefficient (refer to fig 8.5) . It tended to change the plane of motion and provided very little movement to the effector.

Flexinol springs of two dimensions were procured from Dynalloy. Inc in order to compare with the springs created thus far in the project. Spring 1 was made from NiTi wire of diameter 0.51 mm, with the outer diameter of the spring at 3.45 mm. Spring 2 consisted of a 0.20 mm diameter NiTi wire, with the outer diameter of 1.37 mm. Both of the springs had approximately 10 coils and austenite finish temperature of 90˚c. When these springs were tested with the effector, it was seen that it provided more prominent and controllable motion than the springs previously tested. This is could be due to the purity of the materials as well as the lack of Cu.

8.2.1 Mechanical testing

Mechanical tests were conducted on the procured Dynalloy springs using a Q800 DMA machine in order to measure the relationship of load and displacement. They were both tested at 100% and 200% strain and the produced load were compared. The length of spring 1 was reduced by half (5 coils) in order to fit the machine.

The samples were looped into small plastic rings to ensure easy and proper clamping in the machine (refer to fig 8.5). The test procedure was as follows:

In the machine, the samples were stretched to different lengths (100% and 200% elongation)

	Spring 1 (wire dia 0.51 mm)	Spring 2 (wire dia 0.20 mm)
100% Strain		
50˚C	2.6 N	0.2 N
90˚C	4.6 N	0.3 N
diff	2.0 N	0.1 N
200% Strain		
50˚C	1.7 N	0.4 N
90˚C	3.6 N	0.8 N
diff	1.9 N	0.4 N
Average	1.95N	0.25 N

Table 8.1 Results of mechanical testing

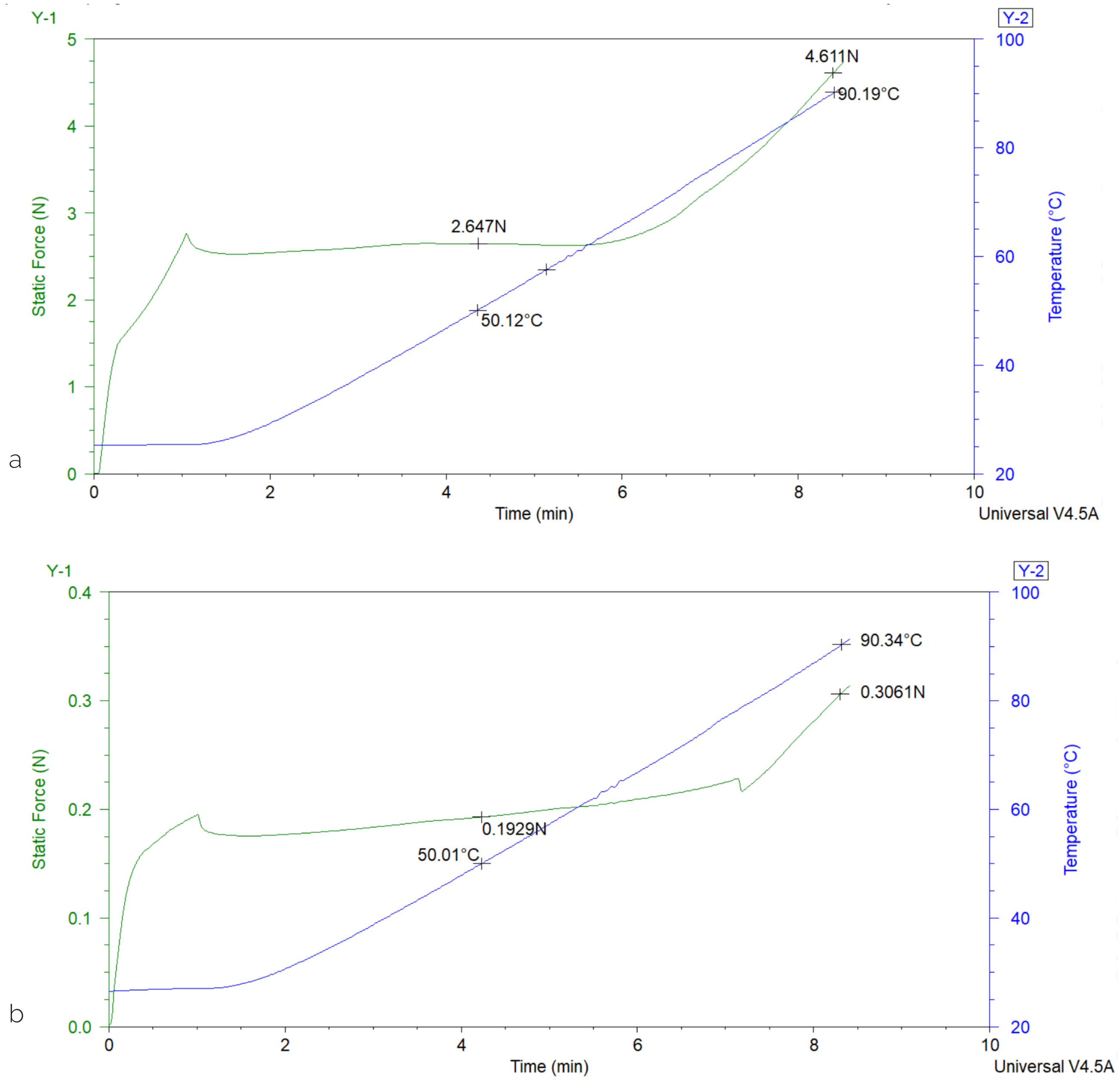


Fig 8.6. a- Spring 1 with 100% strain, b- spring 2 with 100% strain

after which they were fixed in place. The samples were then activated with heat and the load produced between 50˚C and 90˚C were noted. The results of the test can be found on table 8.1 and the stress-temperature-time graphs for 100% strain for both samples in fig 8.6. The graphs for 200% strain can be found in Appendix H.

It can be seen that the force exerted by both samples have minimal difference between 100% and 200% strain. There is a major difference, however with the force exerted between both the springs. Spring 1 exerts ~1.95 N while spring 2 exerts ~0.25 N. In order to provide stronger haptic sensations, it was decided to move ahead with spring 1 for the demonstrator.

8.3 Electronics

During the testing and exploration phases of the project, the actuators were activated with the help of a power supply with a manual voltage and amperage control. In order for the demonstrator to be used in a wearable format as well as be portable, a new electronics system had to be incorporated.

In the set-up, 4 SMA springs have been incorporated, but a maximum of 2 would be activated at the same time. All the springs are connected in parallel which means that the prescribed voltage is the amount required for one spring i.e. 2 V. A QSKJ DC-DC Adjustable Step-down Buck Converter XL4005 of 5A was

used to make the demonstrator compatible to a lithium polymer battery. 4 mosfet modules were incorporated (one for each spring) to control the voltage/current flow to each spring. With the help of a Seeeduino Lotus board each SMA spring could be controlled individually with a button. The code can be found in Appendix I.

The springs were wired with Litz wires as they are more pliant than the conventional PVC insulated wires and hence would not interfere in the movements of the SMA springs. In order to connect the springs to the wires, crimping is done (refer to fig 8.7). This is because there is a risk of overheating the SMA wire in the soldering process. The Litz wires have an insulating lacquer layer which often hinders the connections when being crimped. In order to overcome this, the lacquer at the tips of the wires have to be burnt and then coated with tin filament (meant for soldering) before being crimped to the springs. Closer to the electronics setup, the Litz wires were connected to the conventional PVC insulated wires using screw terminals. At this distance away from the demonstrator, these wires do not hinder the movement of the SMA springs.

The setup was mounted on a 3d printed PLA plate with the help of screws and the Seeeduino Lotus board was connected to a computer. Refer to fig 8.8 for the complete setup.

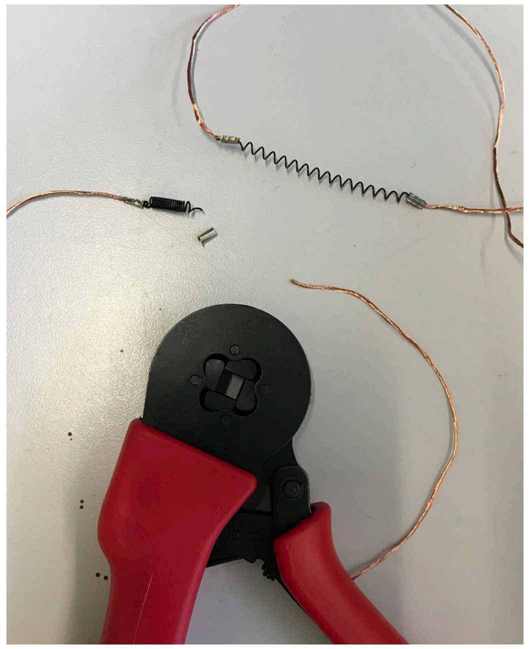


Fig 8.7. - Crimping process

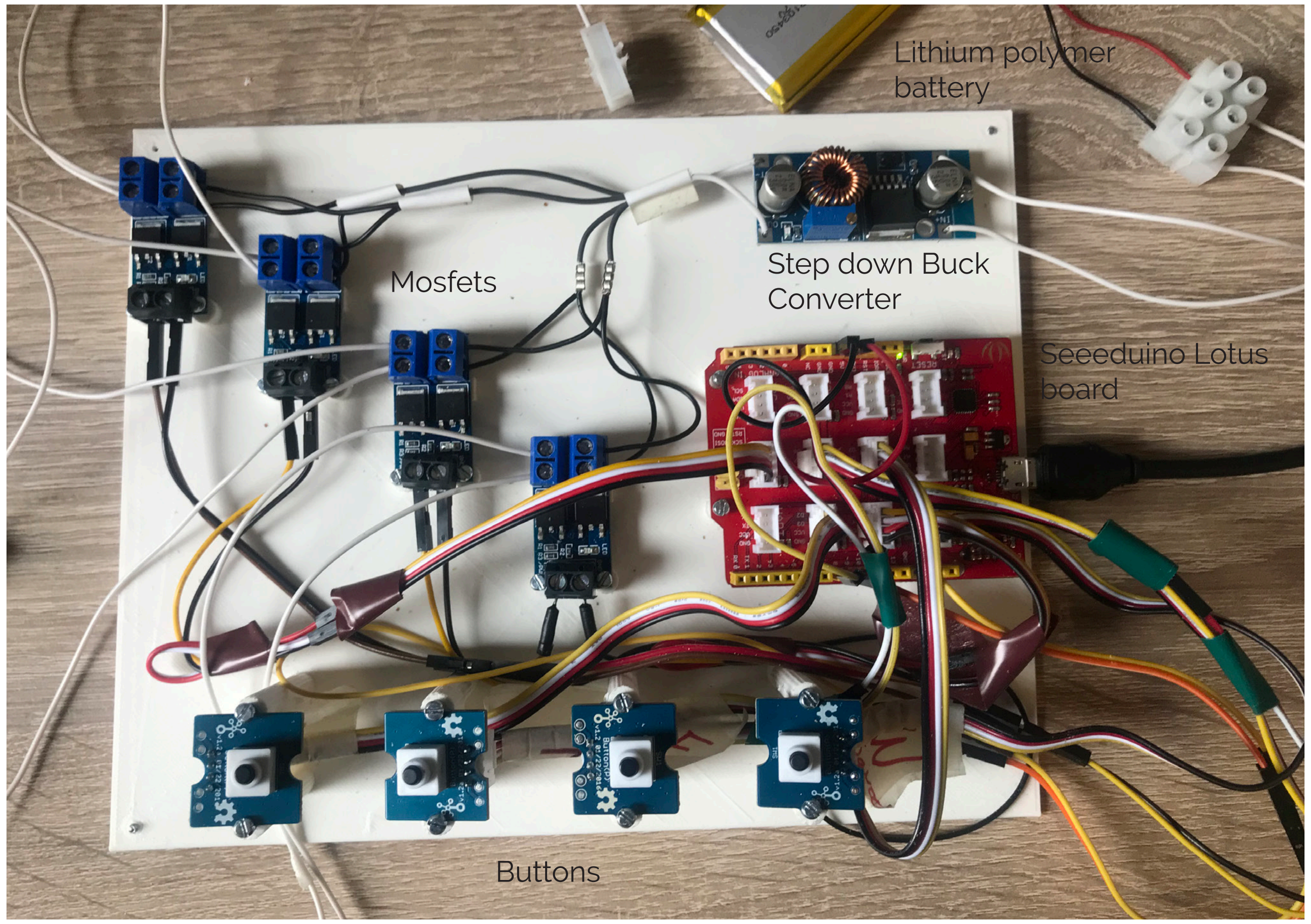


Fig 8.8. Electronics setup

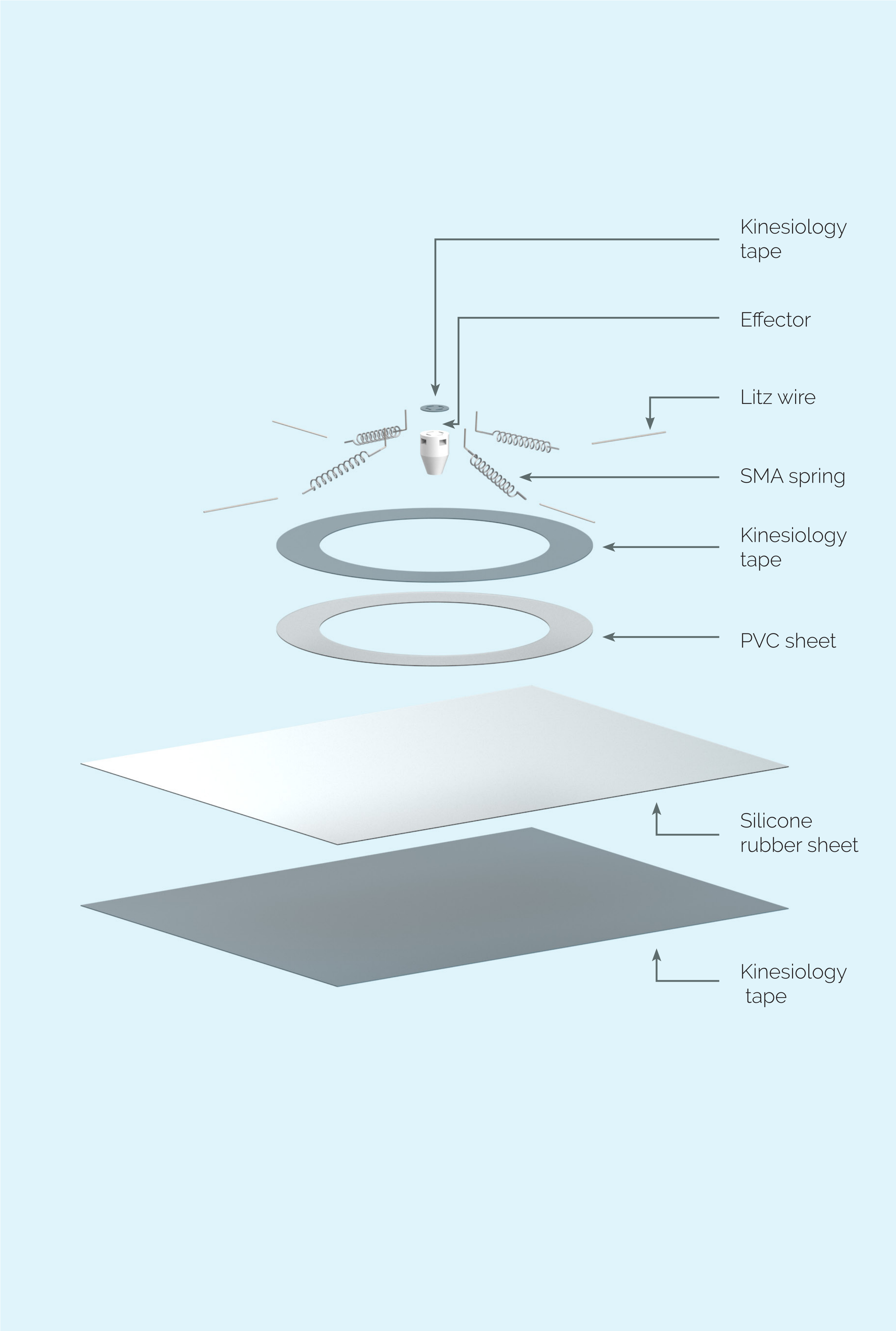


Fig 8.9 Layers of the demonstrator

8.4 The Build

The final demonstrator consists of multiple layers as can be seen in fig 8.9.

The first layer is the heat barrier layer which is in contact with the skin. This consists of the kinesiology tape and silicone rubber sheet.

The second layer is a structural support frame made of PVC sheet. This is in the form of a flat ring connected to the silicone rubber with the help of industrie secondelijm adhesive. A flat ring made of the kinesiology tape is then placed on top, as this forms a better connection with the wires.

The four springs crimped with the Litz wires are looped into the effector. There is a protective layer of kinesiology tape on the effector to protect the PLA from damage due to heat. The wires are then both glued and stitched to the others layers to ensure that the SMA springs don't slip out when activated. The electronics can then be connected. Refer to fig 8.10 for the completed wearable section of the demonstrator.

The entire setup can be attached to different body parts with the help of kinesiology or surgical tape.

