University of Twente

Emulation of electroactive polymers

Graduation Project Creative Technology

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Acknowledgements

To start this paper off, I would like to thank a few people who helped me a lot during the process of making this paper. In the extraordinary pandemic times we find ourselves in right now it requires the students as well as the supervisors to improvise quickly and being flexible. First of all I would like to thank my supervisor Edwin Dertien for guiding me through the process of writing and researching. His feedback motivated me to keep going and to keep me on track. I would also like to thank Angelika Mader for giving me constructive feedback after my presentations. Finally, I would like to thank Allan Vaele for answering questions regarding the subject quickly and accurately.

Abstract

To emulate the electroactive polymers, different actuators have been compared in order to find the most suitable emulator. By using literature research, nitinol wire seemed to be the most suitable. Mainly because of its way of actuation and similarity of actuation. Also, this wire is widely available which makes it easier to test and tinker with. To characterize nitinol wire, a test setup was made which had to be able to actuate as well as measure the force which is created by the nitinol wire. Not only the force was measured but also the current, voltage and temperature in order to get a clear vision of the characteristics of nitinol wire. The force was measured with loose straight wires with different diameter, a different shape (a spring shape in the case of this paper) and a way of knitting the nitinol wire into the fabric. Next to these quantitative measurements, some qualitative measurements were taken, to research if the actuation was perceivable for a human to feel.

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1. Introduction

Today, humans often interact with the world by the use of many electronic devices. The user gives input to these electronic devices, and the device produces output in the form of feedback. This feedback can be perceived in many ways because it makes use of our senses. The most obvious forms of feedback are visual feedback and auditory feedback but nowadays also haptic feedback is used, which makes use of the ability of humans to feel. An advantage of haptic feedback over the traditional forms of feedback is that it can be unobtrusive and silent. A simple form of this feedback is the vibration motor of a phone. This is still a very basic use of haptic feedback but haptic feedback can also be implemented in fabric, which opens a much wider range of applications. When this is implemented in wearable fabric (clothes), a large area can be covered by haptic actuators which results in a more sorts of feedback but also more precise feedback. An example being the application of this technology in learning to control robot arms and machinery results in a much faster learning time [4]. The beforementioned is an illustration of a current use. However, if this technology is further developed, a whole new dimension can be added in interacting with devices. Nowadays haptic feedback is mostly done by motors, which are most of the time bulky and make noise. Haptic feedback in garment can also be achieved by the upcoming technology of electroactive polymers. This technology does not limit itself to only feedback, but also opens a new perspective on fashion. Fashion can be made interactive by for example introducing moving fabric.

Electroactive polymers are developed by the EU project WEAFING. The project aims at developing smart wearables using these polymers. Nevertheless these polymers are not fully developed yet. Because the electroactive polymers do not exist yet, the effect of it in wearables cannot be investigated by the use of these electroactive polymers. This is where nitinol wire has the potential to be a suitable emulator. This wire can also shrink and thus the behaviour of electroactive polymers can be emulated without using the not yet existing electroactive polymers. This is useful for the WEAFING project because now the effect of electroactive polymers in fabric can be investigated before they exist. When the polymers are fully developed, they can be implemented in wearables directly, because the effect of them is already investigated. Nitinol wire shrinks at a certain temperature. This could be a possible material to emulate electroactive polymers.

The research question of this research is as follows: How can the implementation of electroactive polymers in fabric be emulated by the use of other actuators?

The next chapter, chapter 2, will focus on the already existing technology regarding actuation in fabric. Literature research will be done to see what research has already been carried out. The chapter thereafter, method and techniques, will describe the methods and techniques which are used to create a set-up in order to test the behaviour of nitinol wire and will give a description on which principles the methods are based on. In chapter four, the ideation will be described. In this chapter applications of haptic feedback will be researched. This chapter will be followed by the specifications of the concept. The chapter following the specification will be the realisation. This chapter will actually take the theory of the methods section into practice. This practice will then be evaluated in the evaluation chapter which comes after the realisation. When the evaluation is done, a conclusion can be drawn, which is done in chapter 8 after the evaluation. Further research of this topic can be done. This future research is given in this last chapter which is called future work. Appendices are attached at the end of the paper.

2. State of the art

This chapter will discuss related research which has already been done on the subject of other actuators which could be incorporated in fabric. First, a couple of requirements will be given on what makes a good emulator for the electroactive polymer. After the requirements, different actuators will be described and what could make or what could not make them suitable for emulation of electroactive polymers. Then, the best way of incorporating the actuator in the fabric will be discussed.

2.1. What makes a good emulator for electroactive polymers?

A good emulator for electroactive polymers should share as much characteristics as possible with the actual electroactive polymer. The reason for this is that the actuation and effect of the actuation will be as close as possible to the real electroactive polymers. First of all, the feeling of actuation should be the same. When the feeling is different, the haptic sensation of the user or wearer of the fabric is different so it does not represent truly the electroactive polymers. This also includes the maximum force which can be actuated. The maximum force according to research of the early electroactive polymers is Preferably the actuation method should be the same. This makes sure that no additional hardware is needed when actuating the emulator. When extra hardware is eliminated it represents more the actuation of the actual polymers without needing to add bulky hardware. Finally, of course the eventual actuation should be the same. The electroactive polymer contracts, so the emulator should be able to make this actuation.

2.2. Different Actuators

There are a lot of different actuators which can be used in fabric. All having different effects on the skin and different actuation principles on which they act. Each actuator has its pros and cons when it comes to actuation in fabric. In table x is an overview depicted of all different actuators and what they can and can not do.

Motorprinciple/translation on skin	Pressurize	Temperature change	Suction	Vibration	Stroke	Pinch	Tap	pulse	Tickle
Pneumatic cylinder	✓	×	×	✓	✓	×	×	✓	✓
Pneumatic bellow	✓	×	×	✓	✓	×	×	✓	×
Pneumatic suction	×	×	✓	✓	✓	✓	×	×	✓
Resistive heating (SMA-wire) Single straight wire	✓	✓	×	×	✓	✓	×	×	✓
Resistive heating (SMA-wire) Helical shape	✓	✓/×	×	×	✓	✓	×	×	×
Resistive heating (SMA-wire) spring shape	✓	✓/×	×	×	✓	✓	×	×	×
Vibration motor	×	×	×	✓	✓	×	✓	✓	✓
Modifiber (twisting wires)	✓	×	×	✓	✓	×	✓	✓	×
Electroactive polymer	✓	×	×	×	✓	✓	✓	✓	×
FEA (Fluidic Elastomeric Actuators)	✓	×	×	×	×	×	✓	✓	×
Peano muscle	✓	×	×	×	×	✓		✓	×

Table 1 Table of actuators

All these different actuators can be processed in the fabric in a different way. Where each different way results in a different type of feedback. These types of feedback can be seen in table two. This table can be used to eventually process implementation of the nitinol wire.

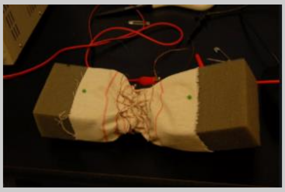
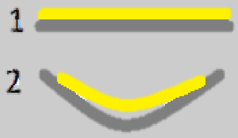
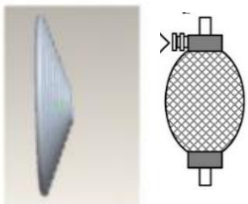
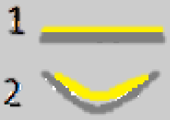
Perception	Principle
Pressure	 Placing the actuator along the width of a sleeve
Stroking	 Placing the actuator in the length of the fabric of clothing or sleeve.
Movement (bending)	 When an actuator is attached to a rigid, non/shrinkable piece of fabric, it bends when actuated.
Pressure point	 Helical springs can extend and flatten which causes a pressure point. A McKibben fiber (or bellow) could also be used
Tingling	 Same as movement but at a single strand scale. Small actuator strands which make up “hairs”

Table 2: perception vs. principle

2.2.1. Which different actuators seem suitable?

To emulate electroactive polymers, different actuators can be used which all rely on different mechanical properties and actuation methods. This means one is more suitable for emulating electroactive polymers than the other. A very close emulator for the electroactive polymer is a knitted PVC-gel [13]. The haptic sensation is achieved by putting in voltage in waveforms into the wire, this causes a haptic sensation which can be felt by the user. This is also an electroactive polymer but this is not widely available yet and is still under development. The largest drawback however is the high voltage at which it operates (in the range of 1kV).

Another way of actuators in fabric is by the use of McKibben muscles [6]. These are tubes, in which air can be pumped. When this is done, the pressure increases and the muscle will contract and when air is pumped out again, the pressure decreases and the fibre returns to its original shape.

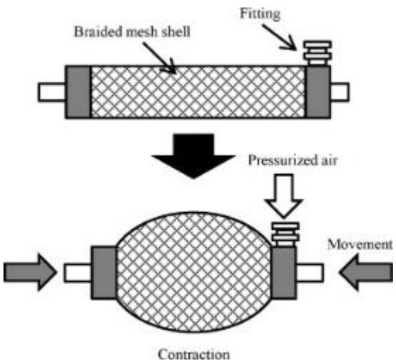


Figure 1 McKibben muscle working principle [17]

This process can be seen in figure 1. Eventhough the stretch movement is comparable to the movement of the electroactive polymer, it can also be seen that not only the length will change, but in addition to that, the diameter of the muscle will increase. This is not a favourable effect because this is not the case with the electroactive polymers. In addition to the increase of the diameter of the muscle comes the fact that additional hardware is needed in order to pressurize the muscles. These drawbacks make the McKibben muscles not the ideal emulator for the electroactive polymers.

The third actuator becomes rather close to the electroactive polymers. A project called ModiFiber also researches actuators which can be incorporated in fabric [5]. By using a wire which is twisted in a silicone coating as seen in figure 2, the total wire contracts when it gets heated up. It can get

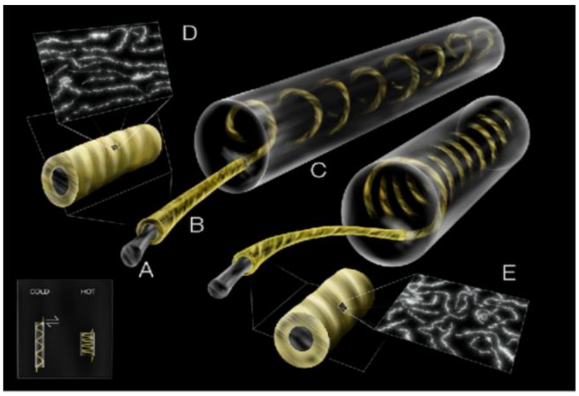


Figure 2 Schematic drawing of the ModiFiber [5]

heated up with resistive heating. This seems like a good emulator however, just like the McKibben fibers, the diameter increases significantly which is not favourable. Also, in order for the wire to shrink, the wire has to be heated up to 80 degrees celcius. When the wire is woven into clothing, the wearer could get burnmarks when the wire is heated up. In addition, the reaction time is relatively slow. The reaction time of the wire is approximately 4 minutes.