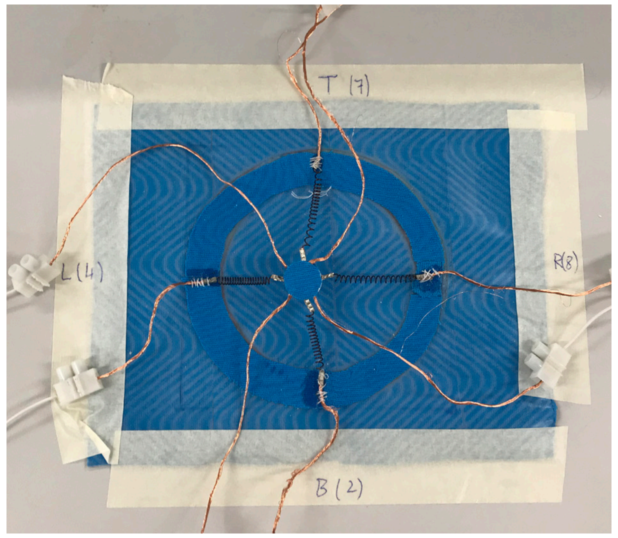


Fig 8.10 Completed wearable components of demonstrator

Please scan the code to see a video compilation of the SMA spring explorations for this demonstrator

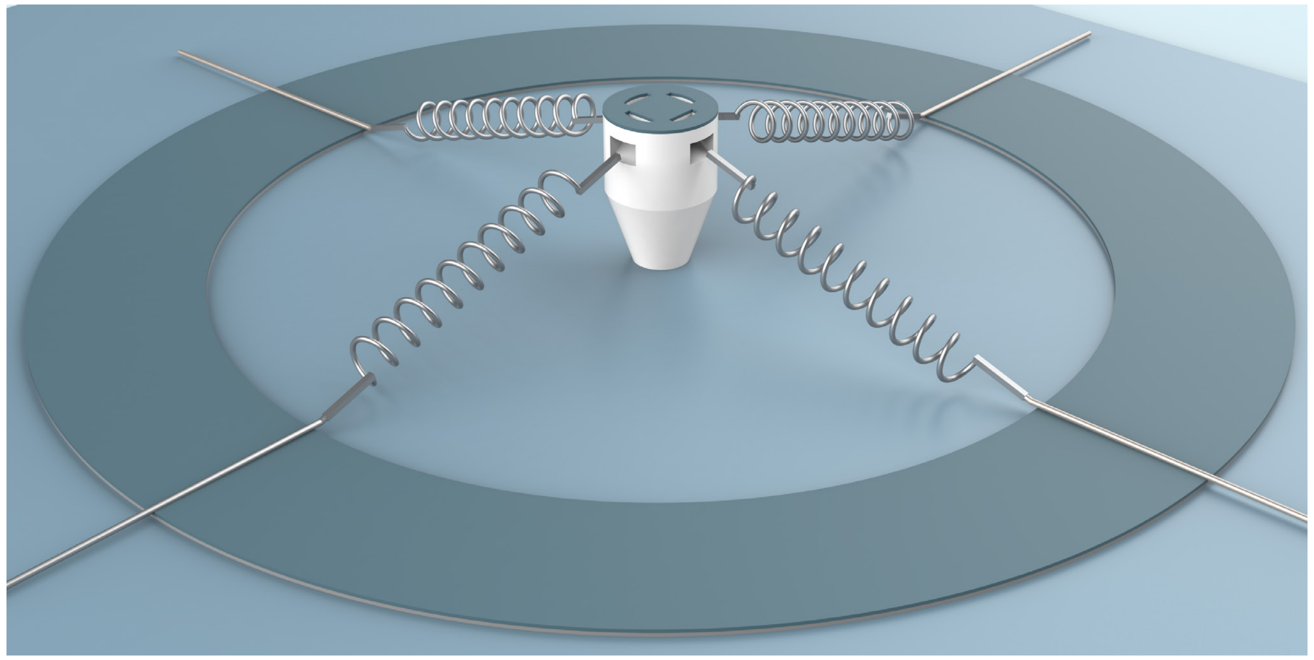


Fig 8.11 Effector setup of demonstrator

8.5 The Testing

A set of tests were conducted in order to understand the perception of the haptic demonstrator and whether simple patterns delivered by it are distinguishable. Short brainstorming sessions were also conducted at the end of the tests to gather insights into potential applications for the setup.

8.5.1 Participants

The test was conducted on 5 participants ages 27 and 28. Two participants identified as male and three as female. They were asked to wear loose clothing during the experiments and gave written informed consent prior to the start of the tests. Refer to Appendix K for the consent form provided to the participants. Two of the participants were aware of the project and types of motion to be expected i.e., directional motion. The other participants were informed about the components of the wearable device and that once activated, they would experience some form of movement on their skin.

Since the demonstrator was made to be portable, the tests could be conducted wherever the participants felt most comfortable.

8.5.2 Test Setup

The demonstrator was tested on the forearm (both inner and outer side), upper arm (outer side) and back of the participants (4 of the 5 participants). Refer to fig 8.13 for the different placements. The demonstrator was attached to the body with the help of kinesiology/ medical tape. It was secured in place and ensured that the participant was comfortable. Care was taken that the effector was in contact with the skin (on top of the heat barrier layer). The demonstrator was aligned in such a way that it was always oriented in the same position for all participants i.e., the same spring would move in the same direction for all the participants. Since there are differences in arm and torso structures between the participants there were some variations on the exact placement of the demonstrator. For the arm experiments, participants were asked

Fig 8.12 One of the test locations

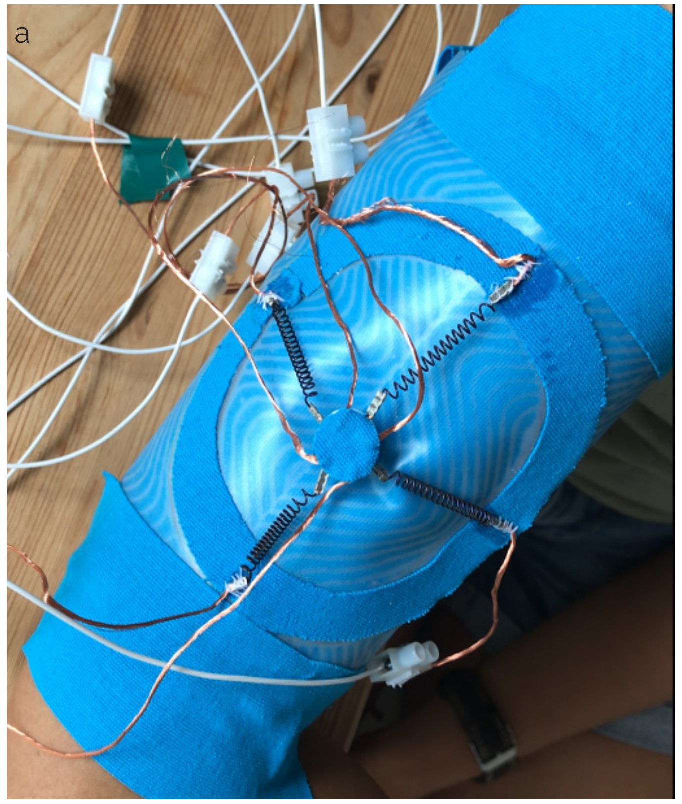
to sit with their arms resting at a desk while for the experiments on the back, they sat sideways on a chair.

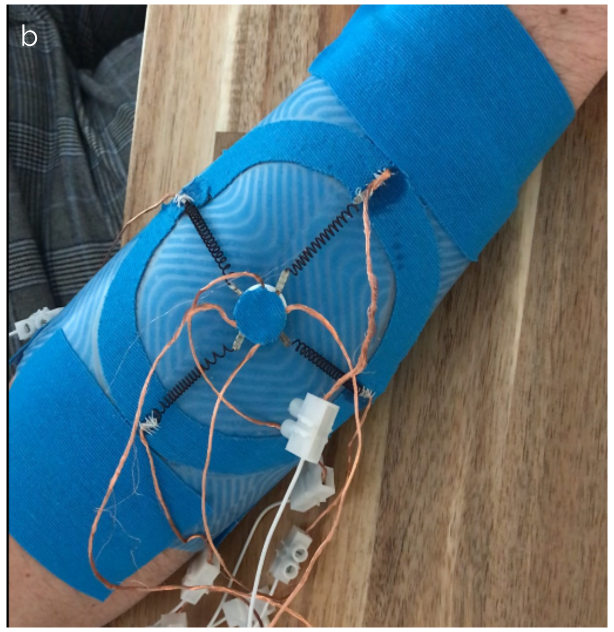
8.5.3 Test Procedure

After written consent was provided by the participants and the demonstrator was attached to the body, a trial experiment was conducted. One of the springs were activated (upward motion) and the participants were asked to describe the sensation they experienced however way they liked. At this stage if the sensation was described as very faint, the demonstrator was removed and re-attached to ensure good contact with the skin.

The next step was testing the perception of the other movements. Different springs were activated one at a time, enabling the effector to move in different directions. The participants were asked again to describe the sensations and if a specific direction was perceived. They could also compare the sensation to the previous one they experienced.

Two springs were then activated one after the other and the participants were asked to identify whether the two sensations were the





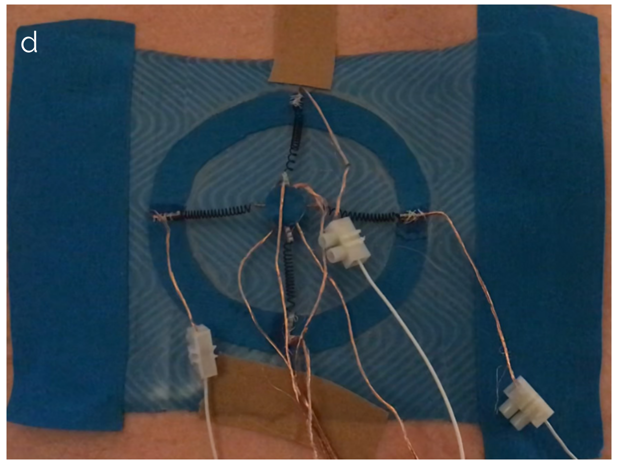


Fig 8.13 Different body placements a- Upper arm, b- Lower arm outer side, c-Lower arm inner side, d- back

same or not.

The test then ended with a discussion of possible applications for the demonstrator. First, as general applications and then specific to the project's context area of the blind and visually impaired.

8.5.4 Analysis

It is important to note that there is accumulated heat produced by the demonstrator which is perceivable to the participants if multiple springs are consecutively activated. It is thus important to have small breaks after 2 – 5 trials to allow the SMA springs to cool down. At this stage the effector and heat barrier layer can be re-adjusted. Occasionally, some participants reported a lack of sensations due to the twisting of the heat barrier layer, which thus needed to be adjusted. When shifting the demonstrator to a new location, it was also important to use new tape in order to ensure that the demonstrator is tightly secured.

8.5.5 Results

Discrimination and Identification

All the participants were able to distinguish between the sensations created by activating each SMA spring, although they didn't always identify a specific direction unless asked. Table 8.2 presents the accuracy rates in the direction identification for each location. One participant mentioned that the direction of the first motion is easy to perceive but later it becomes difficult to identify because it becomes in relation to the arm and not the previous location. The lower arm outer side location as an average had the most correctly identified directions, although the highest accuracy score was located on the upper arm by participant 2 (88.9%) and on the back by participant 1 (83.3%). Up and down movements were the most identifiable in terms of direction.

Body Location	Sensation Identification Rate
Lower arm inner side (3 participants)	33.3%
Lower arm outer side	41.6%
Upper arm	38.4%
Back (4 participants)	28.5%

Table 8.2 Accuracy rate of participants identifying the type of feedback

There was difficulty identifying the type of sensation for each trial. This is explained further in the next section.

Perception of Sensations

There was a difference in how the same set of haptic feedback was perceived between the four locations. On the three arm locations, left and right motion was often perceived as pressure or squeezing. It was perceived as being a thin band, a thick band and a point, but there was no clear connection between this perception and the location or specific SMA spring which was activated. On the back there was more of a perception of dragging or pinching. Other identified sensations across the four locations included twisting, circular motion, a ripple, a tingle and heat. The participants were extremely aware of all forms of haptic feedback during the test procedure, including that from the medical tape (though they were able to identify that it was due to the tape and not the demonstrator).

All the participants perceived the sensations as organic and were the most comfortable comparing the feedback to other experiences. Some sensations were perceived as lighter and more subtle than others, across all four locations. Comfortable amounts of heat were perceived by 4 of the 5 participants. These participants believed that the heat was one of the types of haptic feedback provided by the demonstrator.

The following are the experiences the sensations were compared to:

- Finger against skin
- A tiny human
- A massage
- Ants crawling
- Water jet
- Acupressure
- Sweat trickle
- Feather
- Gush of blood

3 of the 5 participants expressed that the sensations were interesting throughout the set of tests. One participant constantly mentioned that it was very comforting. Another participant said that the sensations such as a water-jet, massage, and pressure felt good while the ants crawling was strange.

Interview

After the test procedures were completed the participants were asked to discuss what they had just experienced, compare to previous haptic devices they had used and brainstorm potential application for the demonstrator if incorporated as is.

All the participants had experienced some sensations more prominent than others. Two participant asked if there was a way to increase the intensity for better noticeability, while the others were comfortable with it being a subtle form of feedback, according to what it will be used for.

All the participant had only experienced

vibration as a form of haptic feedback through technology. One participant said that she only depended on touch sensations through humans not technology and therefore found vibrations to be 'weird'. She also mentioned that the sensations delivered by the demonstrator were more comfortable and natural and that there was no need to associate the sensations to human touch in order for it to feel organic. 4 of the 5 participants preferred this form of feedback as compared to vibration. The 5th participant mentioned that vibration may be preferred for urgent notifications because of the sound associated to it as well as its high intensity.

As per the location, the back was the least preferred location. It was mentioned that the sensations were more subtle and one could get used to it. It was compared to a trickle of sweat which one may be aware of initially but it is easy to ignore. It would also be difficult to sit against something or lie down when wearing such a structure on the back. One participant mentioned that it would be more comfortable as a wearable on the arm if there was an easier attachment system.

Application

The participants were initially asked about general applications for the setup as is and then were informed about the context area of the blind and visually impaired. Most of the participants mentioned that a majority of applications can be used for both BVI and non BVI users. It was also brought up that the device can be a 'free object' open to users assigning whatever value they want to each sensation. Topic specific applications are explained below.

Sports:
As a wearable on the arm, the demonstrator was compared to a Fitbit or smart watch. The device could be used to provide more comfortable and natural forms of feedback than the vibrations normally available in most of these devices. One participant who uses a running application on the phone said that she listens to music while exercising, but there are auditory cues when to change the pace which becomes an unpleasant interruption to the music. It was suggested that haptic feedback of the demonstrator could be used as the cues instead. Another application was

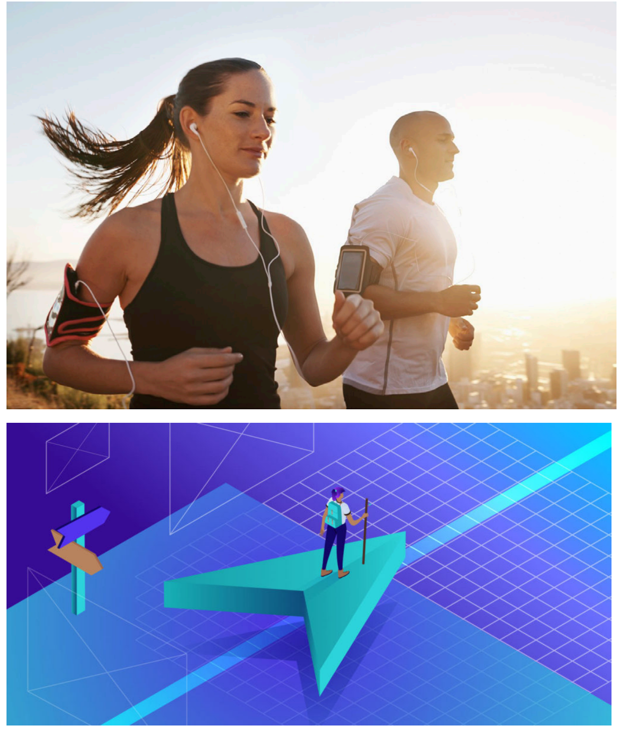


Fig 8.14 a- In sports for runners (image ref-Noddings, 2017) b- As a navigation guide (image ref-Web Designing Service, n.d.)

incorporation into sports training for posture or grip correction

Navigation:
It was mentioned that if the intensity for each motion was increased, the demonstrator could be used to convey directional information. It can also be linked to traffic signals to indicate the amount of time left for the signal to be green so one can safely cross the road. If linked to proximity sensors and other systems, it can detect objects in one's way or the end of a curb/sidewalk. In this case, it would act as an extra reassurance that one is moving in the correct direction. The directional feedback could even indicate small changes such as sharp or slight directional change.

Warning or Notification:
The demonstrator as is could be connected to a heart rate monitor to indicate different values to the users or become reminders for taking medicine etc. If the intensity of the demonstrator was increased, it could be used as a form of alarm or urgent notifications.

It can be used for cooking as an indication if food is done. For this case it was specifically mentioned that the heat form of feedback can be used as an indicator, especially if one has to step away from the kitchen.

Tactile feedback by the demonstrator can also be used to filter quickly through messages or emails to indicate if it is important or 'trash'. Currently it is being done through audio cues for the blind and visually impaired but potentially can be done faster if the information is provided differently.

Human touch:
The demonstrator was compared multiple times to human touch and a massage. It was mentioned that it could be used for remote care such as mimicking a mother's touch for hospitalized children or for kids on the spectrum. If controlled, it can also be a form of remote acupressure or physiotherapy as well.

Other:
Other types of applications included posture correction. For example it can be incorporated in furniture such as the back or arm rest of a chair. It was also mentioned that it can be used to convert visual information into tactile icons as means of communication. It can also add to an experience such as conveying if the weather outside is good. Something one is aware of usually by looking out of a window.

Fig 8.15 Convey visual elements outside a window to users. (photo by Jeremy Bishop on Unsplash)

8.6 Discussion

All participants preferred the arm location to the back, but the exact location on the arm differed for each participant. They all commented that the back required the most amount of concentration. There was also a variety of unforeseen types of sensations provided by the demonstrator. A reason for this could be due to the passive materials. For example if the barrier material folded slightly, the user experienced a pinching sensation. It was also seen that the effector would sometimes tilt over first and then drag in the direction of the SMA spring hence creating new sensations.

Motion to the left and right on the three arm locations were the least identifiable feedback. It was compared to a blood pressure belt a few times during the test procedures.

It was also mentioned that the heat provided by the springs helped in the noticeability of the feedback and in some cases even for the identification of direction.

There was discussion that at least two or three motions could be easily recognized to which values could be provided. There would be a small learning curve while using the demonstrator, in order for someone to be able to identify the value provided to it.

There was an overall preference to the organic form of haptic feedback provided by the demonstrator to the most commonly used types which are vibrations. The applications proposed in the brainstorming sessions were a mix of replacements of currently available haptic technology, those specific for the organic nature of the feedback provided by the demonstrator and completely new applications of haptic technology.

8.7 Conclusion

The demonstrator successfully provided multiple types of haptic feedback to users. The purpose of using the setup to convey direction was not strong in the current setup, although users were able to distinguish between each sensation. Amongst the feedback provided during the test, the up and down motions were the most perceivable and identifiable sensations. It was also noticed that this was perceived more when there was larger displacement, for example motion from the bottom most spot to the top most, although the smaller displacements (eg middle to top) produced a different type of sensation.

Squeezing and pressure were also perceived at different moments of the tests and were considered pleasant and comfortable.

The preferred location for such a wearable was on the arm. The heat from the springs, if controlled, can become an additional type of haptic feedback meant to intensify the noticeability of the actual motion of the effectors.

As mentioned earlier, participants were able to find value in such a device since two or three sensations are distinguishable but in some cases the effect of the motion was subtle. In order to improve the demonstrator, it is important to narrow down on the variety of sensations which can be provided by it and increase their intensity and noticeability. It was also observed that the passive materials also played a role in the perception of the feedback and therefore should be taken into consideration when selecting the specific types of feedback to go forward with.

Take-away

- Demonstrator produced distinguishable sensations but exact identification of all sensations was difficult
- Identification of all the directional movements was difficult
- All sensations were perceived as organic and natural
- Some sensations were perceived better than other as well as some being more preferred
- Most participants preferred this form of haptic feedback over vibrations
- Location on the back is the least preferred while preference on the arm changed per person
- Need to increase intensity of specific sensations in order to be able to provide value to them for applications
- All participants found there to be a large variety of possible application for the demonstrator

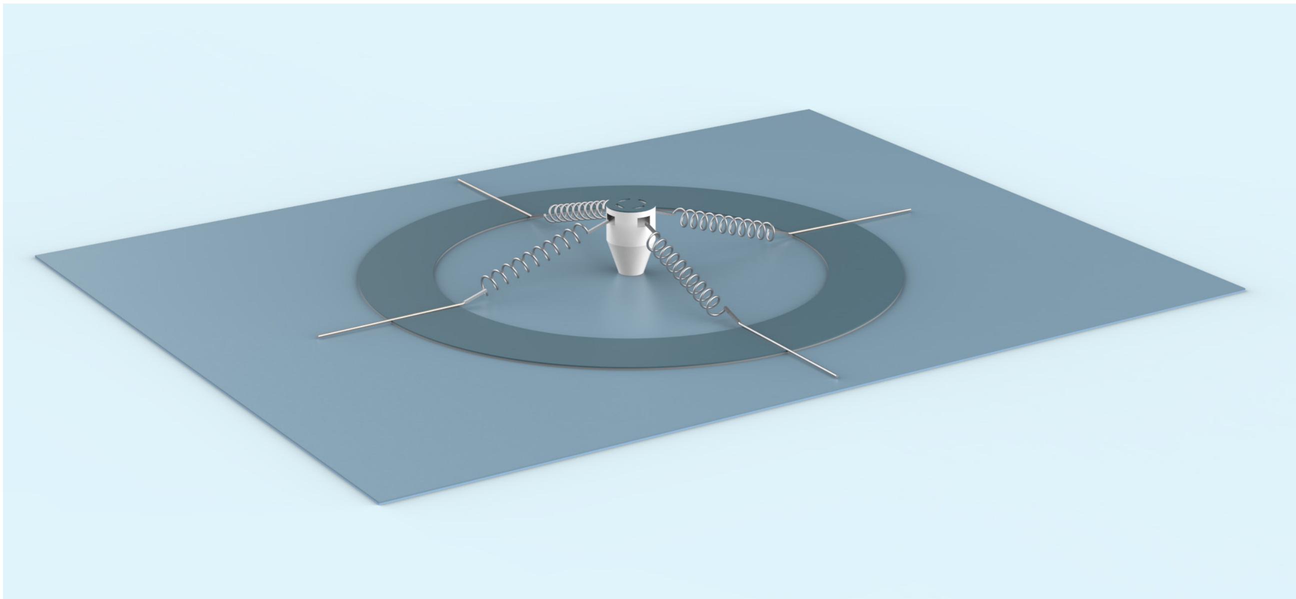


Fig 8.16 Demonstrator render

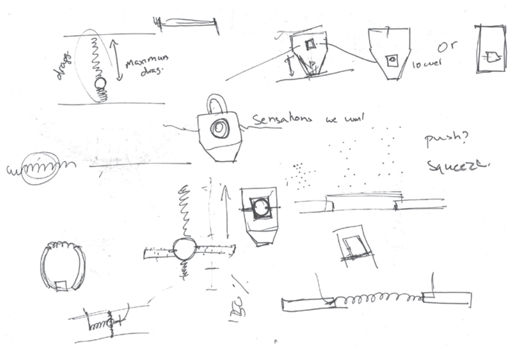
9.

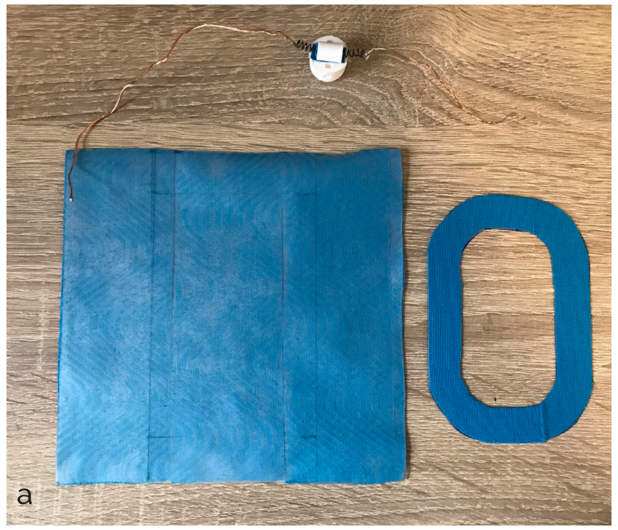
Refined Demonstrator

It was seen in the previous section that in order to improve the working of the current demonstrator, it is important to narrow down on specific forms of feedback and increase their intensity.

After analyzing the results of the tests, it was decided that two types of feedback would be looked into for further exploration- dragging and squeezing/pressure.

In the current format, a squeezing sensation around the arm could be perceived when two opposite SMA springs were activated at the same time. This was tried again a few times and was concluded to be very subtle. In order to improve the intensity, new methods of providing this sensation was ideated upon and a new format was selected to test (refer to fig 9.1). In this format, one spring is attached to the effector in place of the left and right springs of the previous demonstrator. These wires are fixed to the heat barrier layer at both ends.





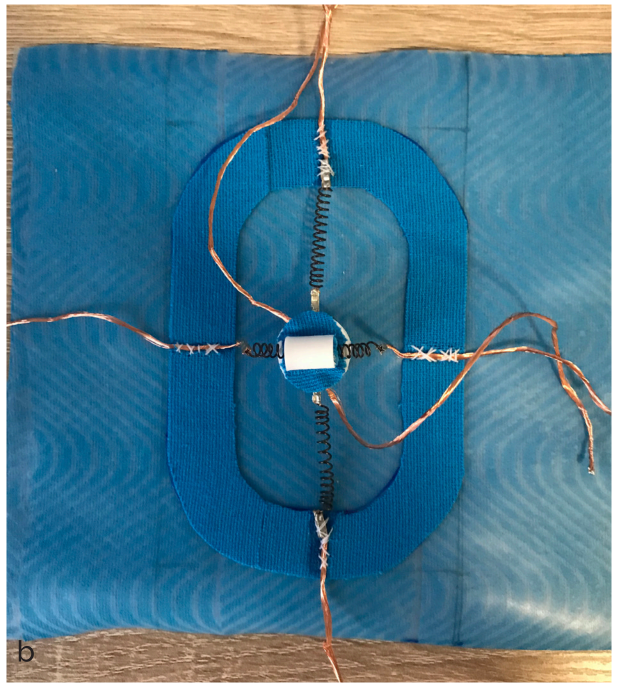


Fig 9.1 Refined demonstrator a- Ideation sketches, b- Heat barrier layer, structural support layer and effector, c- Completed new demonstrator

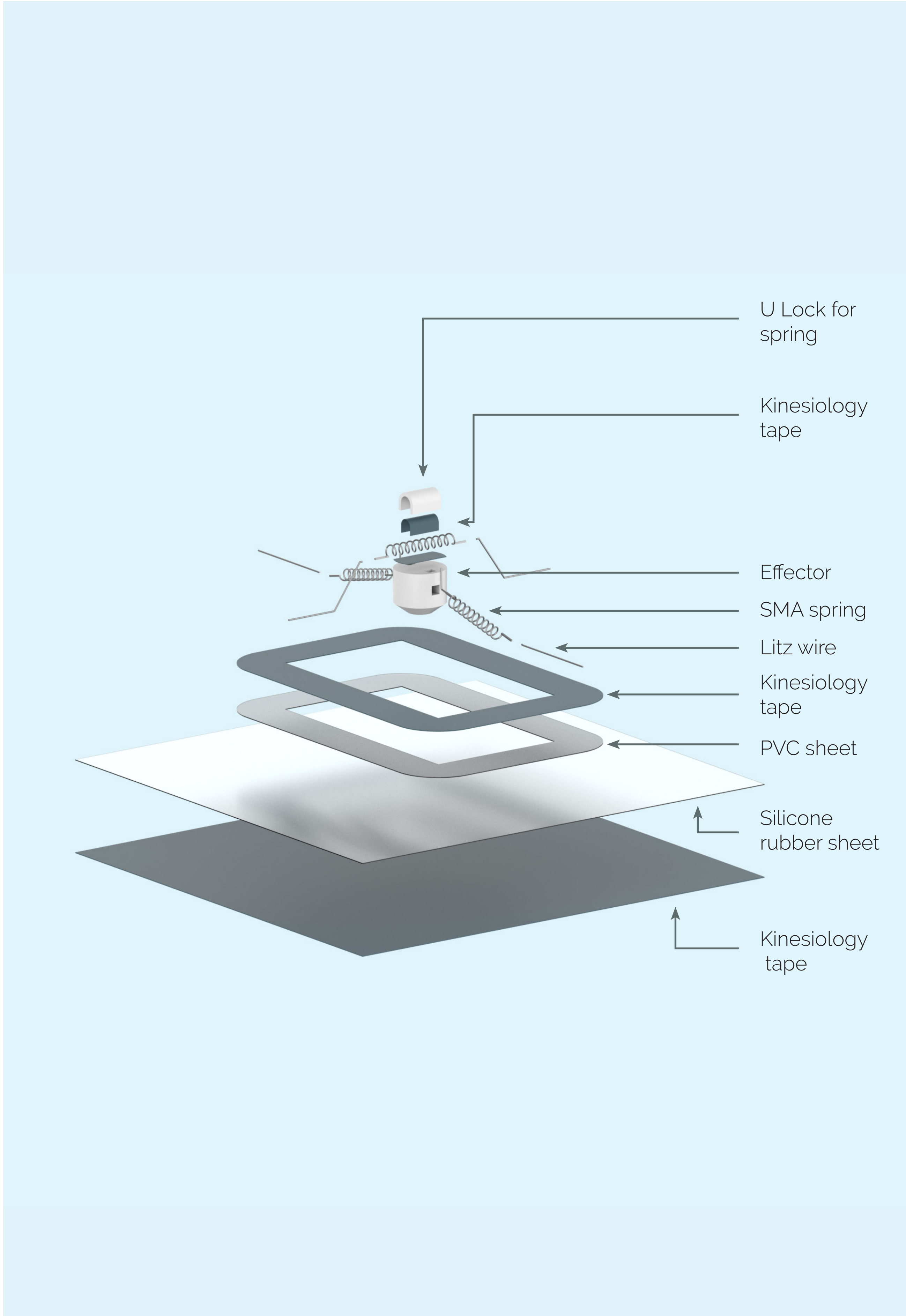


Fig 9.2 Layers of the demonstrator

Another observation from the tests was that the effector would sometimes topple over before dragging in the direction of the SMA springs. In order to reduce this, the chamfer angle at the base of the effector was reduced. The attachment details on the effector for the new squeezing format was also incorporated. The effector is 3d printed in PLA in three parts- the chamfered base, the main body and a u lock for the spring (refer to fig 9.3). Since the SMA spring is to run through the top of the effector and the u lock, it was important to protect the PLA component with the help of kinesiology tape.

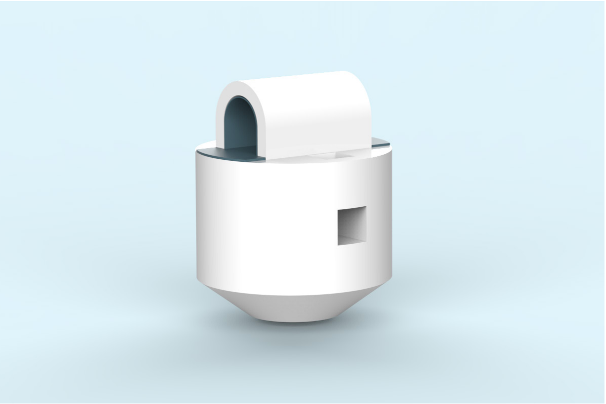


Fig 9.3 New effector design with U lock for spring

A new demonstrator was then built and connected to the same electronics setup. A pilot test was conducted with a participant from the previous demonstrator test.

The demonstrator was tested on the outer and inner sides of the forearm. It was attached with the help of the medical tape and the participant sat with his arm resting on a table.

After the consent form was signed, the tests were conducted. Each spring was activated individually and the participant had to describe the sensation. The next part of the test was to understand whether the sensations were noticeable without too much anticipation. For this part of the test, the participant was asked to listen to music. This was to prevent any association between the button sound and the haptic feedback. The springs were activated randomly at different time points and the participant was asked to notify the experimenter when a sensation was felt and describe it.

The participant experienced no heat throughout the test and said that the setup was comfortable. The participant was able to identify the correct sensations 66% of the time and all the sensations were noticeable. The inner part of the arm was considered to have a stronger set of sensations although it scored less in identification of the sensations.

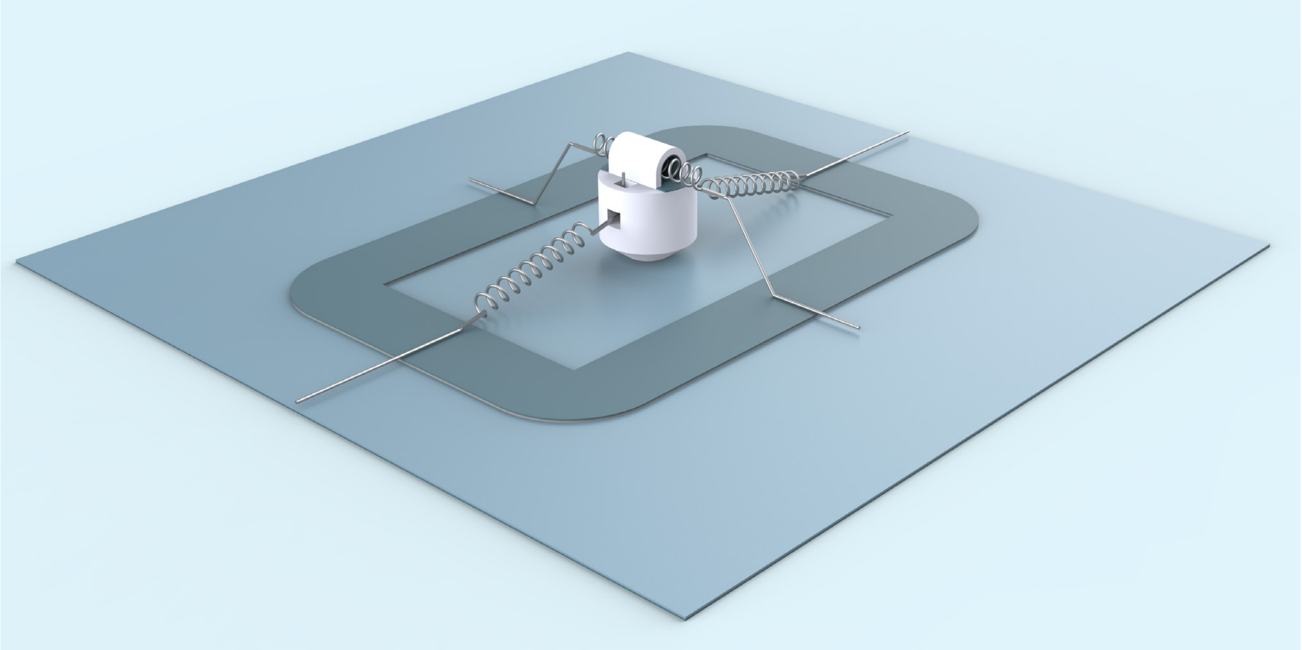


Fig 9.4 Demonstrator render

9.1 Testing with Target Group

The new demonstrator was then presented to the target group. Four BVI members were enthusiastic to experience the demonstrator after which interviews and discussions were conducted.