The fourth and last actuator which will be discussed is nitinol wire. This is wire made from a nickel-titanium alloy. This wire can be trained in a certain form by heating up the wire to approximately 500 degrees celcius [8]. When the wire cools down, it can be bend in any shape but when the wire is heated to approximately 50 degrees celcius, it returns to its trained shape. It also shrinks in length. Additionally, when the shape is trained to be contracted, it can become close to the electroactive polymer. Also the actuation is the same with nitinol wire in comparison with the electroactive polymer. When a voltage is applied over the wire, the wire heats up thanks to resistive heating, which causes a change in shape and, most importantly shrinkage. A drawback is that the wire becomes warm or hot. However this is less of a problem with nitinol wire because this wire can already be activated with a temperature of 50 degrees celcius. Yet, some research is already done to create a sort of nitinol wire which can return to the trained form at at temperature of 40 degrees celsius [12].

2.2.2. Which actuator turns out to be the best?

When the pros and cons are balanced for each actuator, it can be concluded that the nitinol wire can be seen as the best suitable for the emulation of electroactive polymers. Not only is the actuation close to the electroactive polymer, but also the way the actuator is controlled is the same.

2.3. Incorporating the emulator in fabric

When the most suitable emulator is found, there are still many ways to incorporate the actuator in the fabric. Actuators can be incorporated in fabric with different techniques where every technique has a different (visual) effect with accompanying properties of fabric. The following findings are based on the use of nitinol wire. Research has already been done to investigate the most effective way of using nitinol wire to fully use the potential of the wire. Not every technique of stitching or sewing is suitable for the nitinol wire due to for example the thickness and the stiffness of the wire [14]. Another way of incorporating the wire is by stitching the wire onto the wool. This is a very pragmatic solution and not ideal because the wire is clearly visible and not really incorporated into

Figure 3 a) stitch loop b) tuck loop c) miss loop [11]

fabric but rather used onto fabric. Researchers already use this technique because it is relatively easy and does not require special machinery or tools [1]. However, this is aesthetically not ideal because the wire can be clearly visible which can lead to a distraction from the actual shape of the wearable or clothing. Even though it might seem harder, a lot of articles state that sewing and knitting the wire into fabric can be done. This also creates different possibilities of knitting and sewing which include different loops to get different strengths and effects. Researchers investigated three different types of knitting loops to conclude which loop creates the strongest pulling force. The three loops are: stitch loop, tuck loop and the miss loop.

The tuck method appears to have the largest strength to deform the fabric. Another take on using nitinol wire is not to incorporate the wire as part of the fabric but use the wire on a higher level by using for example coils between layers of fabric. Researches state that coil shape or spring shaped wire can create the strongest pulling force. A concept has already been made for an insulating jacket where the coils can change height, this creates an air gap which serves as an extra insulation layer. [20]. Spring shapes are used in a research where an active hugging vast is described. The concept is a vest where two halves of the vest can be compressed with the use of nitinol springs, this creates a hugging feeling [2].

2.4. Requirements test set-up

The best way to incorporate the electroactive polymers in the fabric should be testable. It should be possible to measure the effect of different loops and different incorporation methods. This can be done by creating a test setup which can measure the force which the fabric or a single actuator can create. A test setup can be based on the device which is already been made by *hardwareX* [19]. This device can be seen in figure 4.

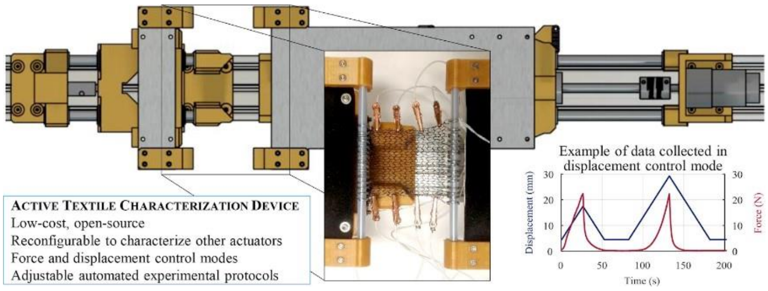


Figure 4 Active garment measurement setup [17]

This setup makes use of different motor drivers where the voltage drop and current is measured to investigate what generates the greatest force. This setup can be used as a base for the setup used in this research. The setup in this research should amongst others be able to enable a precise actuation of the emulator. This gives a wider range of testing possibilities when for example certain different forces have to be investigated. This results in another requirement, which is measuring the force which is generated by the fabric. This gives more information on which way of integration of active garment results in the greatest force and thus, which is the most effective.

2.6. Conclusion

To conclude the state of the art, it can be said that nitinol wire seems like the best emulator for the electroactive polymers. It is widely available to test with and is also relatively easy to control. A lot of research has been done on this wire so there is already a lot of knowledge through those researches which can be applied in this research. Even though the wire gets warm when the user wears the fabric, which could be considered not representative for the electroactive polymers, it can be used by for example adding a layer of fabric between the wire and the wearer. Next to the temperature aspect is also the manufacturing aspect which should be taken into account. The wire should not be too thick because then it would be difficult or impossible to sew, but also not too thin because this makes the effect of the wire a lot less. A thickness of approximately 130 micrometres seems to be a good trade-off between not too thin and not too thick [11]. To get the strongest pulling force of the wire, it should be formed into a helical or spring shape to get the greatest force out of the wire.

3. Method

This chapter will discuss how the experiments will be conducted. Also will be mentioned what a conventional design workflow looks like.

3.1. The Creative technology workflow

Creative technology is a multidisciplinary study program which focusses on inventing and developing new concepts and new inventions by using existing technology. These existing technologies can be combined, further developed and applied by the use of creative thinking. This creates new inventions which aim to improve or add something to the life of the people using the new creative outcome. Creating something can be done by working in a systematic workflow. This systematic workflow which is used in Creative Technology is developed by Mader and Eggink (2014). This workflow is meant as a basic structure which can take any shape according to the design team or researcher. The workflow can be seen visually in figure 5. It should be visible that a large part of this workflow is circular rather than linear. In the *ideation* phase, novel applications for the already existing technologies are identified. Also interacting and exploring limits and capabilities of technology is part of ideation. This process is also known as tinkering. Tinkering can help a lot when knowledge about a certain technology has to be gathered. As Mader once said:

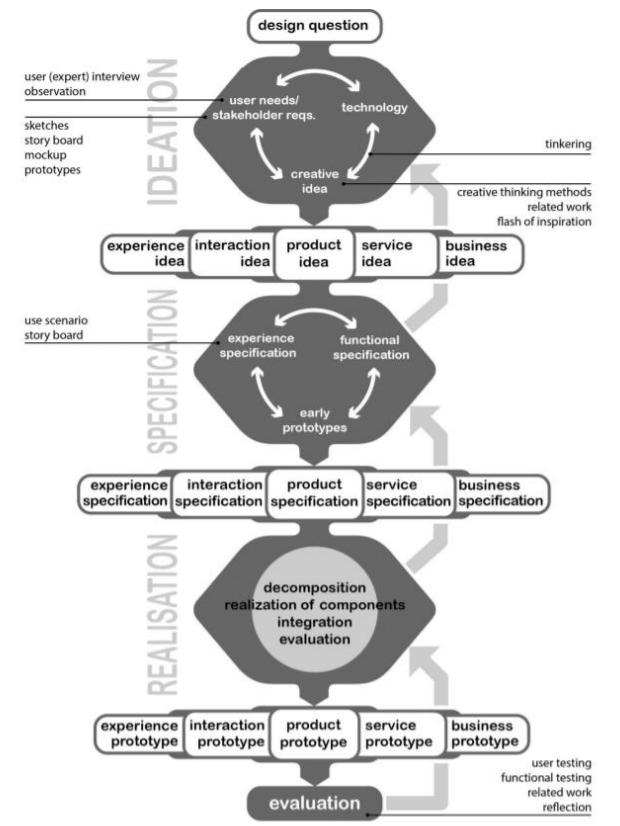


Figure 5 CreaTe workflow (from: Mader A.H. and Eggink W., "A Design Process For Creative Technology")

"Tinkering is a powerful tool of learning"

However, the ideation of this paper differs from the conventional ideation phase. In this paper the ideation focusses more on the eventual applications of the haptic technology rather than iterating through new concepts. This is done to explore what the haptic actuator can and should do and therefore derive requirements for, and specifications of the test setup and emulator. The setup in this paper underwent two iterations. These are described in the *realisation* to create a more logical structure but moreover to better indicate the reason for differences in iterations. This is because the iteration took place during the realisation.

In the *specification* an early prototype can be given to see what it conforms to in terms of what it can do and also give some iterations of the design. This however is different in the case of this paper. The iterations are described in the realisation because the iterations developed throughout the experimenting process. This makes it easier in this case to explain design choices. In the *realisation,* the technology is put through the test and see where things go wrong to spot weaknesses in the design and how the design is improved into the follow-up design. The realisation is also used for functional testing. Finally, the final design has to be evaluated in the *evaluation* phase to see if the design accomplished the goal.

3.2. The Approach

To characterize an actuator or different implementations of an actuator, experiments have to be conducted. This can be done by building a custom setup which has the ability to gather information and store the information in a useful way so it can be processed later. To design such a setup, the first thing that has to be done is figuring out what sensors are going to be used and on which principles they are based. When this is done the setup can be designed around these principles. Not only these principles should be taken into account but also other practical aspects such as formfactor of measuring devices or sensors should be taken into account. In most cases (especially in Creative Technology) Arduinos are used because they are versatile and reliable. Another thing which has to be decided what manufacturing technique is suitable for the setup. This plays a big role in the designing process. A setup made by laser cutting should be designed such that the eventual 3D setup can easily be made by 2D shapes. When a setup is made by using a 3D-printer, the setup should not be too bulky to avoid long printing times and material waste. Also, (depending on the printer) the scale should not be too large because it has to fit on the print bed of the 3D printer. And of course the usual 3D-print rules have to be taken into account, for example limitation of overhangs.

3.3. Evaluation

After the experiments are conducted, the setup has to be evaluated and after evaluating the setup, the main research question of the paper can be answered. Only if the setup fulfils its purpose, the main question can be answered. If this setup does not meet the requirements, it has to be revised. The setup eventually has to accurately control and monitor the nitinol wire. To see if nitinol wire is the right emulator for the electroactive polymers, the wire should be able to be precisely controlled and be able to exert a large enough perceivable force. If this is the case, it could be said that nitinol wire is a good emulator for the electroactive polymer.

4. Ideation

In this chapter, the ideation of the research is described. There are a lot of different applications in which haptic feedback can be integrated. This chapter aims at describing what can be done to integrate actuators in fabric in order to create haptic feedback.

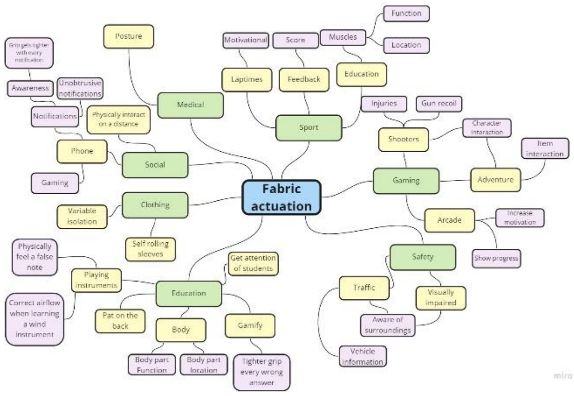


Figure 6 Mindmap

4.1. Applications of fabric actuators

There are a lot of potential applications when haptic feedback is incorporated in fabric. This ranges from educational purposes to entertainment purposes. This way of feedback opens up a whole new dimension for perceiving information which means not only a more immersive way of feedback but it can also provide a more accurate way of giving feedback. Different locations on the body can give feedback and also different haptic sensations. The following subchapters will elaborate and supplement the mind map displayed in figure 6. The full size mind map can be found in Appendix 11.1.