Participant 1

Gender: Male

Medical condition:
• Retinitis pigmentosa (RP)
• 1% vision with narrow line of sight

Current sources of assistance:
• iPhone with screen reader
• Apple watch
• White cane
• Guide dog

Experience with haptic technology
• Vibration in an apple watch

Participant 2

Gender: Male

Medical condition:
• 0% vision

Current sources of assistance:
• iPhone with screen reader
• Computer braille
• White cane
• Wife
• Tactile watch ("more like a gadget")

Experience with haptic technology
• Nothing specific

Other
• Doesn't like to be touched unless it is useful

Participant 3

Gender: Female

Medical condition:
• Progressively losing sight
• Both eyes vision is different (around 50% in left eye and 25 % right eye)
• Caused by diabetes and other health complexities
• Neurological impairment
• Loss of vision in the centre of eye

Current sources of assistance:
• Magnifier
• White cap and specific dark glasses

Experience with haptic technology
• Nothing specific due to neurological impairment

Other
• Can't use braille or touch ID because of neurological impairment
• In winter, fingers feel like they are falling off

Participant 4

Gender: Female

Medical condition:
• 0% vision

Current sources of assistance:
• Tested multiple devices in the 70's such as Ultrasonic aids
• Bone conduction headphones
• Guide dog
• Braille display
• White cane
• Screen reader

Experience with haptic technology
• Iphone vibrations
• Testing different handheld vibrating devices meant for object detection
• Vibration in handheld braille display

Other
• Willing to use devices with large training period

The purpose of the demonstrations conducted with the user group was to gather insights into how they perceived the haptic feedback from the device and where they think it can be incorporated. It was insightful to compare the perception of not only between the target group and non-target group but also individually. As mentioned earlier, diversity in population is important to be taken into consideration when designing assistive devices.

9.1.1 Test Setup

The demonstrators were presented at a 'Digiwijs meeting', a meeting in which blind and partially sighted members help each other on the topic of digital devices. The demonstrations were conducted individually on the participants, one at a time, but discussions were sometimes as a group.

The demonstrator was tested on both the outer and inner side of the forearm. The participants sat with their arm resting on a table.

9.1.2 Procedure

The consent form was read out and discussed with all the members. After verbal consent was provided by the participants, the tests were started.

The springs were then individually activated, after which the participants were asked to explain what they perceived. Two springs were then activated one after the other and the participants were asked to identify whether the two sensations were the same or not.

The test then ended with an interview and discussion of their experiences and possible applications for the demonstrator.

9.1.3 Perception of Demonstrator

The demonstrator could provide three types of haptic feedback to the users- up and down motion and squeezing/pressure.

The directional motion provided by the demonstrator was described as a wheel moving along the arm by participant 1 and a walking animal by participant 2. Participants 3

Fig 9.5 Moments from the test

and 4 described it as a finger running down the arm. Though once, participant 3 experienced it as a non-directional pressure. Participant 2 mentioned that the first upward motion was a bit uncomfortable but the other sensations were all fine.

All the participants experienced the squeeze feedback as gradual pressure, which could be too subtle if not allowed to continue for a few moments. Some sensations were experienced as stronger than others, for example in all cases upwards motion was less subtle than the downward motion. The participants were able to distinguish between the sensations in most cases, although at this stage the type of sensation was not always identified correctly. Many of the participants were also able to identify repetition in feedback.

All the participants except participant 4 experienced the inner side of the arm to be more subtle. Participant 1 said that the sensations were completely different on both sides of the arm while the other participants only felt an intensity difference. Participant 3 could barely perceive the sensations on the inner side of the forearm.

None of the participants experienced any heat from the device and except for one moment for participant 2, they all found the sensations to be pleasant. All the participants mentioned that it was interesting that one setup could provide such a variety of motion. Three of the participants found the directional motion to be the most pleasant and useful.

9.1.4 Recommendations and Applications

It was recommended by some of the participants to increase the intensity of the device in order to grab their attention when there are distractions such as walking through traffic.

When compared to other forms of haptic sensation they had already experienced, it was brought up that there was more variety in the demonstrator. To participant 1, the ideal device would have a combination of these different sensations to be able to provide a variety of information to users.

In terms of location, participant 1 said that he would be comfortable wearing such a device anywhere on the body, if it is useful. He said preferences depend on the application. Participant 2 felt that the sensation may be perceived better if placed on the arm closer to the wrist or on the shoulder.

An aspect which was mentioned as a benefit of such a device was the lack of sound produced by it. It had the potential of providing personal information which other people wouldn't be able to hear as well as allowing the users to listen to their environment (especially important in traffic).

The participants all saw value in such a haptic device for navigation and obstacle orientation. It was mentioned that if a lot of information was to be provided, such a format could be worn on multiple locations. For example, for obstacle detection, it can be worn on both arms.

For navigation, it could be used in combination with the white cane to orient the user. The location of the device would be determined by this application.

Participants 3 and 4 provided a concept of incorporating the mechanism around the central part of the body, like a necklace or belt (refer to fig 9.6). The effector could help orient the user to move in specific directions.

Fig 9.6 Mechanism hidden in necklace meant to aiding orientation

Another application which was suggested was for identification and guidance towards specific objects, such as traffic poles with the button. Participant 4 explained that sound feedback which the traffic poles provide now are at a height. This helps them to generally move towards the direction of the pole but they find it difficult to exactly locate it. Her guide dog is currently trained to do so but she stated that it would be helpful if the device could achieve small jobs such as that. Two participants also showed frustration towards everything being digitalized and was curious if this could be incorporated as an aid for touch screens.

Please scan the code to see the working of the refined demonstrator

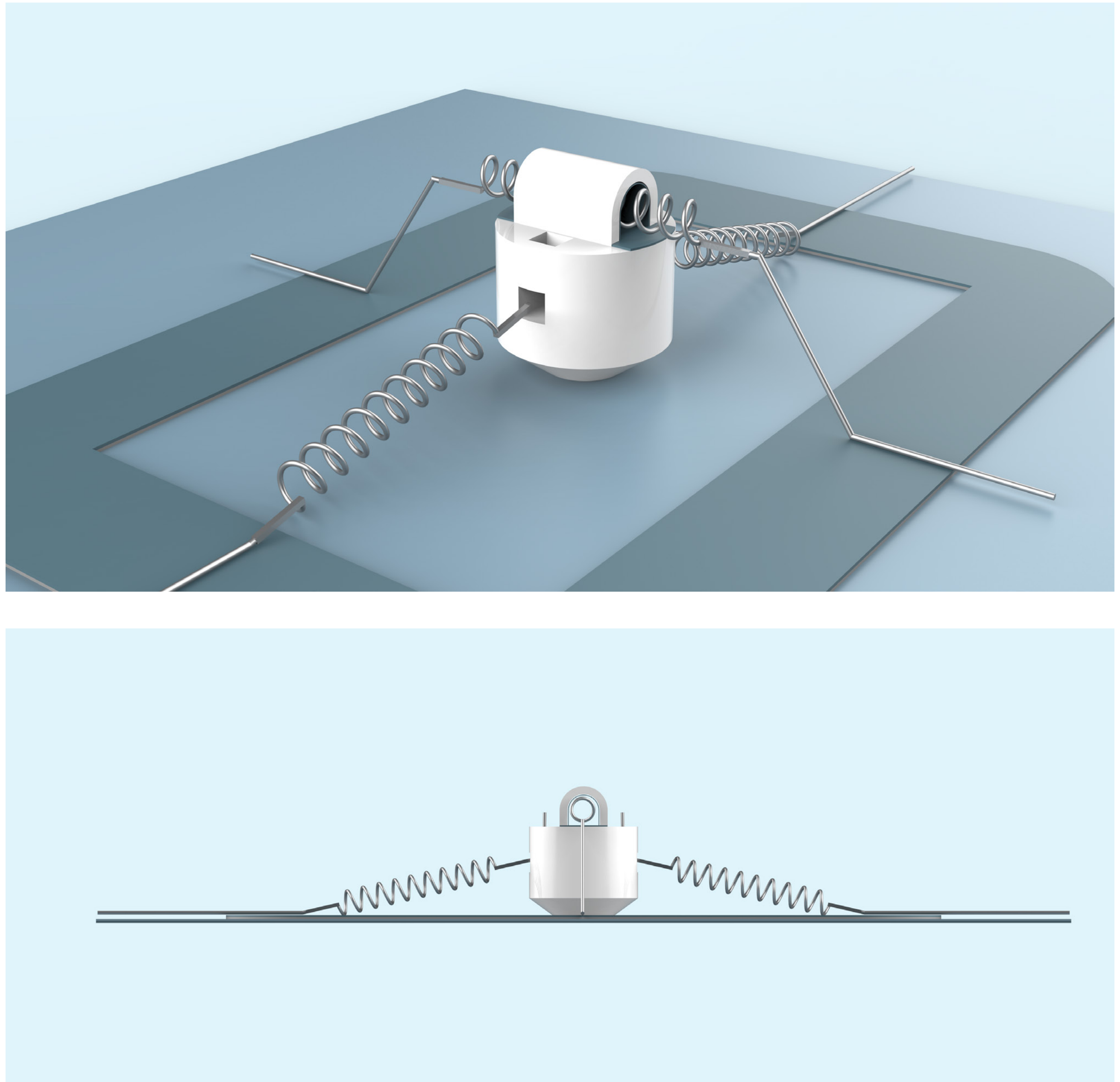


Fig 9.7 Details of the final demonstrator

9.1.5 Discussion and Conclusion

The users were able to perceive the feedback provided by the demonstrator. The participants were able to distinguish between all the sensations and were even able to identify repetition in sensations. Individually there were differences in the preference of location which should be adaptable to the users.

It was also noticed that there was a difference in how the intensity was perceived according to the medical condition of the person. One participant who had vision loss due to diabetes, could not perceive the sensations on the inner side of the forearm very well. There was also a participant who usually didn't like to be touched unless it was necessary. He felt uncomfortable with one of the sensations at one point but mentioned that if the haptic device was useful, he would use it. Personal preferences and conditions therefore have a large impact on the acceptance and effectiveness of such a device.

The users liked the aspect that there were multiple movements from one setup, and dragging motion was the favourite sensation. As applications, the participants unanimously suggested the demonstrator be used for navigation and obstacle detection. It should, though be personalize-able to individual needs.

Along with the demonstrations and interaction with the target audience, the effectiveness of the demonstrator can be determined by verifying it with the design requirements formulated at the beginning of the project. This can be found in table 9.1.

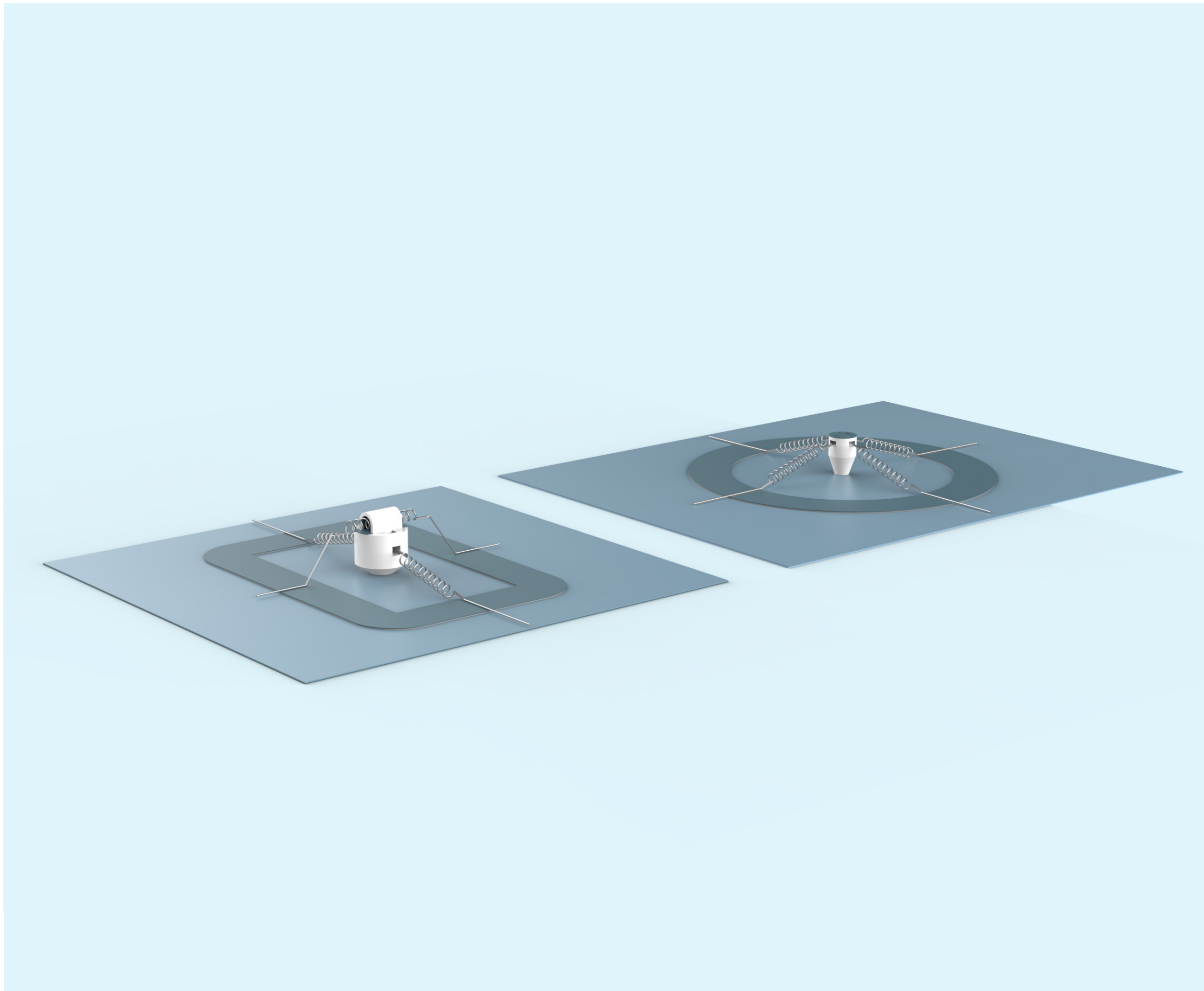


Fig 9.8 Both demonstrators

Requirement	Yes	Not yet	Undetermined	Recommendations/ comments
Demands				
Performance				
The technology should be able to convey information to the blind and visually impaired	■			
The device should not depend on vision to operate	■			
Should provide noticeable haptic sensation	■			
The haptic sensation should be pleasant for the user	■			Increase intensity for some users, there are also individual placement preferences
Movement should be reproducible (complete motion without error atleast 5 times)	■			
Shouldn't generate an uncomfortable amount of heat (>48˚C)	■			Could incorporate temperature sensors
Operation				
Should be operational with electrical power	■			
Should be operational at room temperature (27˚c)	■			
There should be controllable actuation (can be changed midway)	■			
Response time should be less than 5 seconds (from applying stimulus)	■			Can be adjusted according to need
Device should be reusable	■			
Should be safe to use in close proximity to skin	■			
Material				
It should incorporate shape memory materials	■			
The materials used should not irritate the skin	■			

Requirement	Yes	Not yet	Undetermined	Recommendations/ comments
Wishes				
Comparatively simple to manufacture		■		Can be made simpler
Capable of quick movement	■			Can be adjustable
Should be easy to clean			■	Not tested
Silent operation	■			
Multi-modal actuations	■			
Subtle/hidden actuators		■		Can be looked into
Incorporable into multiple applications	■			
Materials should not be very expensive and difficult to procure		■		Vendors can be researched
Easy to setup		■		Attachment method could be made more simple
Design requirements for a wearable haptic device:				
It should be lightweight (<130 gm)		■		Without the electronics the wearable itself is light, electronics to be adjusted
It should be comfortable to wear for prolonged periods of time (at least 60 min continuously)			■	Not tested
Silent operation	■			
The product should be able to function regardless of small changes in placement.	■			Small changes to location do not effect motion but if not kept tight
The user should be able to wear the device without it interfering in activities			■	Not tested with users doing other activities
The user should be able to wear and operate the product without experiencing discomfort or fatigue.	■			
There should not be any sharp edges or corners	■			
Should not limit the motion		■		Connection to the electronics box limits the motion
Should not be sensitive to motion	■			If secured tightly no interference occurs.

Table 9.1: Verification with design requirements

10.

Conclusion

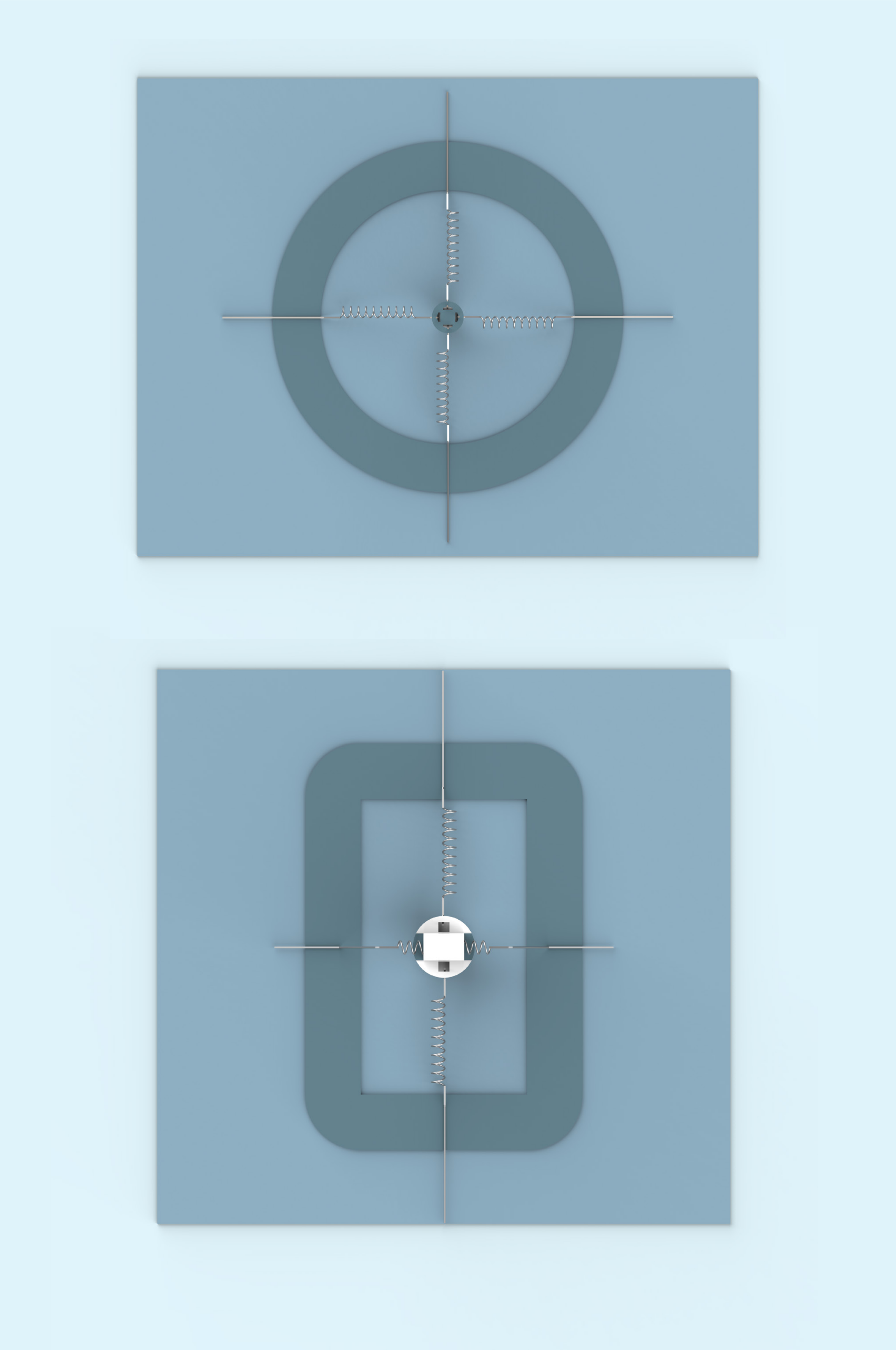
The purpose of this graduation project was to explore how currently available shape memory materials can be incorporated into haptic technology in order to improve the wellbeing and lifestyles of the blind and visually impaired. The process included evaluating different shape memory materials after which shape memory alloys were selected. This selection was done as this material had the most potential of effectively providing a variety of haptic feedback. The evaluation process included both desk research and material exploration. The format of interactive assistive device was also narrowed down to a wearable as it was seen that it would gain the most amount of value from shape memory alloys. These materials can produce pleasant and organic sensations and are often light weight and noiseless. Desk research and interactions with the target group helped gather insights into not only where such forms of haptic wearables are useful but also as a form of a filtering system at every stage of the project.