4.2 Use cases

The first use case is the use in Virtual Reality (gaming) or gaming in general. The actuator can be linked to a (VR)game which can actuate according to in-game events. For example, a side character takes the users arm in the virtual world. This could be translated to the real physical world by a sleeve which has an actuator (for example nitinol wire) which then compresses around the arm of the user. This can be extended to all sorts of events and haptic sensations and actuators. An other example is simulating recoil from a gun in a shooter game by using vibration motors. The goal of implementing haptic signals in arcade games however is not to make them more realistic, but to give a new dimension to the game. Take for example the game Tetris. A screenshot of the game can be seen in figure 7.

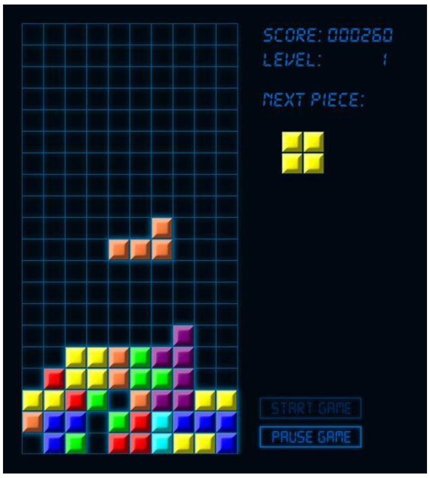


Figure 7 The game Tetris (cdn.pelfusion.com)

The goal is to fit the falling shapes such that one continuous line is formed from left to right. Then, this row is removed. When the blocks are touching the upper side of the screen, the player of the game is game over. This game is fairly simple but it can be made more engaging when haptic feedback is used. For example: The player of the game wears a sleeve or belt with actuators in it. When the game starts, no pressure is applied and the player feels physically and mentally no pressure. However, as the blocks build up and get closer to the top of the screen, the actuator gives more pressure on the user, which causes it not only to experience mental pressure, but also physical pressure. This could make the game more interesting.

Also in sport the actuation in fabric could be used. Athletes could get feedback on their lap times with the help of fabric actuation. This reaches further than only the vocabulary feedback the athlete gets. Instead of (only) vocal communication, a haptic signal is added. This could lead to a more efficient way of communication because now, the communication can be done by multiple channels (auditory and haptic). Another possibility could be that the vocal communication is strengthened by the haptic addition to the communication. The user does not only hears the message, but experiences the message, which could be more intense and thus makes the communication more effective.

Safety is also a category where haptic feedback can play a large role. The most obvious group of people which would benefit the most from the use of haptic feedback is the group of people which have difficulties with other senses to perceive the world around them. Such a group is for example the visually impaired people. Because the world is visually not really well perceivable, hazards can be overlooked. This inevitably causes dangerous situations. However, even though the visual sense is impaired, the other senses are still working. This is where haptic feedback can play a role. By using for example vibration motors in clothes of the wearer, the wearer can get warned whenever an obstacle occurs. This haptic signal can transmit a whole range of information just by using for example vibration. Not only the location of the obstacle can be indicated, but also the sort of obstacle by using different vibration effects. This can be done fairly easy by using the Adafruit DRV2605L Haptic Controller which is depicted in figure 8.

This controller is designed for controlling vibration motors. Other motor controllers just turn on and

Figure 8 Adafruit DRV2605L Haptic Controller (https://www.adafruit.com/product/2305)

of the motor but this board can also generate effects with the vibration motor such as clicking or ramping up the vibration. All these different effects can be linked to different kinds of obstacles which results in a user which is more aware of the environment. Not only visually impaired people could benefit from this technology. But also people who are engaged in a cognitive much demanding task, such as driving. Driving relies for the most part on visual input. This means the visual input channel should not be busy with other things than driving. A lot of cars these days are equipped with a navigation system. This is a screen on which the route is depicted. Haptic signals could possibly be incorporated to avoid the need of looking on a screen. The driver could get a small haptic sensation on the right side of the body, which indicated that he has to go to the right in 1000 meters. The sensation could get more intense when the driver is 500 meters in front of the junction. This can also be done by the use of the earlier mentioned motor controller, the DRV2605L to equip the haptic signal with more information.

A large branch in the mind map is the branch “Education”. Education can be made more effective and more engaging when using haptic signals. Instead of just marking an answer red or green, a sleeve or something alike can be used in order to physically reward or “punish” the student. The sleeve gets tighter of looser according to a wrong or right answer. This makes giving an answer more like a game instead of a traditional exercise. A sign of appreciation can also be given to a student. A teacher can give a pet on a back. This maybe can be translated in a haptic signal by the use of an actuator. This pet on the back can be given even without the need for a teacher to be standing next to the student. Sometimes the teacher has to take a lot of effort in order to get students or children to listen to them. Most of the time this is done by raising his or her voice. This is very obtrusive and is heard by everyone in the room which is far from optimal for the concentration. This could be solved by using haptic actuators. A teacher can directly signal the relevant person without disturbing the rest of the attendees. This can either be done by vibration or a sleeve which exerts more force according to the amount of warnings the person got.

When broadening the concept of education to for example learning an instrument, especially wind instruments, it could give a huge boost in learning how to breathe. Which indicate which muscles to tense in chest or stomach in order to get the right amount of air through the instrument.

When thinking about fabric, clothing is the first thing most people think about. It should be therefore no surprise that clothing can be actuated as well. The main purpose of clothes is to isolate the wearer form surrounding temperature. However, the surrounding temperature is not always constant.

Sometimes the wearer needs more isolation and sometimes the wearer needs less. This idea is already in development in firefighting clothing [14]. When the temperature rises, the actuators in the suit can create an isolation layer which protects the firefighter from the heat. What could also be a concept, but much less extreme, is self-rolling sleeves.

The last category in which actuated fabric could play a role is social life. When thinking about social life, the phone is nowadays the first thing people think of. A phone can already give haptic feedback by vibrating, but this can be extended to not only vibration in the pocket but actuation on different places on the body. This could give more information by using different actuation effects and different actuation locations. This can be done in combination with games to get a more immersive experience but also with notifications. An advantage of haptic feedback of phones in comparison with sound is that it is more unobtrusive for other people around. The actuators could be implemented in for example a shirt. When this shirt is worn, the user can get haptic feedback all

Figure 9 Active hugging vest [2]

around the upper body. By doing this, the user is even more connected to the device than ever before. This sounds beneficial, but there is a flip side. By wearing a shirt like this, the user is more connected to its phone than to the real world. Some people say this is already true for young people. Another take on fabric actuation connected to the users phone is showing this inseparable relation with the phone. A person can get hundreds of notifications a day. The user gets almost "drowned" in messages without even knowing how ''drowned'' they even are in their phone. By using a shirt with for example nitinol wire in it, this can be visible or feelable. This shirt can compress by the wires running around the torso. Every time the user gets a notification, the grip gets tighter. This could show how drowned people are in messages. This compression concept is already used in another project. Not by creating awareness for the amount of notifications on a phone, but for treating people (in this case children) with autism. The vest consists of two halves which can compress by using nitinol wire springs on either side. This can be seen in figure 9.

This creates the feeling of hugging which releases hormones in the brain that come free when an actual person is hugging. This gives the children less the feeling of anxiety [2]. This is addressing the mental health of people, but haptics could also be used to improve the physical health of people. Take for example posture. A bad posture can lead to backpain or shoulder pain. By giving feedback to the wearer about the posture in the form of haptics, the wearer could know where and how to adjust its position. When strong actuators are used, the wearer could even be forced into the right position.

Of course not all applications come without any ethical complications, especially in the education category. These complications will be discussed later in the paper. Later a complete ethical analysis is given which analyses all ethical risks involved with haptic feedback as technology.

5. Specification

In this chapter, the focus will be on what the setup can accomplish. The elaborate explanation of how every component is hooked up, is explained in the realisation

5.1. Capabilities of emulator

The eventual capabilities of the actuation of the emulator should be close to the electroactive polymers. This ideally entails every aspect of electroactive polymer. This results in a short list of requirements or specifications. To start off, the most obvious requirement is haptic sensation. The goal of the electroactive polymers is to produce haptic feedback. This means a sensation which can be felt. Secondly, the actuation should ideally be the same, which entails several requirements. One of the major advantages of electroactive polymers is the small formfactor of the actuation device. This means, eliminating the need for bulky motors or high voltage generators. This ensures that the total actuation setup remains light weight and therefore portable so it easier to integrate the actuator in clothes. Additionally, it should be possible to actuate the actuator accurately and reliably. Which means approximately every tenth of a volt should result in a stable force which does not fluctuate. When an emulator is chosen, it should be taken into account that the price of the emulator should not be too high. Ideally the emulator should be cheap to test as much as possible with the emulator. Finally, the emulator should generate the same amount of force as the polymers. Which according to research of early electroactive polymers is approximately 1.5 grams in for example a knitted sample.

5.2. Capabilities of the setup

The eventual setup is designed for more than only measuring force. It is designed to get a complete overview of the capabilities of nitinol wire. To start off, the setup should be able to measure the force. The force should be measured and then plotted by sending the data to the computer. The actuation of the wire relies on a view different parameters. These parameters should all be kept track of to gather as much data as possible. Nitinol wire actuates when the temperature of the wire gets higher. To achieve this, resistive heating is used. This means sending current through the wire which causes the wire to heat up. This is also used in for example soldering irons and other heaters. A higher voltage or a higher current results in a higher temperature. That is why it is important to measure these two parameters. To actuate the wire, a voltage source has to be hooked up to circuit which can deliver enough power, which is around 8W according to the tinkering process. The voltage should be measured with a maximum of approximately 3V. The current should be measured with a maximum of approximately 2A. As said, the high temperature is what makes the nitinol wire actuate. That is why this is one of the most important parameters to keep track of. Not only for the actuation accuracy, but also for safety. When the wire is integrated in clothes of fabric, the temperature should be precisely monitored in order to avoid injury or damage. The highest temperature which has to be measured is approximately 60 degrees at its maximum. However, the temperature is not meant to get this high but at its most extreme, this temperature should be possible to be measured.

6. Realisation

This chapter will focus on the setup. It will include circuit diagrams and It will describe iterations of the test setup and will give the result of each iteration.

6.1. The Sensors

To measure the force which the wire can create is done by the help of a strain gauge, also known as a load cell (CZL616C) which can be seen in figure 10.

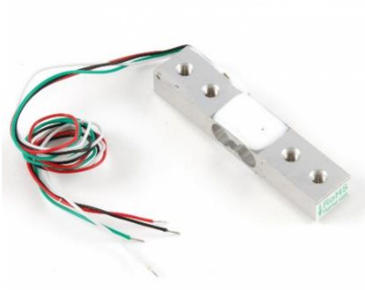


Figure 10 Load cell CZL616C (photo from datasheet)

This sensor can measure force and transform the force into a signal which can be digitalized. The strain gauge can measure up to 780 grams. This is needed in order to try to characterize and actuate the nitinol wire as accurately as possible. To supply the current and voltage, a lab bench power supply is used. A Velleman PS1503SB. This power supply is able to deliver 45W of power which is more than enough for this purpose. To measure the voltage, the analog input of an Arduino is used. This input can measure voltages up to 5 volts, with an accuracy of 0.0049 V. This is plenty enough for most of the experiments. When tinkering in the ideation phase, it became clear that not much more than 3.4 volt is needed. However, with the first knitted sample, the voltage was higher. A voltage divider was used to double the range but cut the resolution in half. To measure the current which is drawn from the power supply, two measurement methods could be used. The screen from the power supply could be monitored and then manually written down every time, or the current could be monitored automatically by using a sensor. Of course the second option was the most precise. Therefore a current sensor is used which can be wired up to the Arduino. To measure this, an ACS712 current sensor is used which can be seen in figure 11.

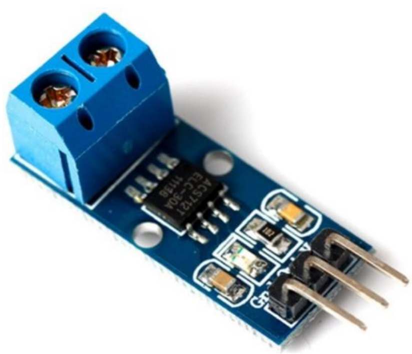


Figure 11 ACS712 (https://benselectronics.nl/acs712-5a-stroomsensor-meter/)

Figure 12 Thermistor (https://www.gmelectronic.com/thermistor-ntc-ntc640-10k)

A thermistor is used to measure the temperature of the wire or fabric. A thermistor is a variable resistor which changes its resistance according to the temperature. When the thermistor is hooked up in a voltage divider, it can measure the temperature simply and reliably.

All these sensors have to be wired up to an Arduino which can then send data to the computer, which then can be logged and plotted using Microsoft Excel. First the wiring of the thermistor is shown, then all the sensors with their corresponding Arduino are shown.

6.1.1.The temperature

The thermistor should be hooked up in a voltage divider with another resistor with the same resistance. This configuration is depicted below in figure 13.

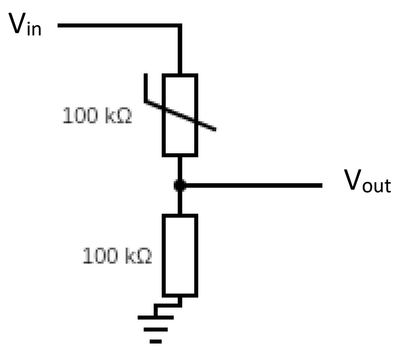


Figure 13 Schematic thermistor

6.1.2. The total circuit

For the strain gauge, a sensor shield is used. This shield is depicted in figure 14. This shield is designed by Edwin Dertien and contains a lot of connected sensors which is meant for educational purposes.

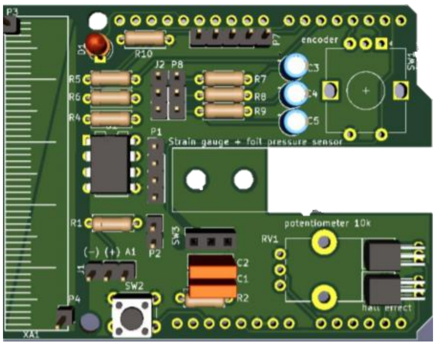


Figure 14 sensor shield (http://wiki.edwindertien.nl/doku.php?id=education:sensors:tools)

This makes it easy to implement the strain gauge. However, this also poses a drawback. Because the shield contains a lot of sensors, it also means that a lot of analog ports are occupied by sensors which are not needed for the purpose of testing actuators. This results in the need for a second Arduino. There is one input left on the shield. This input is used to measure the current flowing through the wire. The other two sensors, the thermistor and the voltmeter, are connected to another Arduino.

Two Arduinos means that two different datasets are generated. Of course they differ in data, but one thing where they also differ is timing. When both Arduinos are collecting only raw data, it is impossible to link the data sets together timing-wise. The rows do not match. This can be checked by adding a timer function in the code, which tracks the time which has passed since the Arduino reset. So if the Arduinos are reset at the same time, the value of the timers would be approximately the same. After some tries of pressing the reset buttons of both Arduinos at the same time, it quickly became clear that it difficult to time the reset at the same time. That is why the reset pin on the Arduino is used. When this pin is grounded, the Arduino resets. The wires coming from the Arduino are joined and then attached to a button which is connected to ground. When this button is pressed the reset pins of both Arduinos are connected to ground which means they both reset at the same time. When this is considered, the circuit looks as depicted in figure 15.

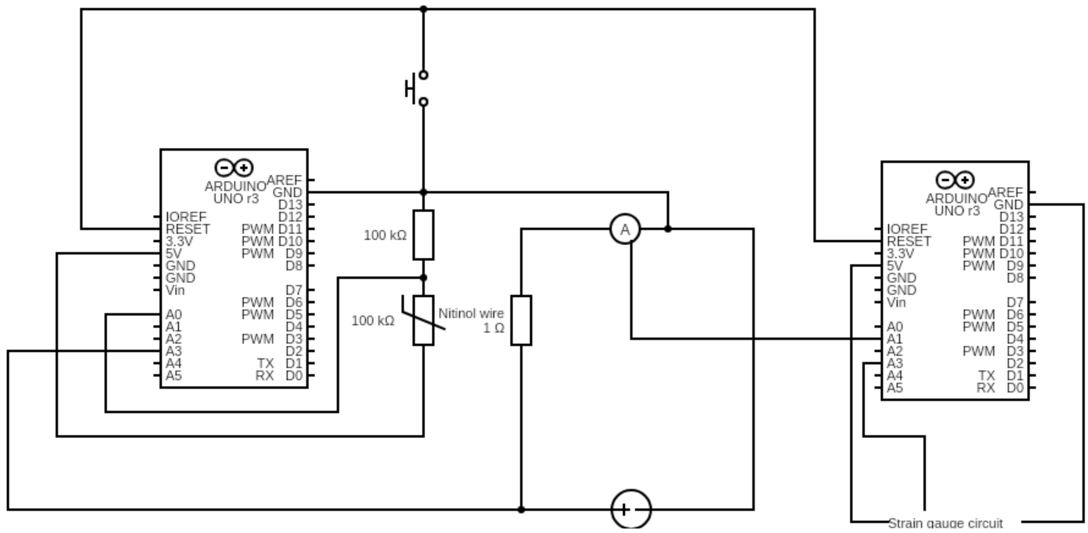


Figure 15 Total circuit

6.2. The physical setup

Only these components do not make a setup yet. All these components need to be connected to a base. Also the nitinol wire should be connected to this base. The first concept was designed such that the manufacturing was relatively fast and use not too much material because the setup will be 3D-printed. It also should not be unnecessary complex. With this in mind the following base was modelled as is depicted in figure 16.

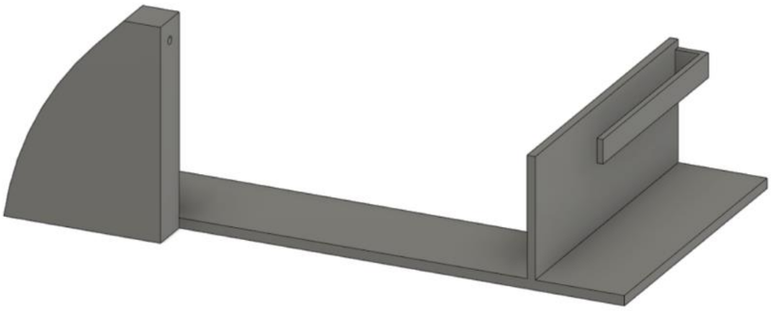


Figure 16 Base of setup V1

This design is simple and does not consume a lot of plastic. The Arduino with the strain gauge attached can be slid in on the right and is held into place with a clamp. This is where one side of the nitinol wire is going to be attached. On the other side a hole is placed. This hole can be used to screw in a hook which can be used to hold the nitinol wire. The same has to be done on the side of the strain gauge because the wire can not be directly attached to the rectangle shape. This is where a bracket should be designed to hold the wire in place on this side. This bracket can be seen in figure 17 and 18. This bracket also contains a hole to screw in a hook.

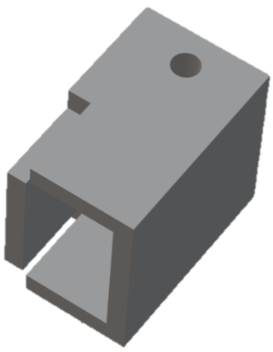


Figure 17 Bracket for strain gauge

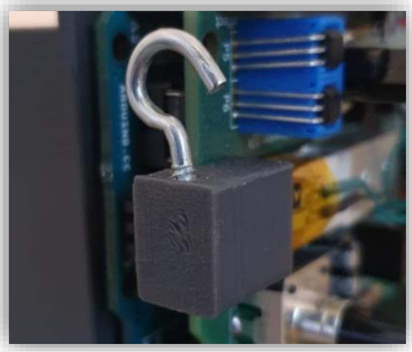


Figure 18 Photo brakcet for strain gauge

This concept worked when looking at the fitment and principle. The force could be measured when the Arduino was in place and a nitinol wire was attached. However, when moving to thicker wires which can exert more force on the setup, the setup collapsed under the force created by the wire. This can be seen on figure 19.

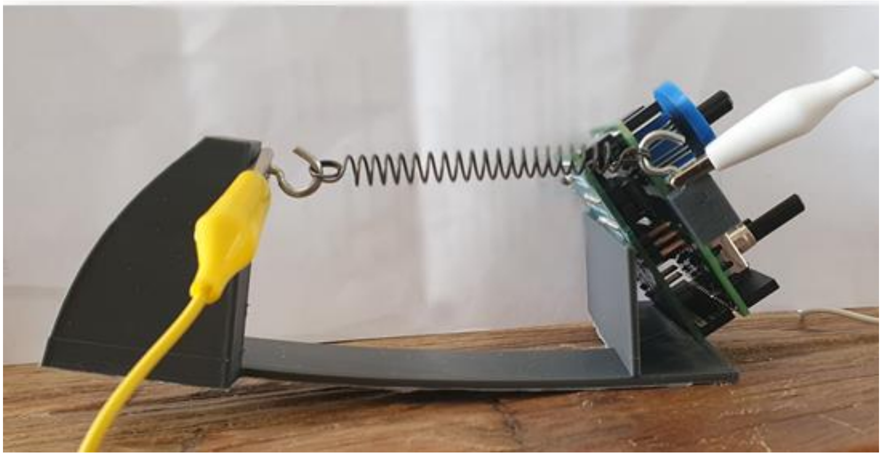


Figure 19 Collapsing of first setup

This resulted in a revision of the design. A solution had to be found not only for the bending construction, but also for preventing the Arduino from dislocating. A few simple tweaks had to made to the design, which resulted in a longer printing time and more material use, but a much sturdier construction. The model for this version is depicted below in figure 20.