Different types of actuators using SMAs were explored which gave rise to the selected 'multi motion of one effector' demonstrator. There were many iterations of this concept, in order to make it effective in providing the required feedback and also make it incorporable as a wearable. During the building process of the demonstrator to be tested, passive materials which support the demonstrator were investigated along with the electronics. The demonstrator was then tested with five participants from outside the target group. The purpose of this was to gather insights into the perceptions of the haptic feedback provided by the device, as well as a preference in location on the body. The results of these tests led to the building of a new demonstrator which was then presented and tested with the target group.

The interactions with the blind and visually impaired are very important to ensure the solutions are actually practical. The demonstration with the target group became almost a brainstorming session for the future of the demonstrator, and they were very enthusiastic to see possibilities of it improving different aspects of their lives.

The final demonstrator built during this project successfully provided a variety of different haptic feedback for the target group. It is a compliant haptic wearable which is capable of providing organic and pleasant sensations to users. Since it is a flexible base demonstrator it can be adjusted to fit the needs of different individuals. Users were pleasantly surprised that one setup could provide such a variety of sensations. It was suggested that it be used in combination with other technology as aids for navigation and obstacle detection.

The outcome of the project is a demonstration of how shape memory materials can be incorporated into a wearable haptic setup as aids for the blind and visually impaired. Recommendations of the next steps for the demonstrator are explained in the next section.



11.
Future Recommendations

This project is a foundation to building a wearable assistive device for the blind and visually impaired using shape memory materials. In order for it to successfully be incorporated as aids for the target group there are recommendations for further work.

As a whole, there were individual preferences regarding placements and specific applications. The next step for the project is to create a small base wearable setup which can be adjusted to different needs.

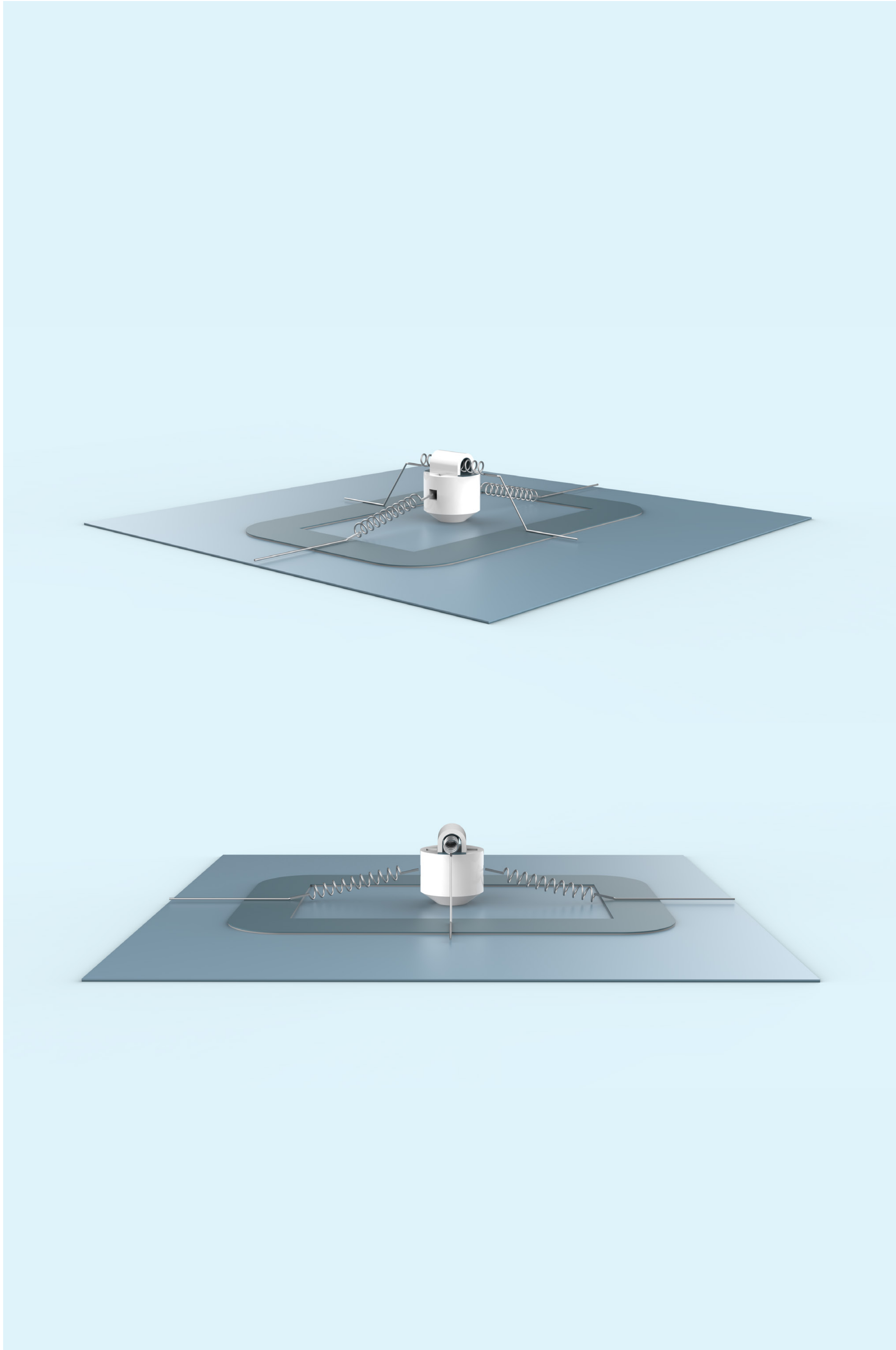
Setup:
In the current demonstrator, the heat barrier layer consists of kinesiology tape and silicone rubber sheet. In order to simplify the manufacturing process, other ready made composite materials can be looked into as well as different attachment methods. The current passive materials had the possibility in interfering with the haptic feedback produced by the device if not attached securely to the body. This can be overcome by new attachment systems.

The demonstrator also produced a comfortable level of heat during the tests, but it is recommended to be able to control the temperature of the setup, possibly with the help of temperature sensors to ensure the safety of the setup as a wearable.

Electronics:
The current demonstrator contains a bulky electronics setup. In order for it to be incorporable as a wearable device it is recommended to redesign the electronics components so that the size is reduced.

Haptic Feedback:
During the user tests, it was recommended to increase the intensity of sensations according to the application. An example of how this can be done is by adjusting the current or type of wires used in the setup. The response time of the demonstrator can also be made adjustable in order to be incorporable in different applications

Target Group:
For further work on this project, it is recommended to include the target group at every stage. Insights from these interactions help in ensuring that the device is truly helpful for them. The demonstrator should be tested if they interfere with activities or other assistive devices used by the target group. The noticeability of the haptic feedback when there are distractions should also be determined.



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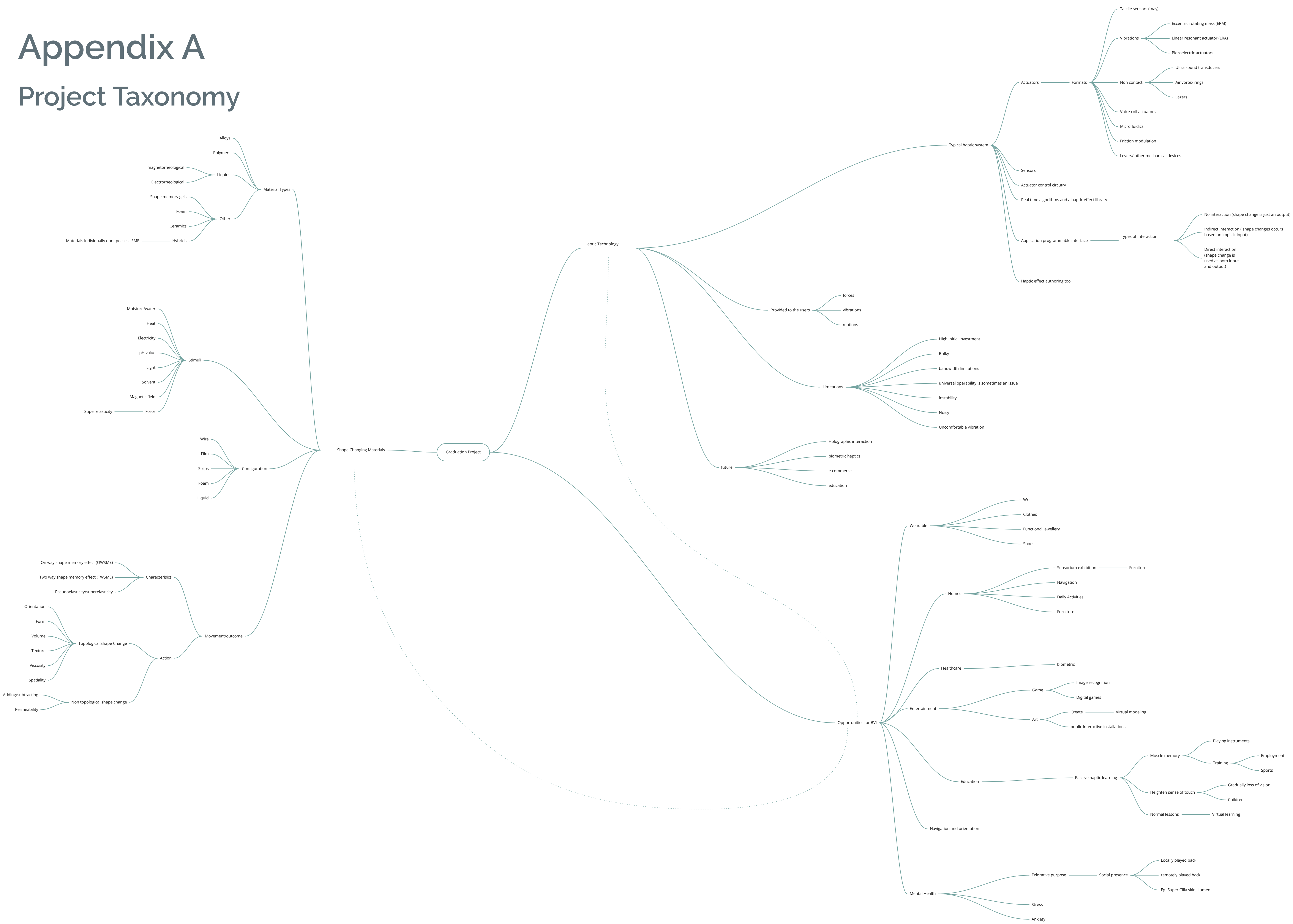
Appendix

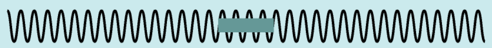
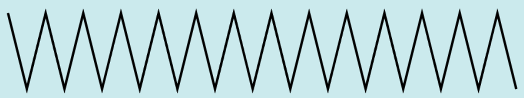
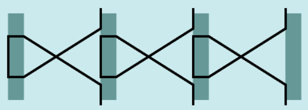
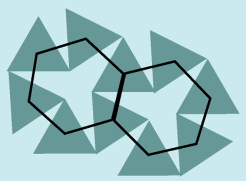
Appendix A

Project Taxonomy



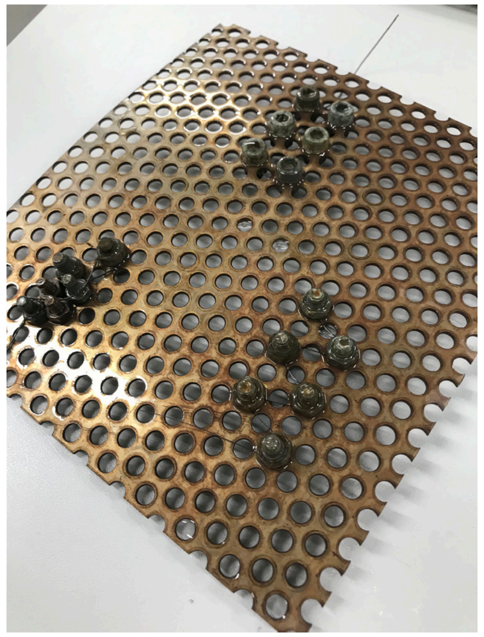
Appendix B

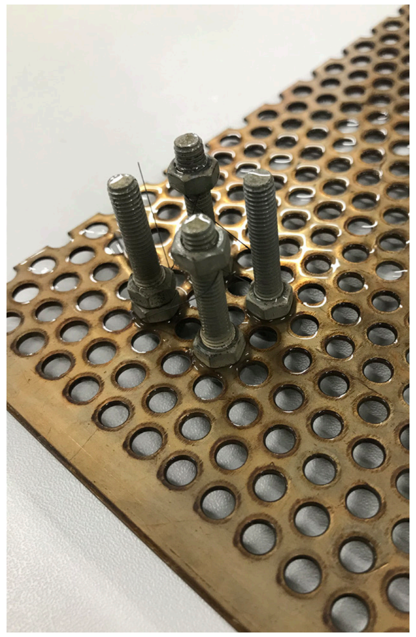
Overview of SMA formats in literature review and their preferences

Setup	Feedback	Finger	Wrist/ hand	Arm	Back	Neck/ shoulder	Chest
Wire	Squeeze	Squeeze					
 Spring	Squeeze	Squeeze	Squeeze (subtle)				
 Spring with end effector	Pinching Stretching Pressing Pulling Dragging Expanding		Dragging	Dragging	Pressing	Dragging	Pinching
 Zigzag	Grabbing Stroking Encircling/ rolling 3 taps down 3 taps up		Grabbing Encircling/rolling	Stroking Grabbing 3 taps down 3 taps up Encircling/ rolling			
 Wire + tactile bar	Stroking			Stroking			
 Wire + structure	Squeeze		Squeeze				

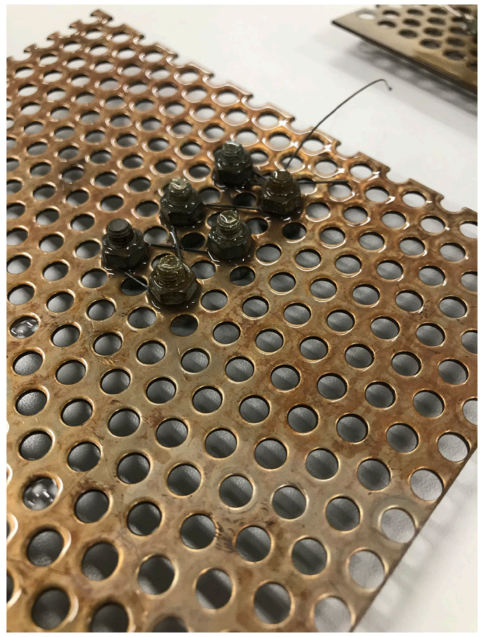
Appendix C

Shape Memory Alloy Exploration

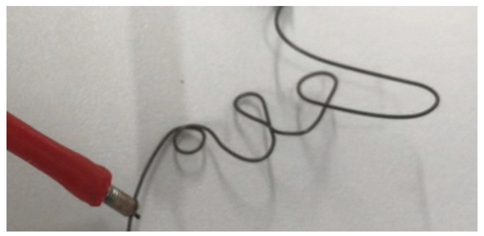


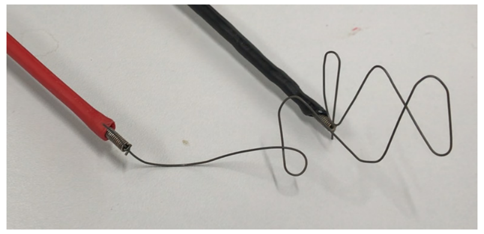


A 3d structure was attempted using FLEXMET 0.008 mm diameter NiTi wires. The recovery when heat was applied to it was not clear

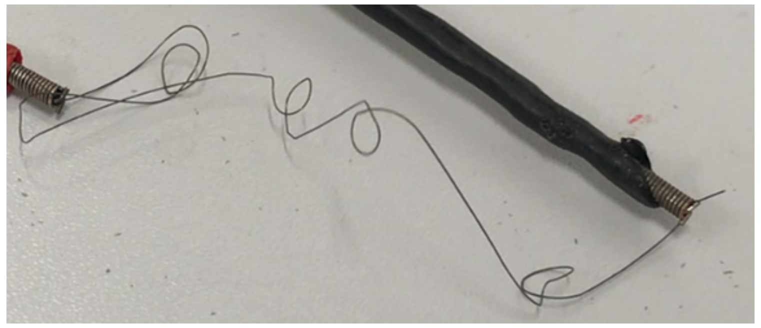


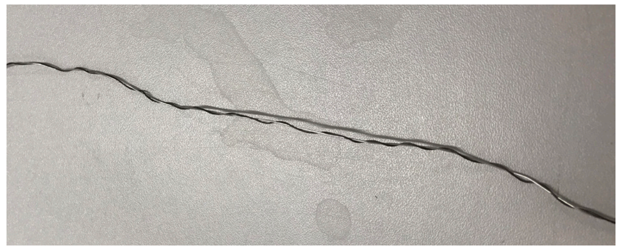
Two different types of flat actuator structures were programmed using FLEXMET 0.05 mm diameter NiTiCu wires. The shape recovery after the application of heat was very prominent and quick.





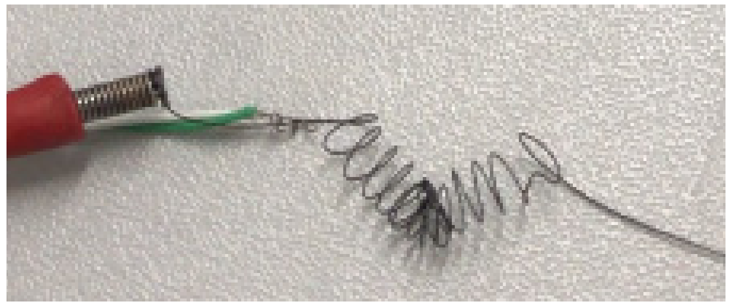
A flat actuator structure was programmed using FLEXMET 0.008 mm diameter NiTi wires. The first text burnt the wire because of the high power supply. This material was also more tricky to fix in place, due to its less flexibility as compared to SMA wires containing copper.

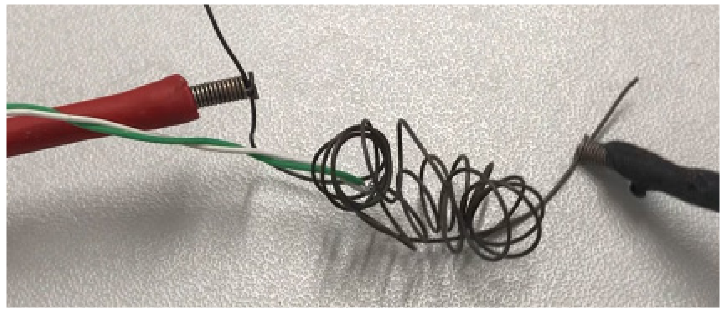




A straight annealed wire was entwined with a NiCr wire. There was no response to heat.

A 0.05 mm diameter NiTiCu wire, programmed as a flat spring was enclosed in electronic tape. There was complete shape recovery when heat was applied.

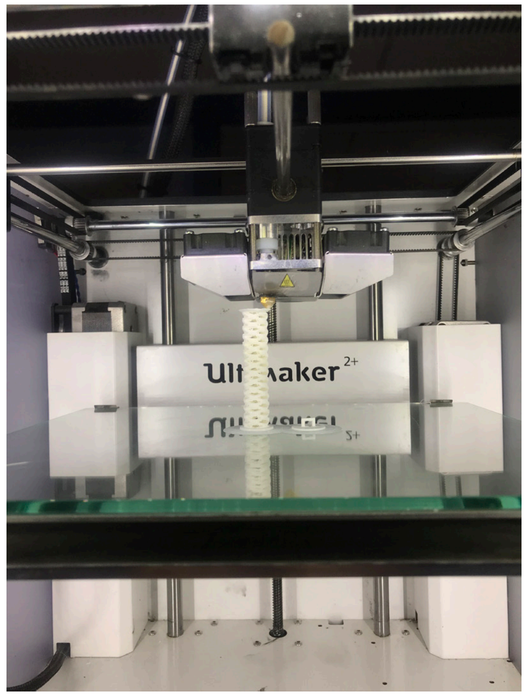


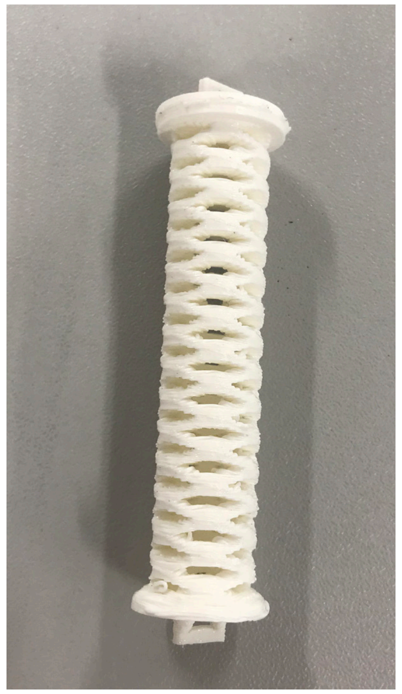


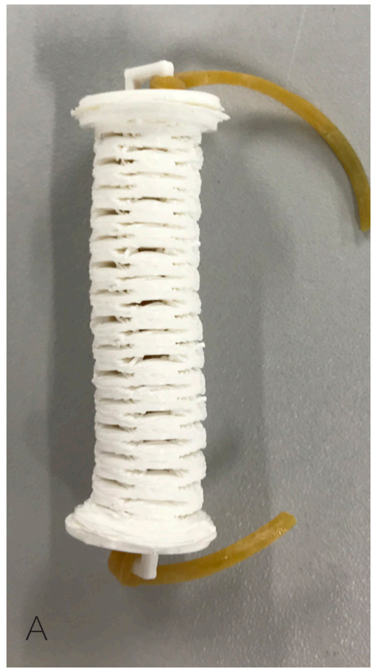
A 0.008 mm diameter NiTi wire and a 0.05 mm diameter NiTiCu wire, both programmed as springs were tested. They both recovered a deform shape due to not securely being fastened before placing them in the ceramic oven

Appendix D

Shape Memory Polymer Exploration



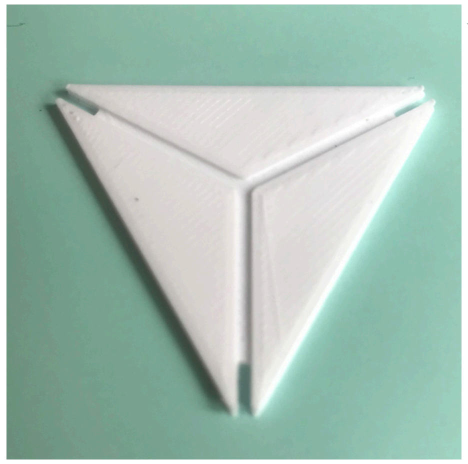




A

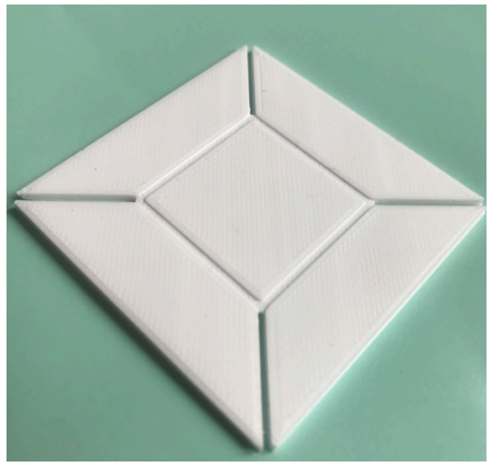
B

A graspable structure created from wave springs and was 3d printed. When submerged in water, this structure could be compressed, twisted and bent . When submerged in hot water again it recovered its original form. In order to test the reproducibility of such a structure, elastic bands were attached. In format in fig A, the structure was first compressed and allowed to cool after which elastic bands were stretched and attached to both ends. The purpose of this was to allow the structure to re-compress when removed from the hot water. In fig B, The elastic bands were attached to bent structure, to force it to re- bend when removed from the water. In both cases the elastic bands were too strong for the PLA to change its shape

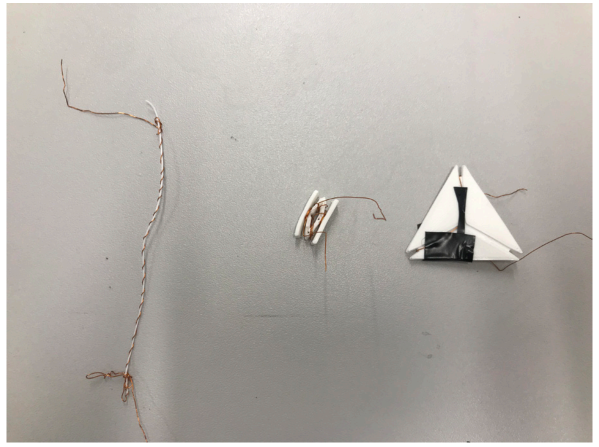


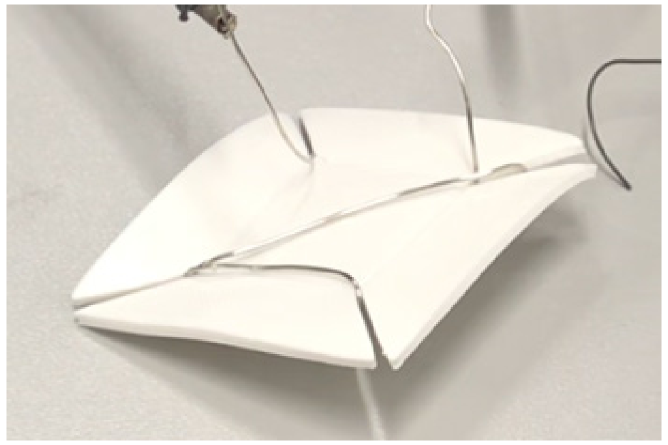
Flat format with a one sided score detail was printed in PLA. This had minimal effect on how the material recovered its shape although it did help in guiding how the material can be deformed.

Flat format with two sided score and slit details were printed in PLA. The two sided score had no impact on both the material recovery and deformation process. The slits did help however in both. Self bending occurred after testing the material multiple times.



First a single unit flat spring like structure was printed and tested. This structures successfully presented the shape memory effect with clear but slow shape recovery. Multiple units were then printed in a long structure. In the recovery process of this structure there was a tendency to curl unevenly. There was therefore not 100% shape recovery.





Appendix E

Harris Profile

Magnetorheological fluids

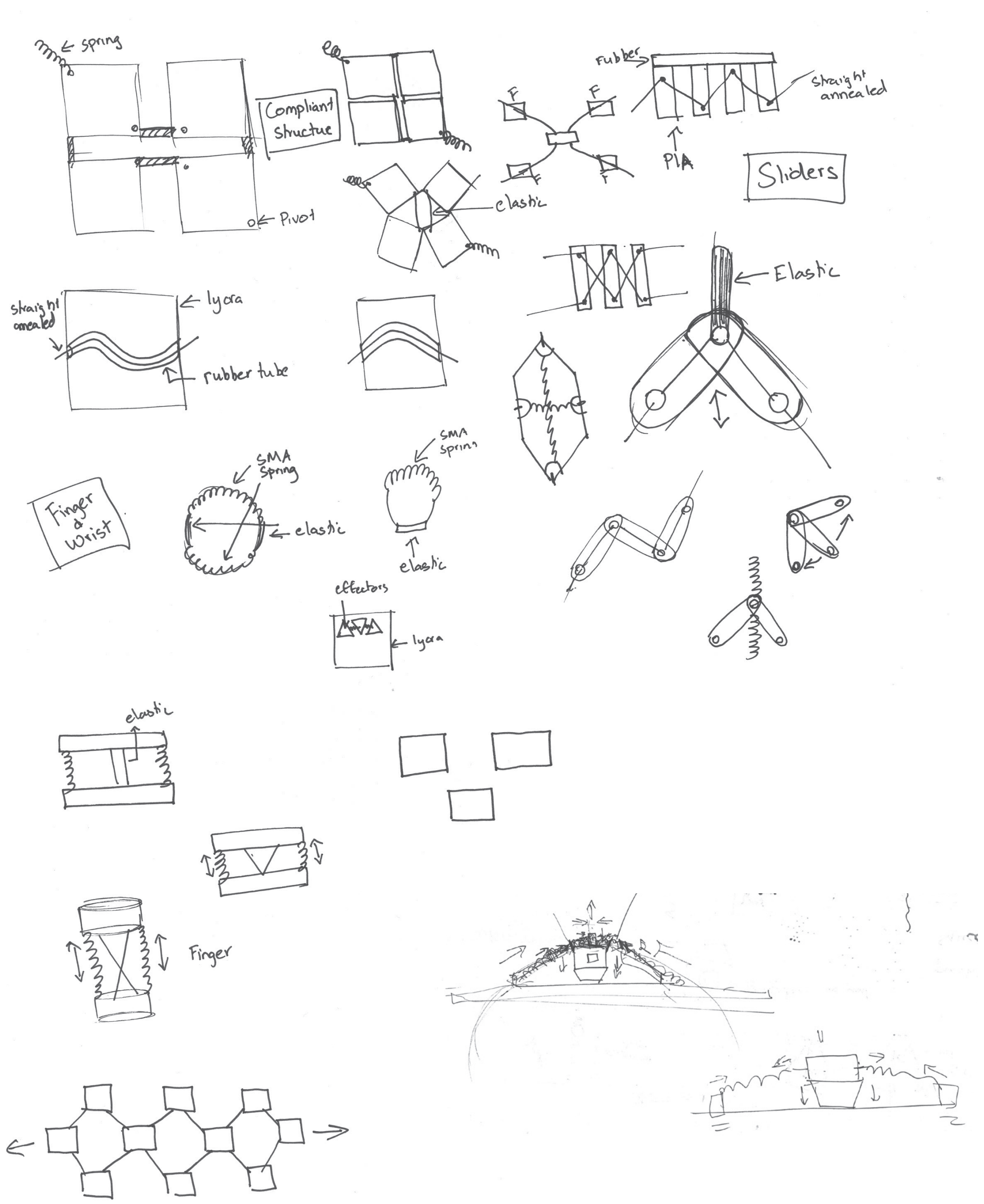
	--	-	+	++
Demands				
Should provide noticeable haptic sensation			■	■
The haptic sensation should be pleasant for the user			■	
Movement should be reproducible (complete motion without error at least 5 times)			■	■
Shouldn't generate an uncomfortable amount of heat (>48˚C)		■		
Should be operational with electrical power			■	■
There should be controllable actuation (can be changed midway)			■	
Should be safe to use in close proximity to skin			■	
Wishes				
Comparatively simple to manufacture		■		
Capable of quick movement			■	■
Materials should not be very expensive	■			

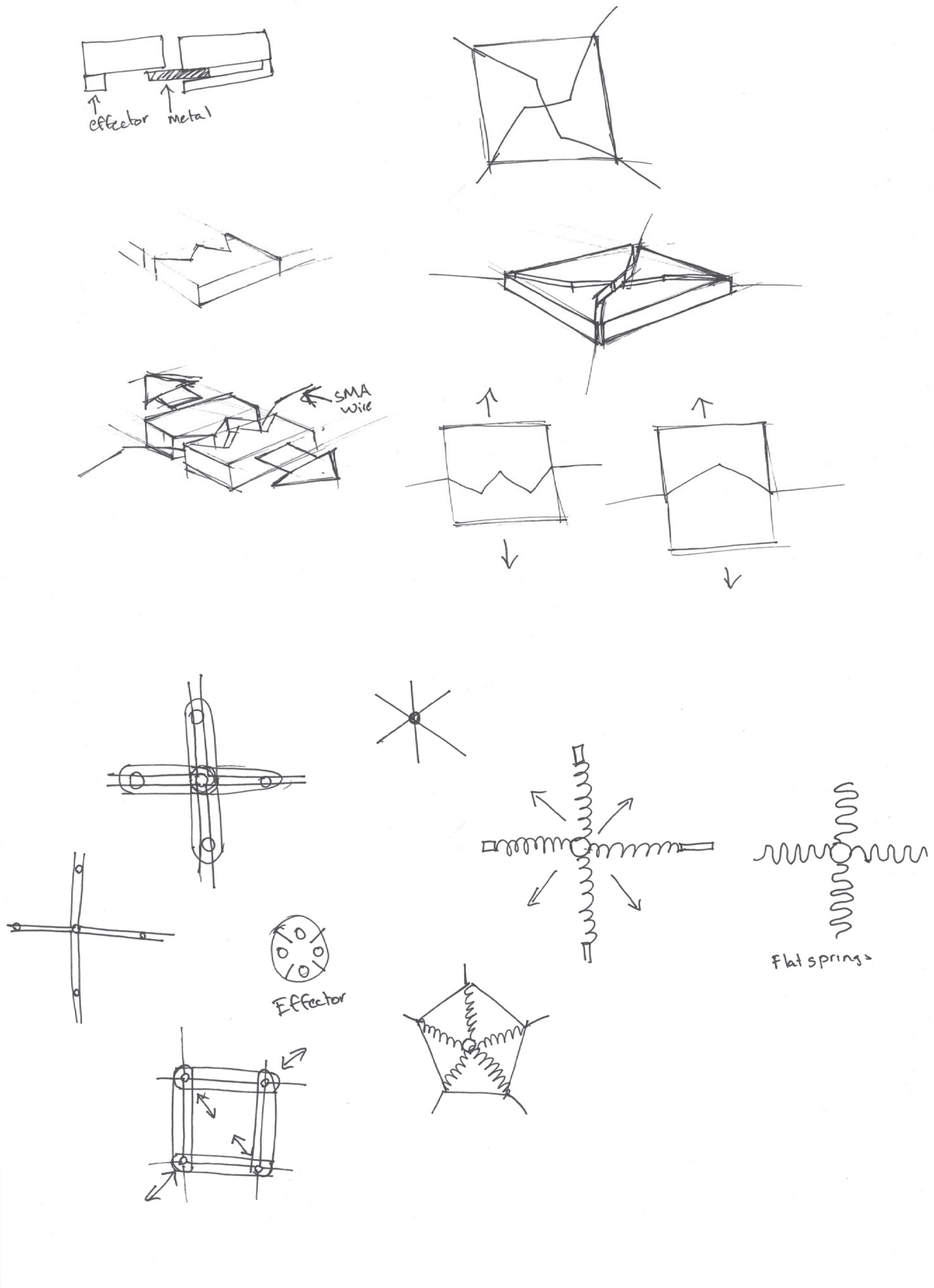
Electrorheological fluids

	--	-	+	++
Demands				
Should provide noticeable haptic sensation			■	
The haptic sensation should be pleasant for the user			■	
Movement should be reproducible (complete motion without error at least 5 times)			■	■
Shouldn't generate an uncomfortable amount of heat (>48˚C)		■		
Should be operational with electrical power			■	■
There should be controllable actuation (can be changed midway)			■	
Should be safe to use in close proximity to skin		■		
Wishes				
Comparatively simple to manufacture		■		
Capable of quick movement			■	■
Materials should not be very expensive	■			