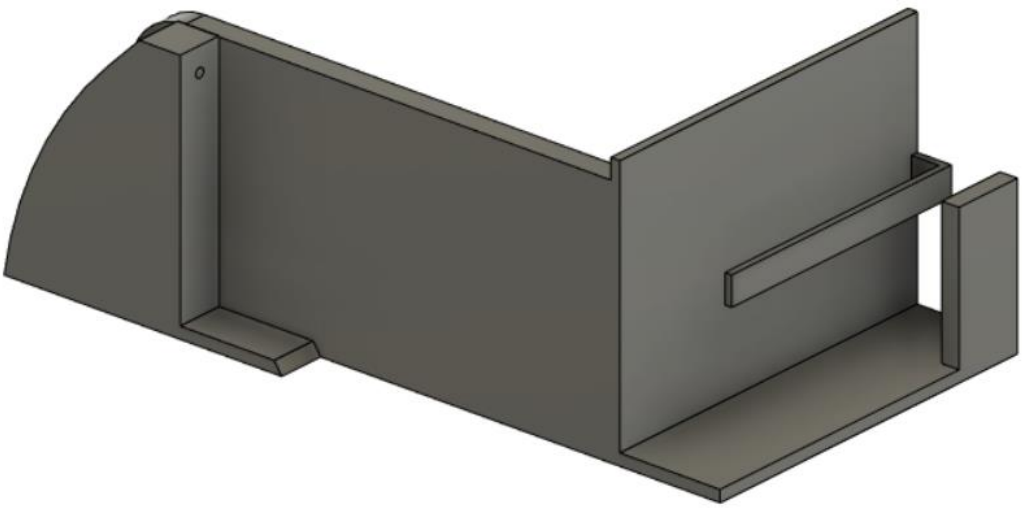


Figure 20 Test setup V2

This design has a wall which makes it a lot sturdier. It also has a back support for the Arduino board. In figure 21 below can be seen what the setup looks like (without the second Arduino).

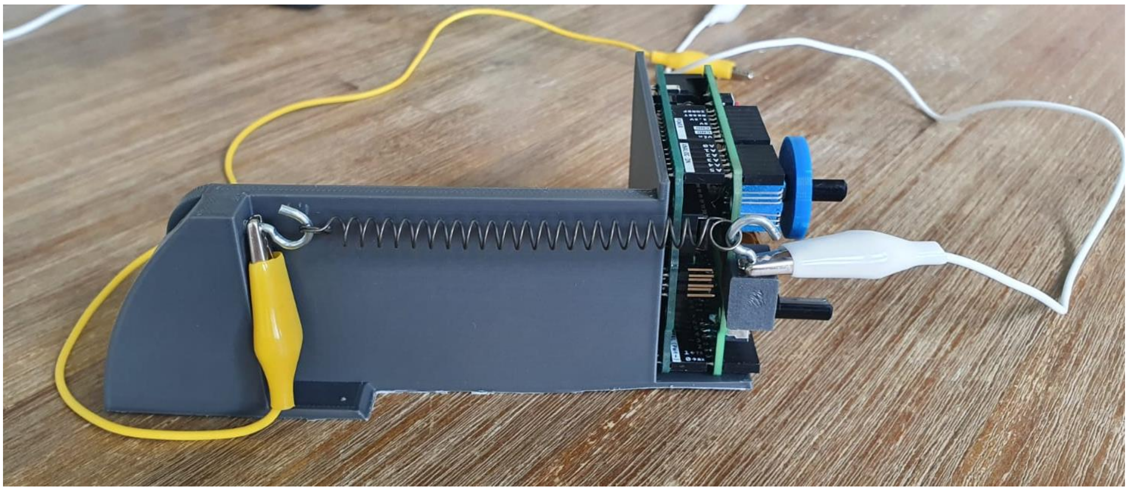


Figure 21 setup after revision

The complete setup with the second Arduino and all the wiring can be seen in figure 22.

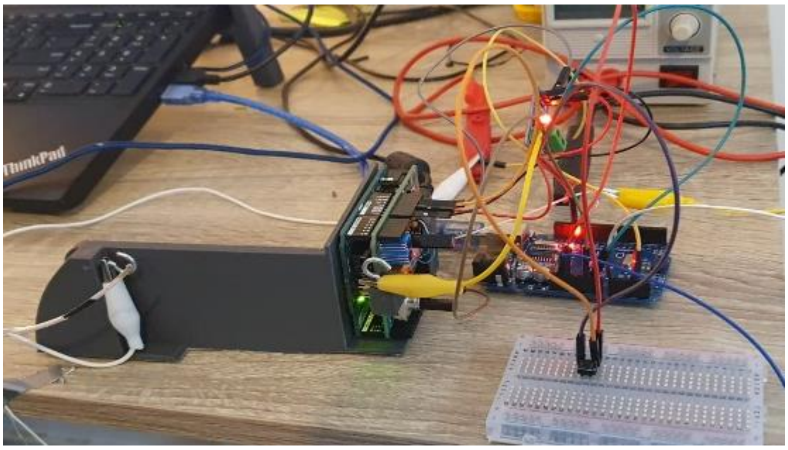


Figure 22 Total test setup

As seen in figure 21, a nitinol spring is attached on both sides of the setup by using hooks. This was the first thing which should be tested. The reason for this is that the spring shape, according to the literature research, exerts the strongest force. When the setup "survives" the stress of the spring, it should withstand the force of the other shapes. As stated before, different diameters of wire result in different pulling forces. Every diameter has its advantages and disadvantages. For implementing wire onto fabric, the wire can be thicker than when it has to be processed in the fabric. As mentioned in the literature review in the second chapter of this paper, a thickness of 0.13 millimetre seems to be a good trade-off between enough effect and the relative ease to process, but does not have the largest effect. That is why multiple thicknesses are researched. The first thickness which will be tested is the wire with a diameter of 0.15 millimetre, this is close to the 0.13 millimetre. Because this is not the most effective thickness, also a thickness of 0.50 millimetre is used to see what force can be exerted at this thickness. As it turned out, the wires are not easy to attach to the hooks. They are very stiff. To solve this, the wire is threaded through the hole of the hook. Then the hook is screwed in again to keep the wire in place. The result can be seen in figure 23.

Figure 23 Setup with the wire in place

An advantage but at the same time a disadvantage of a thermistor is the small formfactor. The shape makes it ideal to put at places where there is not much room. The disadvantage is that the contact surface is small which makes it difficult to measure the temperature accurately. This can be solved by increasing the surface contact. This is done by adding thermal compound which can also be found in computers to conduct heat of the processor. This thermal compound can be seen in figure 23 by the grey substance applied to the thermistor and the wire.

6.3. Knitted samples

Not only simple loose wires should be tested, but also the incorporation into the fabric. For these experiments nitinol wire is used with a diameter of 0.15mm. This is really thin wire which makes it easier to manufacture by hand into a knitted structure. For the experiments, different ways of integrating the wire are used to compare the strength. The first way which is used to incorporate the wire is by knitting the nitinol wire with a right stitch. This stitch is used because it can be compared to the research where testing has already been done on the early electroactive polymers [9]. This can be seen in figure 24 In figures 25 to 28 can be seen step by step how this is done for the first sample with nitinol wire.

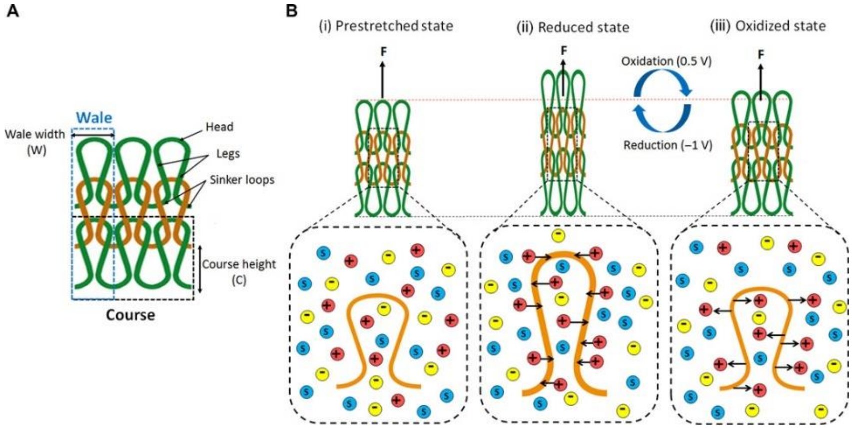


Figure 24 knitted EAP sample [9]

Figure 25 step one of knitting process

Figure 26 step two of knitting process

Figure 27 Step three of knitting process

Figure 28 Step four of knitting process

This way of knitting resulted in the sample which can be seen in figure 30. A technical specification sheet can be found in Appendix 11.4.

Figure 29 Resulting sample

The setup for testing this sample can be seen in figure 31.

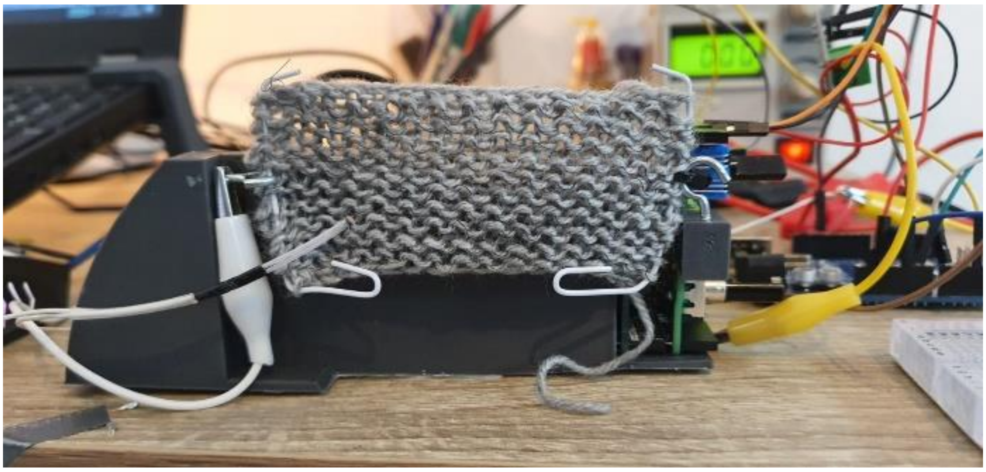


Figure 30 Setup with first knitted sample

When this sample was tested, it became clear that a second sample was needed. Some aspects of integrating the whole fabric with nitinol wire were overlooked. Because the actuation now consists of one long wire, the voltage should be higher to heat up the whole fabric. This poses another problem. The wire heated up very locally which caused the wire to heat up to a very high temperature at certain spots. This caused the yarn to smoke and eventually melt as can be seen in figure 32.

Figure 31 Burnt first sample

The yarn melted at both contact points on either side. A second sample or iteration should contain a shorter strand of nitinol wire or multiple short wires in order to actuate the fabric. This is exactly what is done in the second sample. Only one strand is used to research if the actuation now could be done without the wire getting too hot. The knitting process is basically the same as seen in figures 25 to 28 however, in the second sample the strand of nitinol wire is shorter and the nitinol wire is pulled straight to eliminate the stretch, so the pulling force can be measured.

Also, the hight of the sample is made lower because this does not influence the pulling force since the wire is only knitted in the middle. A section of the second sample can be seen in figure 33.