Appendix F

SMA Actuator Ideation





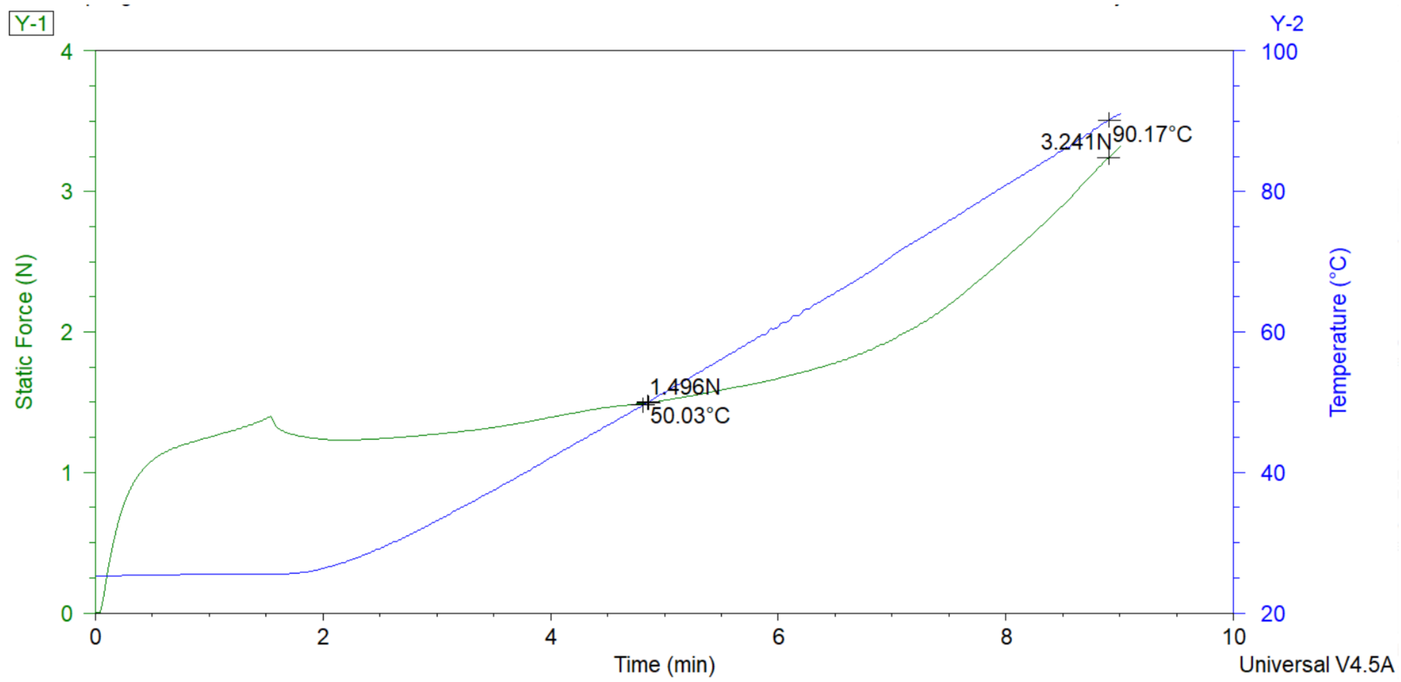
Appendix G

Weighted Objective Comparison of Two Actuators

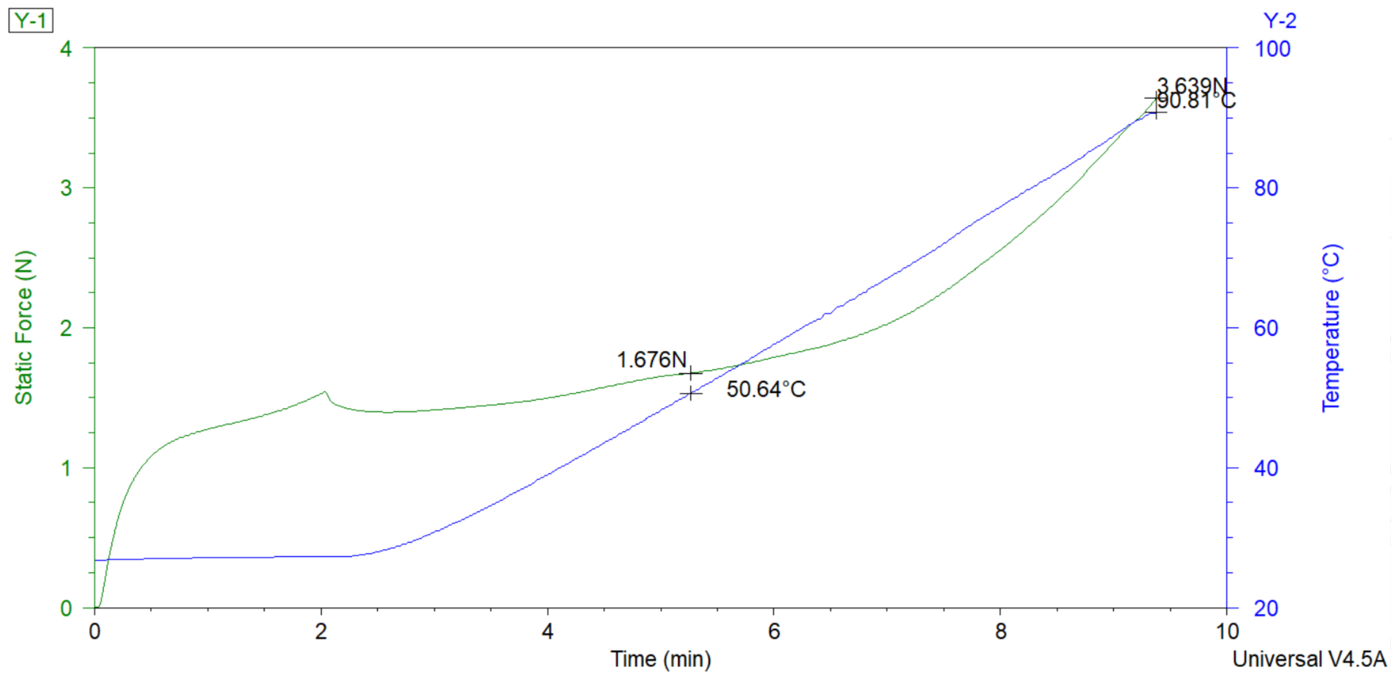
Factor	Ranking	Slider	One effector
Material System			
Movement should be reproducible (complete motion without error atleast 5 times)	5	1	4
Movement should be reversible (double motion)	5	5	5
There should be controllable actuation (can be changed midway)	4	5	5
Response time should be less than 5 seconds (from applying stimulus)	4	5	5
Manufacturing system			
Less number of steps (>5)	3	4	3
Simplicity of steps	3	4	3
Design			
Incorporable into multiple applications	4	4	5
Large variety of haptic feedback (>2 types)	3	3	2
Small size (<50mm)	3	5	3
Shouldn't generate an uncomfortable amount of heat (>48°C)	5	2	2
		144	148

Appendix H

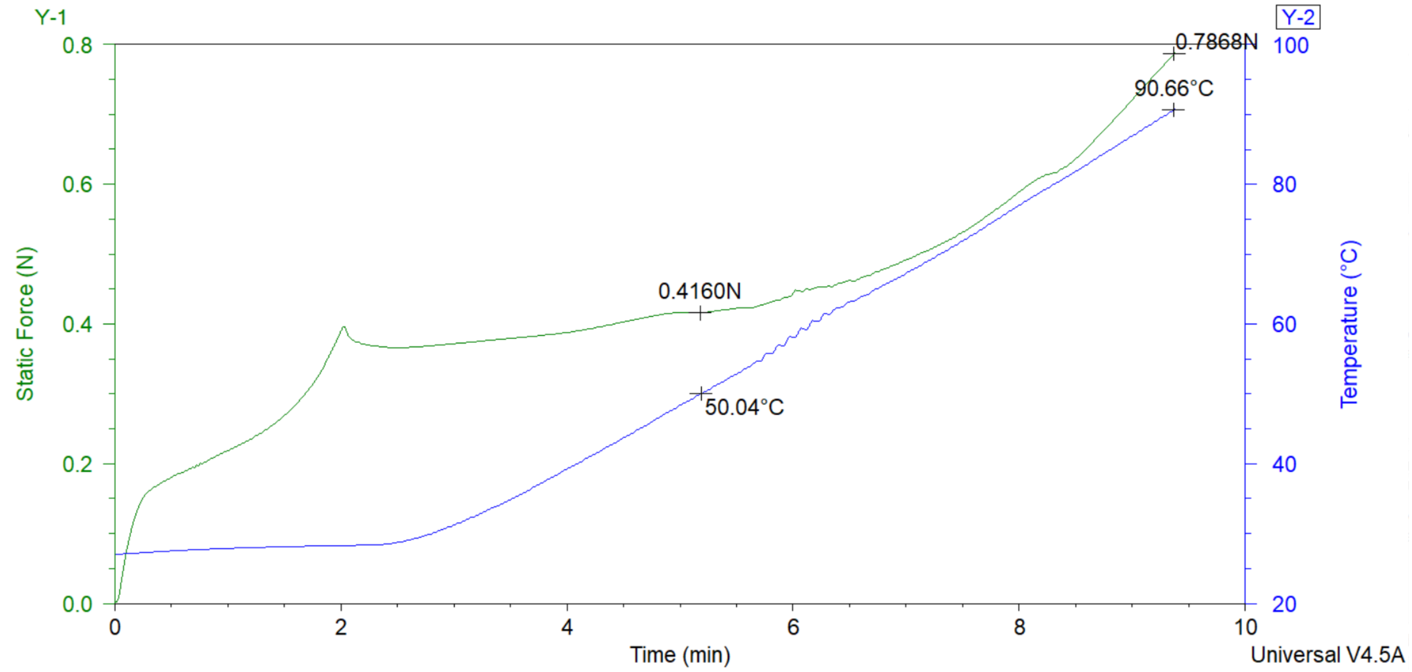
Mechanical Test Results



Spring 1 150% elongation



Spring 1 200% elongation



Spring 2 200% elongation

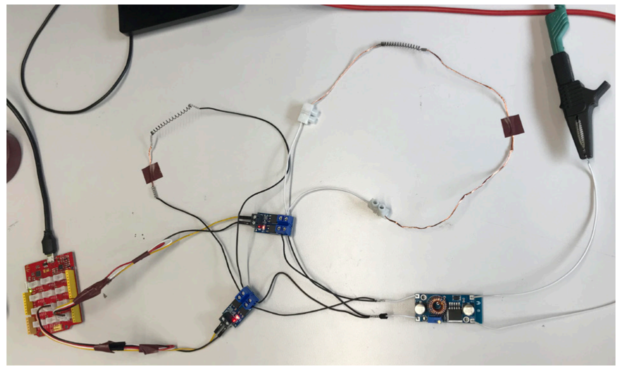
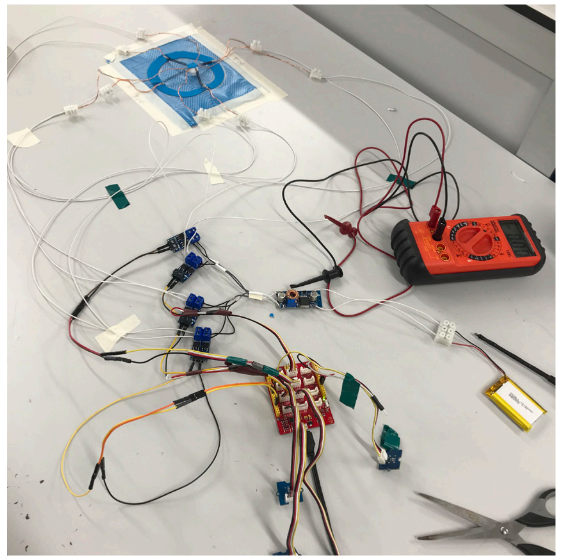
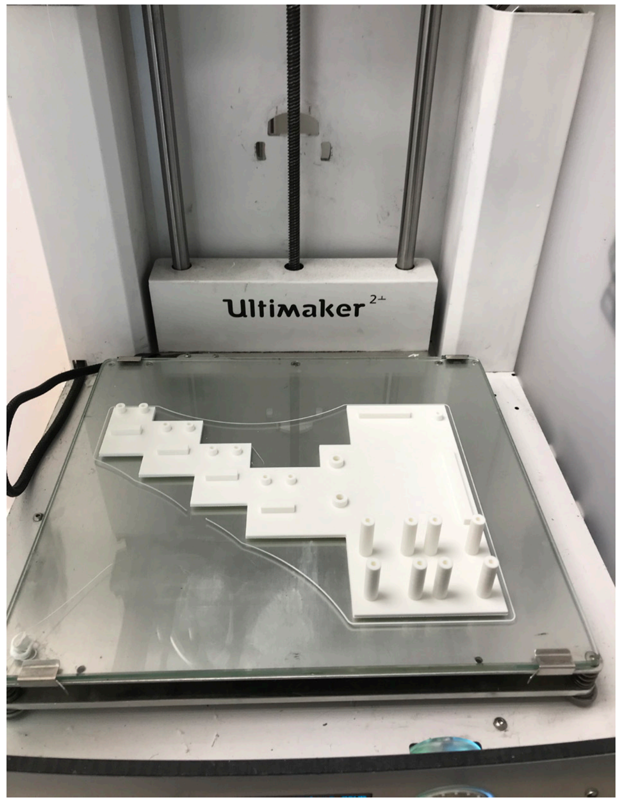
Appendix I

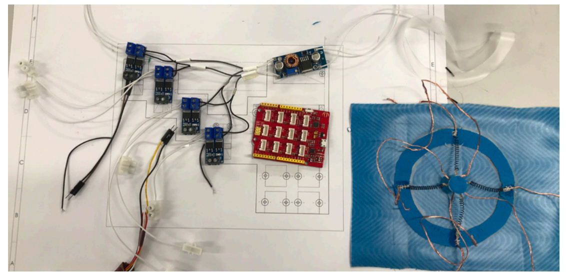
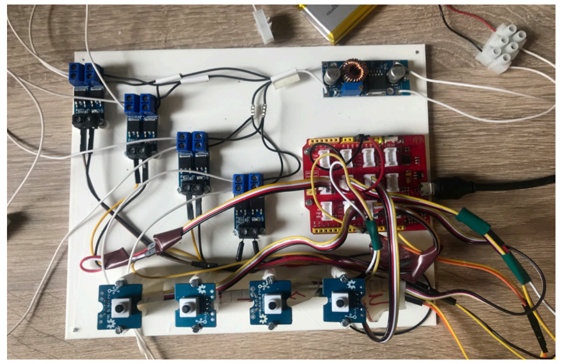
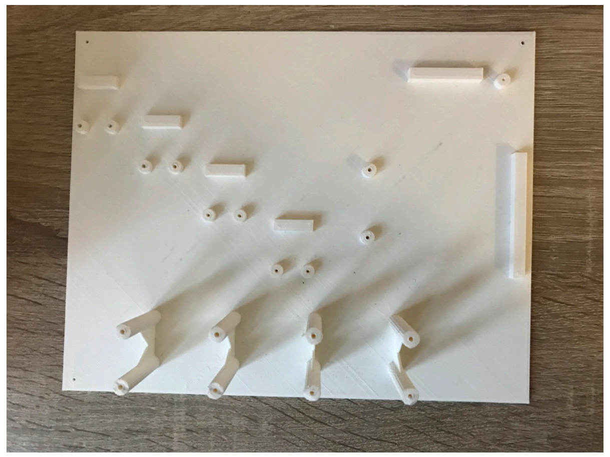
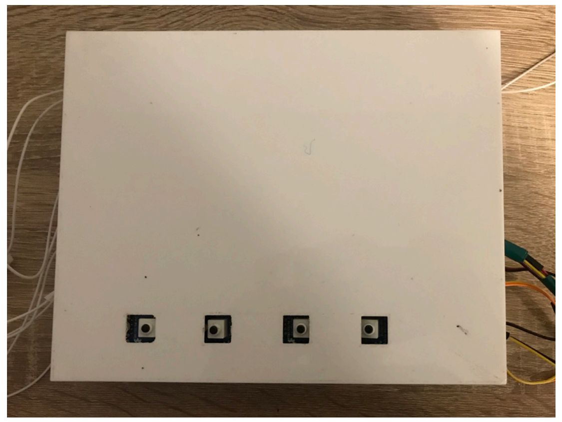
Code

```
int switchStatus1;
int switchStatus2;
int switchStatus3;
int switchStatus4;
int doorOpen = HIGH;
int pinSwitchStatus1 = 7;
int pinSwitchStatus2 = 2;
int pinSwitchStatus3 = 4;
int pinSwitchStatus4 = 8;
int motorPin1 = 6;
int motorPin2 = 5;
int motorPin3 = 3;
int motorPin4 = 9;


void setup() {
 Serial.begin(9600);
 pinMode(motorPin1, OUTPUT);

 pinMode(pinSwitchStatus1, INPUT);

}


void loop() {
 switchStatus1 = digitalRead(pinSwitchStatus1);

 if (switchStatus1 == doorOpen )
 {
  analogWrite(motorPin1, 255);
  Serial.println("button on 1");
 }
 else
 {
  analogWrite(motorPin1, 0);
   Serial.println("button off 1");
 }
 switchStatus2 = digitalRead(pinSwitchStatus2);

 if (switchStatus2 == doorOpen )
 {
  analogWrite(motorPin2, 255);
  Serial.println("button on 2");
 }
 else
 {
  analogWrite(motorPin2, 0);
   Serial.println("button off 2");
 }
 switchStatus3 =
digitalRead(pinSwitchStatus3);

 if (switchStatus3 == doorOpen )
 {
  analogWrite(motorPin3, 255);
  Serial.println("button on 3");
 }
 else
 {
  analogWrite(motorPin3, 0);
   Serial.println("button off 3");
 }
switchStatus4 =
digitalRead(pinSwitchStatus4);

 if (switchStatus4 == doorOpen )
 {
  analogWrite(motorPin4, 255);
  Serial.println("button on 4");
 }
 else
 {
  analogWrite(motorPin4, 0);
   Serial.println("button off 4");
 }

 delay(100);
}
```


Appendix J

Electronics Setup Stages

Appendix K

Consent Form

The purpose of the test is to understand the perception of a Shape Memory Alloy activated haptic demonstrator and whether simple patterns delivered by the setup are distinguishable. This test is a part of a Masters graduation project and will contribute to the study of how smart materials can be incorporated into haptic technology. All data gathered today will be used only for educational purposes, participant's identity will not be revealed. The test can be stopped at any time by the participant.