Figure 32 Second knitted sample

6.4. Qualitative research sample

For a wearable sample, the thicker wire is used. The thicker wire is laced into the fabric to get the best feeling of actuation. The wire is fixed at both ends in the fabric. This is qualitatively measured to research if the actuation can be felt. First the fabric is laid down on a flat surface as depicted in figure 34.

Figure 33 fabric before actuation

This results in shrinkage and thus actuation as seen in the next figure, figure 35.

Figure 34 Fabric after actuation

Figure 35 Sleeve with one nitinol wire

This pattern was chosen for multiple reasons. The first reason is that the fabric has more friction thanks to the double stitch. This makes the fabric more responsive to the actuation wire, in this case the nitinol wire. The second reason is protecting the skin. By having the largest part of the wire outside of the sleeve, the inside only has the small contact points, this reduces the heat on the skin. The result can be seen in figure 36.

To see if the force could be doubled, two wires are integrated in the fabric. The result can be seen in figure 36. The choice of using two wires instead of one wire is based on the result of the experiment with the knitted sample.

Figure 36 Sleeve with two nitinol wires

When one long wire is used, a higher voltage is needed which causes some parts of the wire to become extremely hot. When two wires are used in parallel, it reduces the length and therefore preventing the wire from heating up too much. The actuated and the non-actuated sample can be seen in figure 37 and 38 respectively.

Figure 37 Sleeve with two nitinol wires: no actuation

Figure 38 Sleeve with two nitinol wires: during actuation

6.5. Software

This subchapter explains the code in plain text words. The code itself of the Arduinos can be found in Appendix 11.2 and 11.3. For each Arduino a different appendix.

6.5.1. Strain gauge and current sensor

All the software for this setup is made by using the Arduino IDE software. As previously stated, the setup consists of two Arduinos due to the shortage of analog ports. This means two different codes which both handle different sensors. Firstly, the code of the first Arduino. This Arduino contains the strain gauge and the current sensor. As stated before, both Arduinos start a timer, which is used to synchronise the data streams. For the current sensor, the values fluctuated very much and did not create a stable output. After some research, it became clear that this was not an out of the ordinary occurrence. One article written by *EG projects* gave a solution by averaging 150 samples and thus create a stable output. For the strain gauge some calibration has to be done in order to get the right readings. When wiring up a strain gauge, only raw values between 0 and 1024 are given. This is not useful for getting an idea of the force. Because the strain gauge is linear, it can be easily calibrated by taking two known weights. The raw values have to be checked at both weights and then a map function can be applied. When this is done, the strain gauge is calibrated and every weight (under the limit of the gauge) can be measured.

6.5.2. Voltage meter and temperature sensor

The voltmeter is the most basic use of an analog input of the Arduino, because this is what it is meant to do. Voltage comes in and is translated to raw values between 0 and 1024. This has to be translated back to voltage. A raw value equal to 1 is equal to 0.0049 V. So 0.0049 times the raw value equals the voltage. In case of the first knitted sample, this value is multiplied by two. For the thermistor however, a more difficult approach is needed. A formula or model specially developed for a semiconductor at different temperatures. It is called *the Steinhart–Hart equation*. The formula and variables for the specific thermistor which is used in this setup is already given by *Circuits Online*. Then the only thing which is left to do is connect the code of the thermistor with the code of the voltage meter and make sure that both delays of both Arduinos are the same so the data streams are running synchronously.

7. Evaluation

This chapter will evaluate the results which have been gathered in the realisation of the experiments. It will also discuss if the requirements are met.

7.1. Single wires

As mentioned before in the paper, the experiments were done with multiple wires of different diameters. In figure 39 the results of the thinnest wire, 0.15 millimetres are depicted.

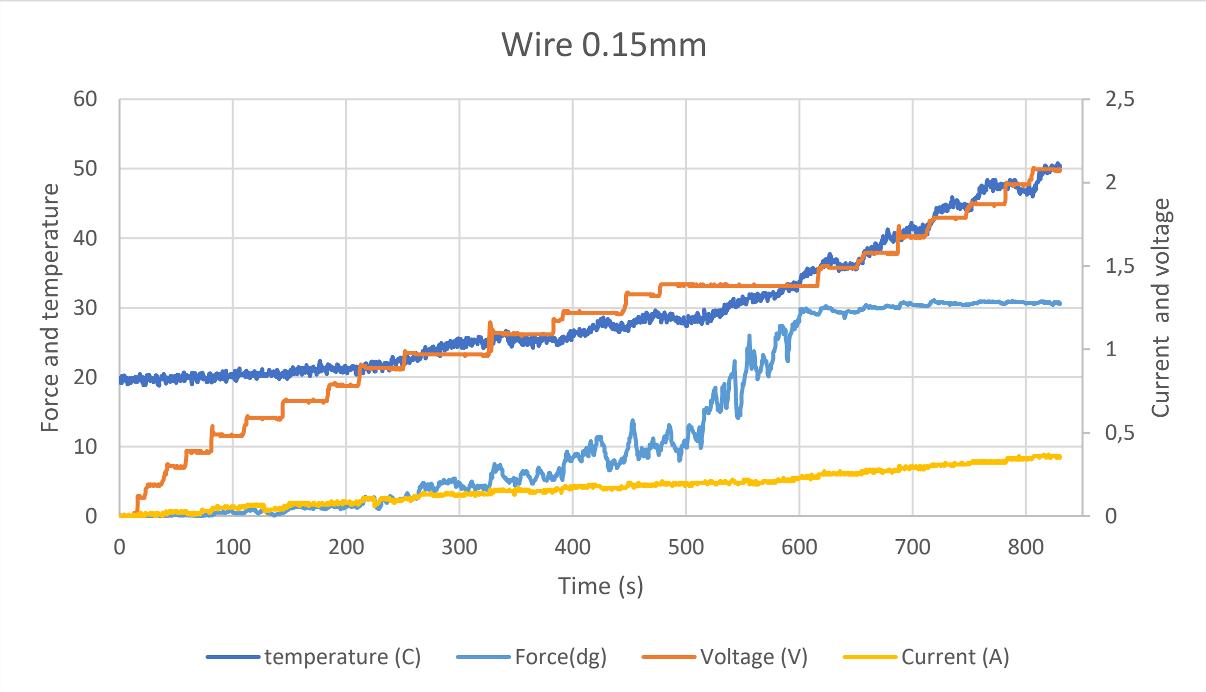


Figure 39 Straight 0.15mm wire: all parameters

In this figure all four parameters are depicted as a function of time. By doing this, it can be seen how all parameters relate to each other. But the most important relation is the relation between voltage and temperature. Voltage can be precisely controlled, so if there is a clear relation between these parameters, the force can be precisely controlled. In figure the relation between voltage and force is given.

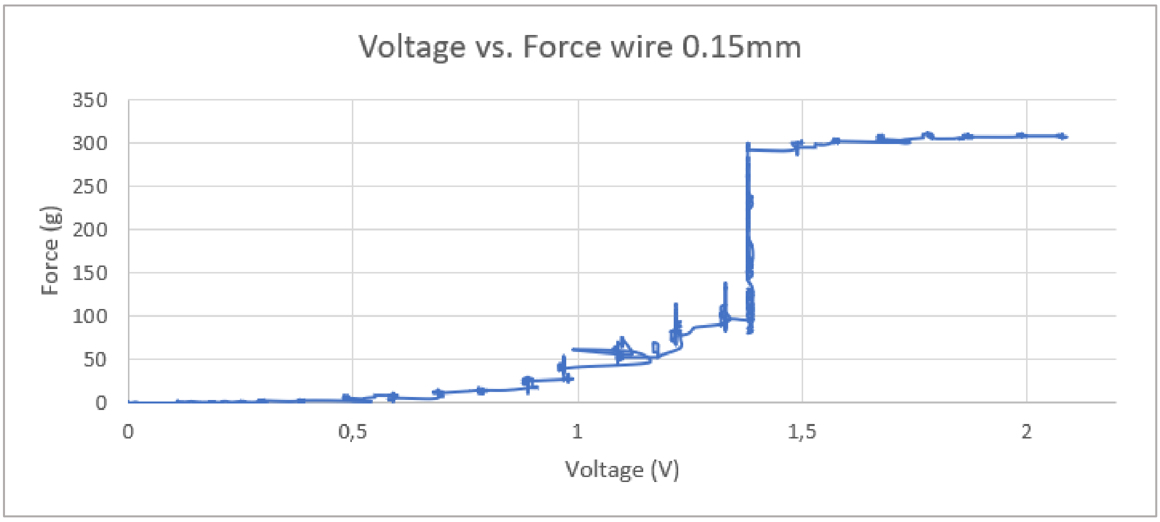


Figure 40 Loose single wire 0.15mm

In figure 41 can be seen how the loose wire of 0.5mm is characterized including all the parameters.

Figure 41 Loose single wire 0.5mm: all parameters

In figure 42 is depicted how the voltage and force relate to each other.

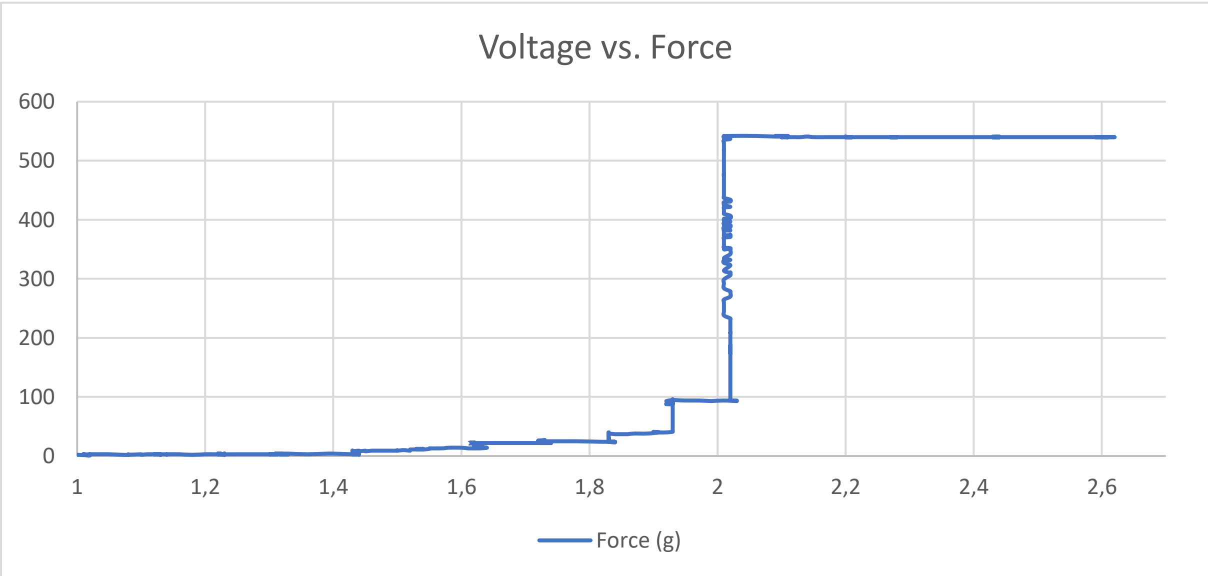


Figure 42 Loose single wire 0.5mm: Voltage vs. Force

7.2. Spring shape

In this subchapter, the spring is researched. According to the literature, by training the wire in a spring shape, it should theoretically be the largest pulling force. Just like the loose wires, in the first figure, figure 43, all the parameters are given.