The Test:

The demonstrator consists of 4 springs attached to one 'effector'. An effector is the element which delivers the sensation to the skin. The setup will be attached to different part of the body with the help of medical tape.

Once switched on, the demonstrator will convey a variety of different patterns to the skin. The participant will be asked to identify the pattern. The participant may also be asked to draw the pattern on paper.

At the end of the test, a short interview will take place regarding the experience of the demonstrator

Name:
Age:
Gender:

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated [/ /], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.		
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.		
I understand that taking part in the study involves wearing the SMA demonstrator on different body locations and perceiving the haptic sensation created by it. This information will be captured through photos and videos (of the body location it is being tested on), written notes and an interview. The identity of the participant will not be revealed.		
Risks associated with participating in the study		
I understand that taking part in the study involves a risk of physical discomfort due to the adhesion of a medical sticker and heat from the electronics.		
Use of the information in the study		
I understand that personal information collected about me that can identify me, such as my name, gender and body dimension, will not be shared beyond the study team.		
I agree that my information can be quoted in research outputs		
Future use and reuse of the information by others		
I give permission for the insights and information that I provide to be archived in the TU Delft Education Repository in the form of a report and/or video so it can be used for future research and learning. My identity will not be revealed.		

Signatures

____________________	____________________	________
Name of participant [printed]	Signature	Date

4750

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Sandhir

initials: P given name: Preeti

student number:

street & no.:

zipcode & city:

country:

phone:

email:

Your master programme (only select the options that apply to you):

IDE master(s): [★] IPD [ ] Dfl [ ] SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: [ ] Honours Programme Master

specialisation / annotation: [ ] Medisign [ ] Tech. in Sustainable Design [ ] Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Gijs Huisman dept. / section: HCD/HICD

** mentor: Sepideh Ghodrat dept. / section: SDE/EM

2nd mentor:

organisation:

city: country:

comments (optional):

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair: Gijs Huisman date: 22 - 02 - 2021 signature:

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 27 EC

Of which, taking the conditional requirements into account, can be part of the exam programme: 27 EC

List of electives obtained before the third semester without approval of the BoE:

[X] YES all 1st year master courses passed

[ ] NO missing 1st year master courses are:

name: J. J. de Bruin date: 23-02-2021 signature: JdB

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: [V] APPROVED [ ] NOT APPROVED

Procedure: [V] APPROVED [ ] NOT APPROVED

comments

name: Monique von Morgen date: 2/3/2021 signature: MvM

Initials & Name: P Sandhir

Title of Project: Aids for visually impaired using smart materials integrated in haptic technology

Personal Project Brief - IDE Master Graduation

Aids for visually impaired using smart materials integrated in haptic techn project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 22 - 02 - 2021 19 - 07 - 2021 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

This graduation project focuses on exploring the currently available Shape Memory Materials- metallic, polymeric base or composites in haptic technology applications in order to improve the wellbeing and lifestyles of the visually impaired.

There is estimated 285 million people worldwide living with a visual impairment [1] and the rate of acquired blindness is expected to keep on increasing [2]. Assistive technology meant for this category of people have been progressively developed in order to enable them to live independent lives [3,4]. It is predicted that the demand for assistive technology for the visually impaired market will have a large growth in the future [3] and it will be continuously expanding according to technological advancements ([4] and citations therein). Through my interaction with the visually impaired for previous projects, I have learnt that a majority of people use the basic aids available in the market such as the white cane, screen readers, magnifiers etc. although some of them are difficult to use to the fullest. For example, the general public tends to stand on the tactile tiles in train stations, leaving them unusable for the visually impaired(refer to images on next page). Therefore, there is a need for development of new, relevant and effective methods of aids which are more easily accessible to the majority of the target group.

Both haptic technology and shape memory materials are gaining popularity now with large, well-known companies exploring their applications. Many of the applications are in situations when the sense of touch is greatly diminished. There is a large opportunity to incorporate haptic technology in situations in which one cannot rely on sight in order to manipulate objects and conduct tasks [5]. There is evidence that tactile sense in sensory substitution aids can be affective as methods of communication by providing information to sensory disabled individuals [6]. The sense of touch has a large potential for incorporation into assistive interventions since it is not localized to specific regions of the body, as is the other senses. Another advantage is that it can also act as an aid independently without taxing other sensory channels. Haptic technology is already starting to get incorporated more into assistive technologies now, areas of relevance include workplace, education, leisure activities, daily activities and navigation. It is important that the information provided through the assistive device is functionally equivalent to what is normally attained through vision [7].

A problem with many largely available haptic solutions is that they are large, produce sounds that hinder their usability and the haptic feedback sometimes does not feel very pleasant. There are other actuators made from smart shape changing materials which can be incorporated into these systems [8]. They have the ability to be thin, flexible, light weight as well as being as effective. A fascinating aspect is that different materials can be combined in such a way that specific properties can significantly change in a controlled fashion in response to an environment, for eg- "robotic fabric" [9]. Shape memory materials have the potential to bring hedonic characteristics to haptic technology and hence make the haptic assistive devices both effective and comfortable interventions for the visually impaired.

This graduation project is to select and evaluate Shape Memory Materials integrated in haptic applications regarding their affective properties and as solutions for improving the wellbeing and lives of the visually impaired. Through this study these technologies will be applied in the form of interactive assistive device (graspable, wearable or touchable).

space available for images / figures on next page

Personal Project Brief - IDE Master Graduation

introduction (continued): space for images

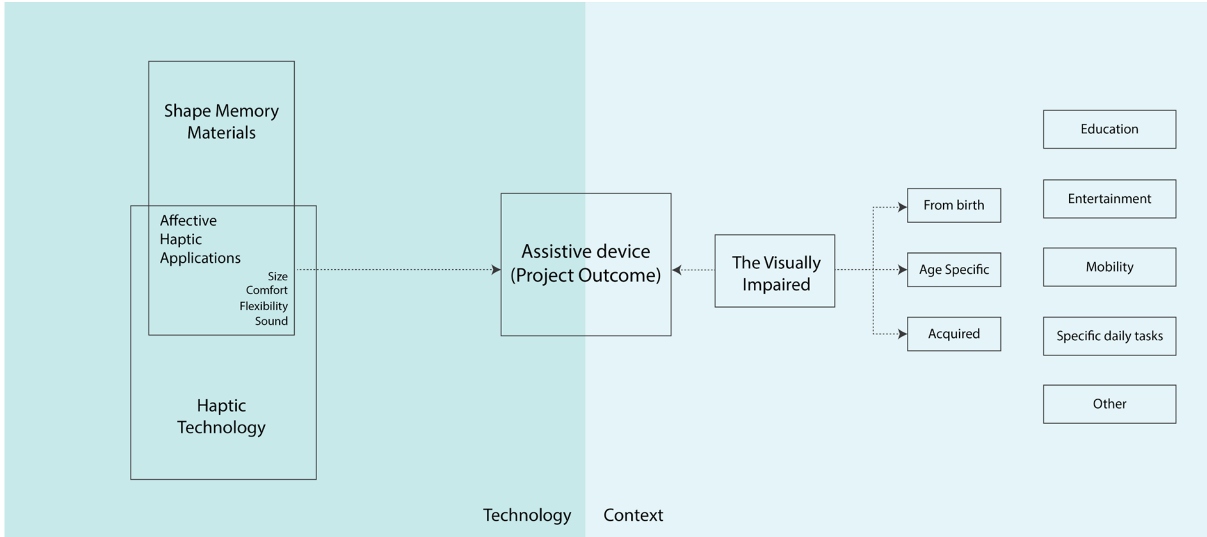
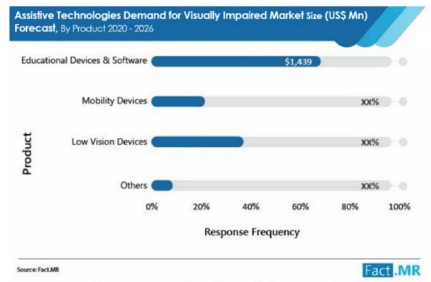
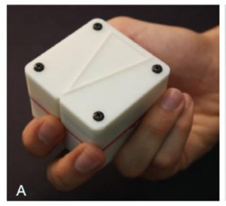


image / figure 1: Overview of Project



Forecast of assistive technological demand for the visually impaired [3]



Example devices;
A: Animotus-a shape changing haptic interface for navigation [10]
B: Wearable haptic navigation device [11]
C: Tactile display of on-screen 3d shapes [12]

Problems found during interactions with the visually impaired for a project in 2019- shadowing in public spaces and testing prototypes

image / figure 2: Research: Example potential areas of interventions

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

This project will address how haptic technology can incorporate shape memory materials to meet 'specific' needs of the visually impaired.

The project will first explore the impact shape memory materials have in haptic applications- How can they improve haptic feedback? What new value can both technologies bring to each other? The study will then move into how this combination can be applied as an assistive device for the visually impaired. The context of the assistive device will be defined during the study as per the most effective capabilities of the technology. Potential application directions include education, entertainment, navigation etc.

The study would include the following:
- Dive into different haptic applications
- Experiment with different shape memory materials
- Define the design requirements of haptic applications in the context of the visually impaired. Specify limitations and opportunities. How can shape memory materials meet these needs?
- Iterative process of testing and selecting materials
- Build prototypes for these applications
- Test and refine applications
- Context area validation
- Refine and deliver solution

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Investigate the capabilties of shape memory materials being incorporated in haptic technology.
The outcome will be a prototype which showcases how this technology is applied to meet the needs of the visually impaired.

The project is a bridge between advancements in technology and the needs of people (in this case, specifically the visually impaired). It brings a sense of direction and purpose to exploring different possibilities in technology and materials.

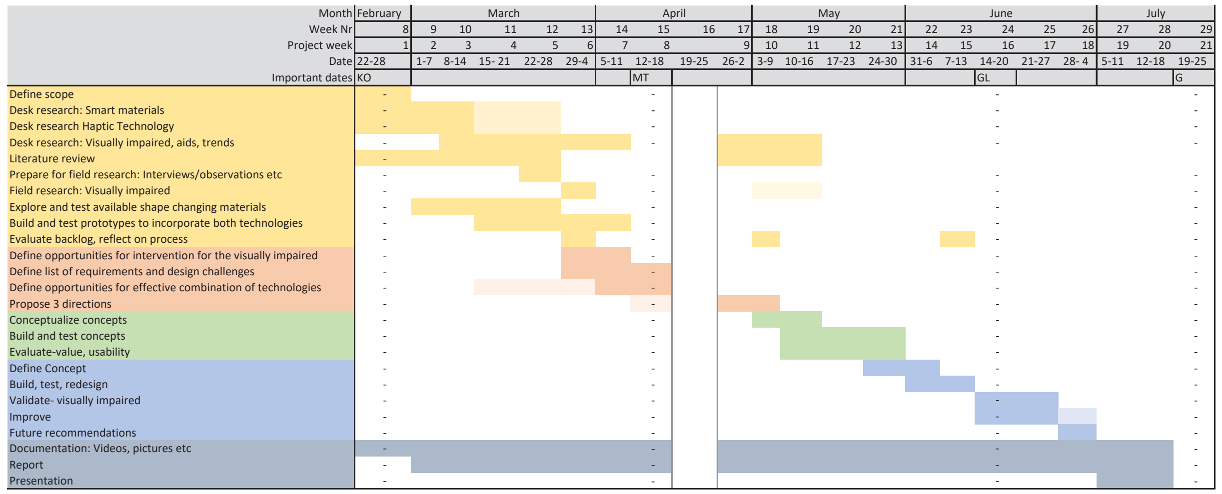
Research:
- Explore currently available shape changing materials
- Different uses and possibilities of haptic technology
- Desktop and field research to gather insights into the needs of the visually impaired (Netherlands)

Create:
- Build prototypes of how shape changing materials can be controlled
- Test how these materials can bring value to haptic feedback
- Create and test prototypes of the application of this combination for the visually impaired

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 22 - 02 - 2021 19 - 07 - 2021 end date



(The light colours in the Gantt Chart refers to activities which would occur to compliment the focus activities in that week. For eg- I will be defining opportunities while evaluating and testing the technologies)

Although the research and exploration will be an ongoing process throughout most of the project, the biggest chunk will be done in the first half of the project. This includes desk research, experimenting with shape changing materials and haptic feedback and field research with the visually impaired.

By the midterm evaluation, the opportunities and validated prototypes will be completed after which directions for intervention will be proposed. The next steps will be the development and testing of concepts in those directions. One concept will then be chosen for further development and evaluation. The concept at this stage will then be tested by the users and improved based on the insights. The end result of this project will be a prototype of how the technologies are applied to aid the visually impaired.
The project report will be worked on throughout the duration of the project along with video and pictures documentation. I have added specific weeks to actively reflect on my plan and process and make changes if required.

Important dates:
Kickoff- February 22nd
Midterm- April 16th
Greenlight- June 16th
Graduation presentation- July 19th

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

This project is of great personal interest of mine. Over time, I have found a passion in designing tangible products to improve the lifestyles and wellbeing of the differently abled. Both through my own experiences with visually impaired relatives as well as previous projects I have done for this target group have made me aware of how they tackle the world today and the urgent need for interventions to improve their experiences. I was very keen on working for this category of society for my thesis project. The exploratory nature of the university has also always been very interesting for me. I really wanted to experiment and utilize different emerging technologies and materials and this project is the perfect combination of my areas of interest- merging technology with specific needs of people. Through my research so far I have found the impact shape memory materials have on haptic technology very fascinating. I really want to diver deeper into it's effects and apply them to a specifc context. Both haptic technology and smart materials are capable of effectively providing information to sensory disabled individuals and hence have great potential to be applied as aids for the visually impaired.

Personal Learning Objectives:
- Haptic technology is already very prominent and is constantly being developed for new and fascinating applications. I want to gain deeper knowledge into this technology and be able to work with it for more projects in the future.
- I want to be able to improve my skills in experimenting and evaluating materials and define solutions based off their capabilities (as compared to force fitting commonly available materials into design solutions)
- I want to learn and improve my scientific/technical debate skills and discussion
- I want more experience in designing for specific needs of people
- I want to work more with my hands- experiment, build and test.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name P Sandhir

Title of Project Aids for visually impaired using smart materials integrated in haptic technology

References

[1] Y. He *et al.*, "Prevalence and causes of visual impairment in population more than 50 years old: The Shaanxi Eye Study: The Shaanxi Eye Study," *Medicine (Baltimore)*, vol. 99, no. 20, p. e20109, 2020.

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[3] "Assistive Technologies Demand for Visually Impaired Market forecast, trend analysis & competition tracking - global market insights 2020 to 2026," *Factmr.com*. [Online]. Available: https://www.factmr.com/report/4635/assistive-technologies-demand-for-visually-impaired-market. [Accessed: 06-Feb-2021].

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[6] F. Sorgini, R. Caliò, M. C. Carrozza, and C. M. Oddo, "Haptic-assistive technologies for audition and vision sensory disabilities," *Disabil. Rehabil. Assist. Technol.*, vol. 13, no. 4, pp. 394–421, 2018.

[7] D. Pawluk, N. Bourbakis, N. Giudice, V. Hayward, and M. Heller, "Guest Editorial: Haptic Assistive Technology for Individuals who are Visually Impaired," *IEEE Trans. Haptics*, vol. 8, no. 3, pp. 245–247, 2015.

[8] M. Cruz, K.-U. Kyung, H. Shea, H. Bose, and I. Graz, "Applications of smart materials to haptics," *IEEE Trans. Haptics*, vol. 11, no. 1, pp. 2–4, 2018.

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[10] A. J. Spiers and A. M. Dollar, "Design and evaluation of shape-changing haptic interfaces for pedestrian navigation assistance," *IEEE Trans. Haptics*, vol. 10, no. 1, pp. 17–28, 2017.

[11] M. Hagen, "WayBand - their first wearable haptic navigation device for the blind and visually impaired," *Closingthegap.com*, 09-Nov-2017. [Online]. Available: https://www.closingthegap.com/wayband-first-wearable-haptic-navigation-device-blind-visually-impaired/. [Accessed: 06-Feb-2021].

[12] "TechCrunch is now a part of Verizon Media," *TechCrunch*.