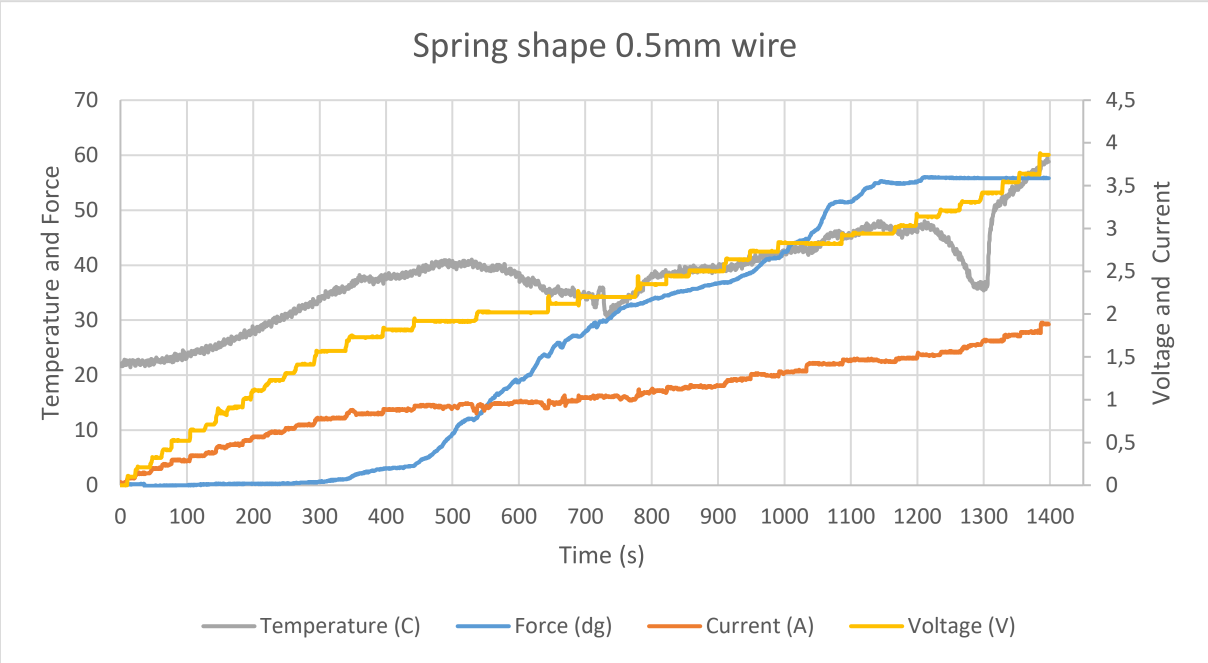


Figure 43 Spring shape 0.5mm wire: all parameters

In figure 44, the voltage is related to the force, to see how accurately this spring can be actuated.

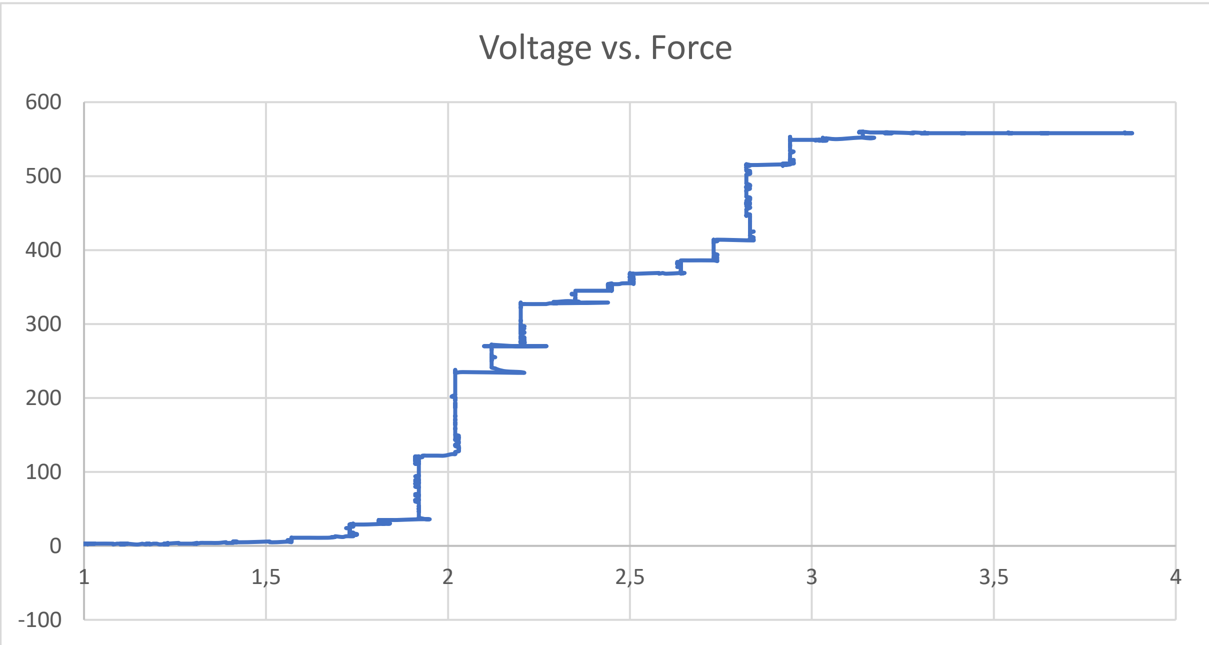


Figure 44 Spring shape 0.5mm: voltage vs. Force

7.3. Knitted samples

Loose, single wires are the basis of the actuation of fabric. The next step is to process the wire into the fabric. That is why it is important to see how and if the fabric generates force and how precisely the wire and therefore the fabric can be actuated. All the parameters of the first knitted sample are depicted in figure 45.

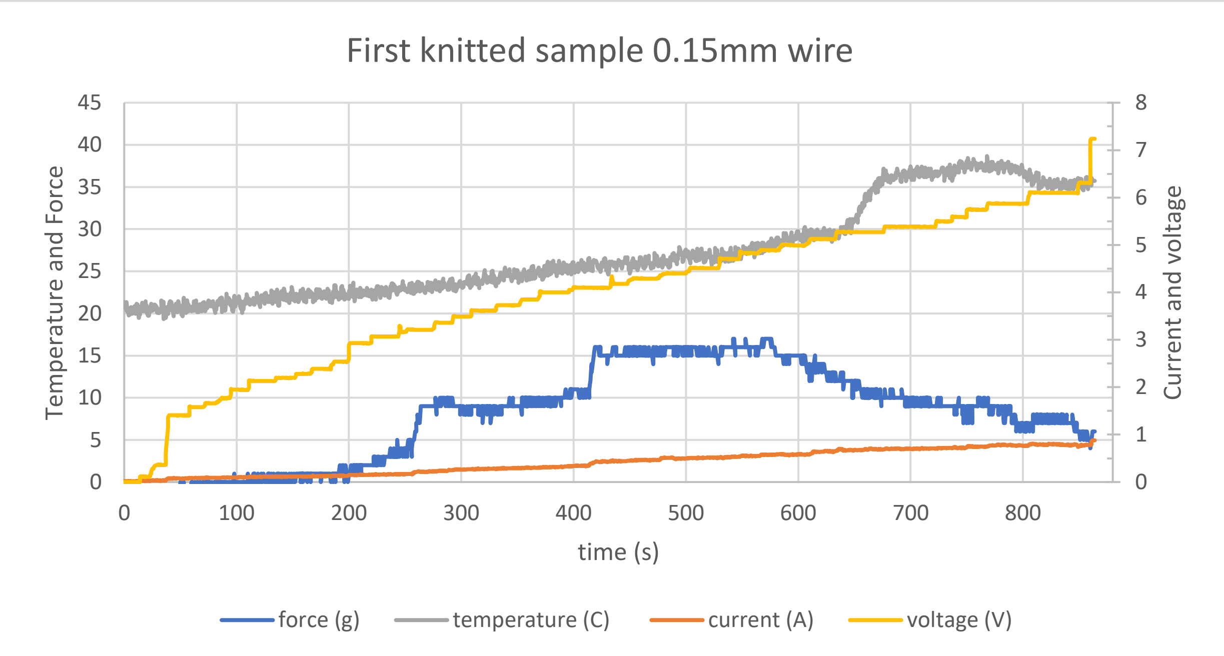


Figure 45 Knitted sample 0.15mm wire: all parameters

The voltage-force relation of the first knitted sample is depicted in figure 46.

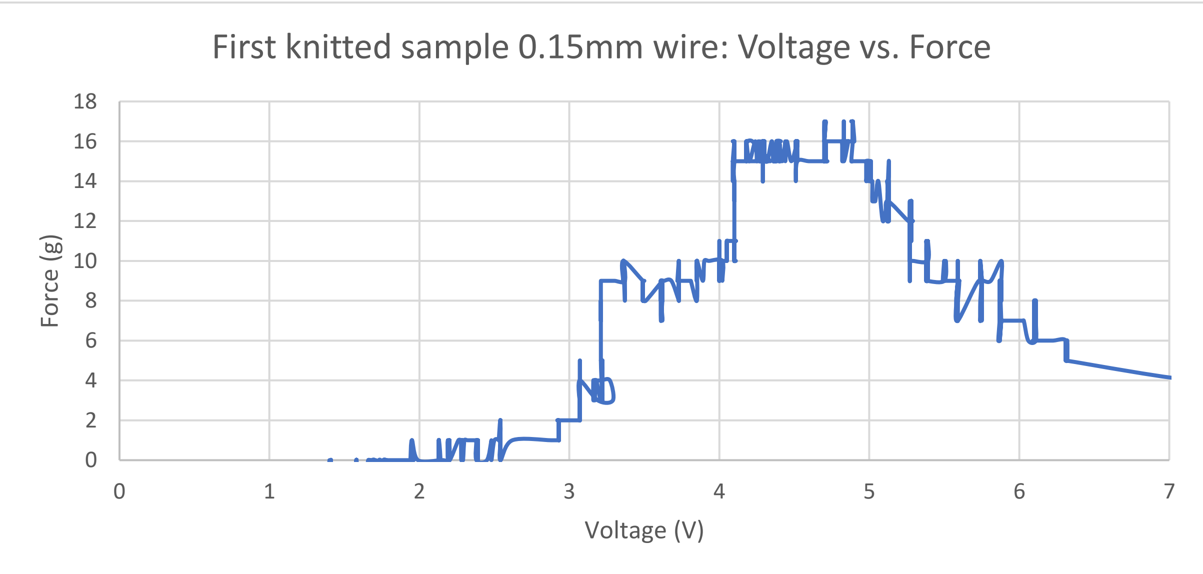


Figure 46 First knitted sample 0.15mm wire: voltage vs. force

After the first sample, a second sample was created. The second sample with all its parameters can be seen in figure 47.

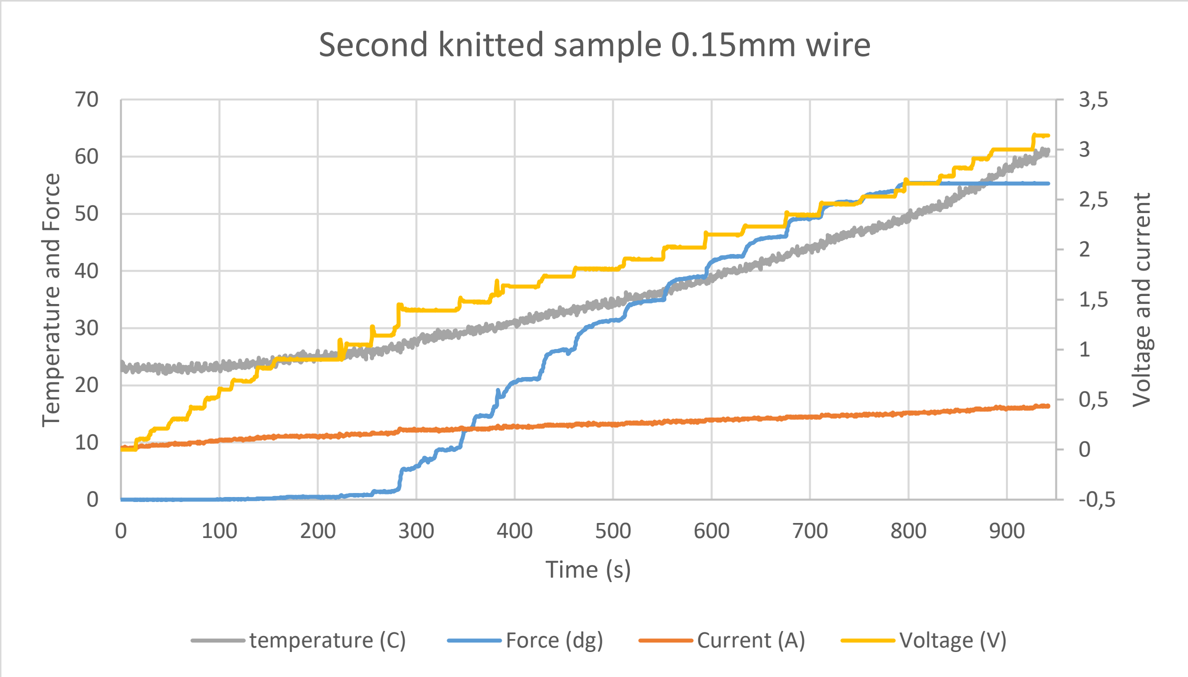


Figure 47 Second knitted sample: all parameters

The relation between voltage and force of the second sample can be seen in figure 48.

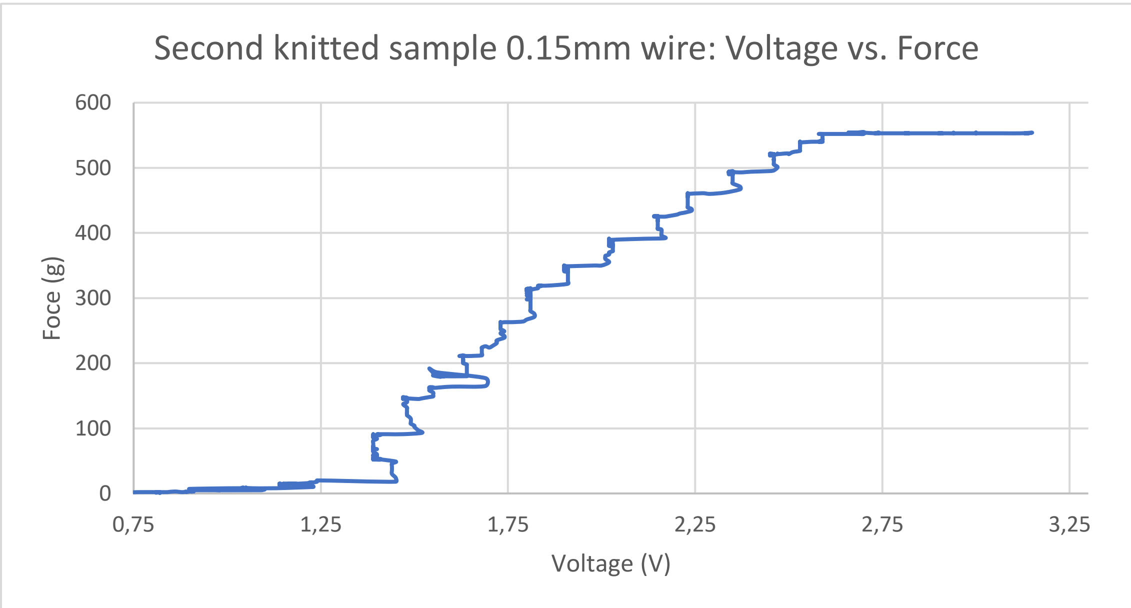


Figure 48 Second knitted sample: votage vs. force

7.4. Requirements

7.4.1. Sensing

This chapter will evaluate if the requirements are met and if the setup can fulfil its purpose. First of all, the force had to be measured. One of the most important aspects of the setup. For this purpose, the setup has proved itself capable of doing this task. The force could be measured accurately and consistently. The strain gauge gave the same result when regularly calibrated in between experiments to ensure the accuracy. The mount on the strain gauge also fulfilled its purpose. Not only to function only for what it was designed for, but also additional functionality. The mount was designed for only the spring to attach, but as it turned out, also the wire and knitted samples could be attached. The current was measured by a current sensor which, after some tinkering in the code, also worked perfectly. In the beginning, the value was much to fluctuating to get a nice result. Eventually this was fixed. The value was compared to the current value given by the lab bench power supply to check if the sensor was accurate enough. The same yields for the voltage which was constantly compared to the voltage value on the lab bench power supply. For measuring the temperature, a thermistor was used which also proved itself capable of reliably measuring the temperature. This accuracy was checked by putting the thermistor next to the, already calibrated thermistor on the (heated) print bed of a 3D-printer. To conclude the sensing capabilities of the setup, it can be said that the setup conforms to the requirements. It senses what it should sense and does so accurately and reliably.

7.4.2 Actuation

Next to the sensing capabilities, the actuation was also an important aspects of the setup. Overall it can be seen in the realisation that actuation was possible. Forces are created by heating up the wire. However, the accuracy and precision varies a lot. For example, the loose single 0.5mm wire in figure 41 has a very steep curve in the voltage-force relation. This means that precise actuation is very difficult to achieve since a low increase in voltage already creates a very high force increase. When this is compared to the second knitted sample in figure 48, where the actuation is much more linear in the voltage force relation, it can be said that the latter can be controlled much more precise and accurate. So to conclude the actuation part of the evaluation, it can be said that the precision and accuracy is very dependent on the form or incorporation method of the wire.

8. Conclusion

This chapter will describe the answer of the research question: How can the implementation of electroactive polymers in fabric be emulated by the use of other actuators? This question will be answered by looking back at the requirements and results of the test setup.

8.1. Result of test setup

The test setup made clear that the behaviour of the wire varies a lot because it depends on a lot of parameters. This does not only yield for the force generated with the actuation but also for the accuracy and precision the wire can be actuated. The precision and accuracy of actuation can be seen by looking at the graph in which voltage is plotted against the force. Ideally, when a voltage is set, a corresponding force should be generated and a small increase in voltage should create a small increase in force. This is best visible when comparing the plot in figure 41 with the loose wire with the graph in figure 48 with the knitted sample. In the graph with the loose wires, the graph becomes infinitely steep. This means precise control of the force is not possible in this area. When a voltage of 2 volt is applied on a 0.5mm thick nitinol wire, the voltage can either be 100 grams or 540 grams. This makes it very difficult to control. The opposite is true for the graph of the second knitted sample. This graph is stepwise and thus the force can be controlled precisely by controlling the voltage. The difference in the graph of the loose single 0.15mm wire and the 0.15mm wire in the fabric could be caused by the insulating property of the yarn. By encapsulating the nitinol wire into the yarn, it can hold much more heat, which conserves the temperature more in the wire without dissipating the heat as much to the surrounding air. This may also be the cause of the much higher force created by the wire in the knitted sample. The first knitted sample generated the smallest force. However, this force comes the closest to the force which can be generated by the electroactive polymers. It should be noted that the force is 10 times as high but it gives an idea of what the potential is of electroactive polymers.

A hypothesis formed based on the literature is that nitinol wire in a spring shape can create the largest force. This is where the single straight wire with a thickness of 0.5mm can be compared to the 0.5mm wire formed into a spring shape. The graph of the loose straight wire can be seen in figure 42. The graph of the spring shape in figure 44. The maximum force of the straight wire is 540 grams. The maximum force of the spring is 560 grams. This is indeed a difference which corresponds to the predictions based on the literature research.

8.2. Qualitative research

For researching the qualitative side of the research, the sample with thicker fabric was used. In this fabric, the 0.5mm thick nitinol wire was integrated. This qualitative research was done to investigate if the actuation was perceivable. This was in fact the case. However, the force of one wire was perceivable but not very strong. This was improved by using two wires. By doing this, the force was perceivable and quite strong. However, as mentioned in the previous subchapter, it was not possible to actuate the wire very accurately. The fabric used for the sleeve does not have insulating properties. This means the voltage-force curve looks like the one depicted in figure42. Thus, it feels like the actuation is either ’on’ or ’off’, but nothing in between. The temperature reached no more than 51 degrees Celsius. The temperature could get higher but the force does not get stronger, so there is no point in heating up the wire more than 51 degrees. This did not feel uncomfortable to the skin.

8.3. How can the implementation of electroactive polymers in fabric be emulated by the use of other actuators?

It can be concluded that nitinol wire can be used as emulator for electroactive polymers, provided some remarks. For the most accurate actuation, the wire should be insulated by for example knitting it together with yarn. Furthermore, the length should be taken into account. When the wire is too long, it becomes too hot, which can damage the fabric or cause injury to the wearer of the fabric. It also should be noted that the force of the nitinol wire is larger than the electroactive polymers but it can give an idea of what the potential of the polymers is.

9. Future work

This chapter will elaborate on what can be researched further. In other words, some recommendations for future work which will elaborate more on the subject.

To elaborate this research, more knitting patterns could be designed. Due to hardware constraints it was not possible to integrate the actuator with complex knitting or sewing patterns. There could be knitting patterns which can exert a greater force. These patterns could then be integrated into sleeves which can then be individually tested to research which patterns create a more perceivable sensation.

In this research only the horizontal force is measured. A force which the actuator can actuate in a horizontal position where every end of the actuator is attached to the setup. This gives insight in how much pulling force can be generated. In some use cases, this is sufficient. However, when making a sleeve or clothing which can be actuated, the pressure is applied in a circular manner. To rephrase, the pressure which is produced on for example an arm. For this purpose, a test setup can be made, which can measure this pressure. An example of such a setup could be a pocket of air or water. This pocket preferably has a cylindrical shape with approximately the size of an arm. Around this pocket or cylinder, the actuator can be placed. The pressure or force which is created by actuating the actuator can be measured by measuring the pressure in the pocket of air or water. This gives a better indication of how much pressure is really applied when the actuator is used in its intended shape.

The force of the actuator could be increased by "training" the wire into a bending or a small circle shape. This could lead into a stronger pressure force. What also could be useful is researching the starting pressure or tension of a sleeve. By doing this, the force could be more perceivable.

10. References

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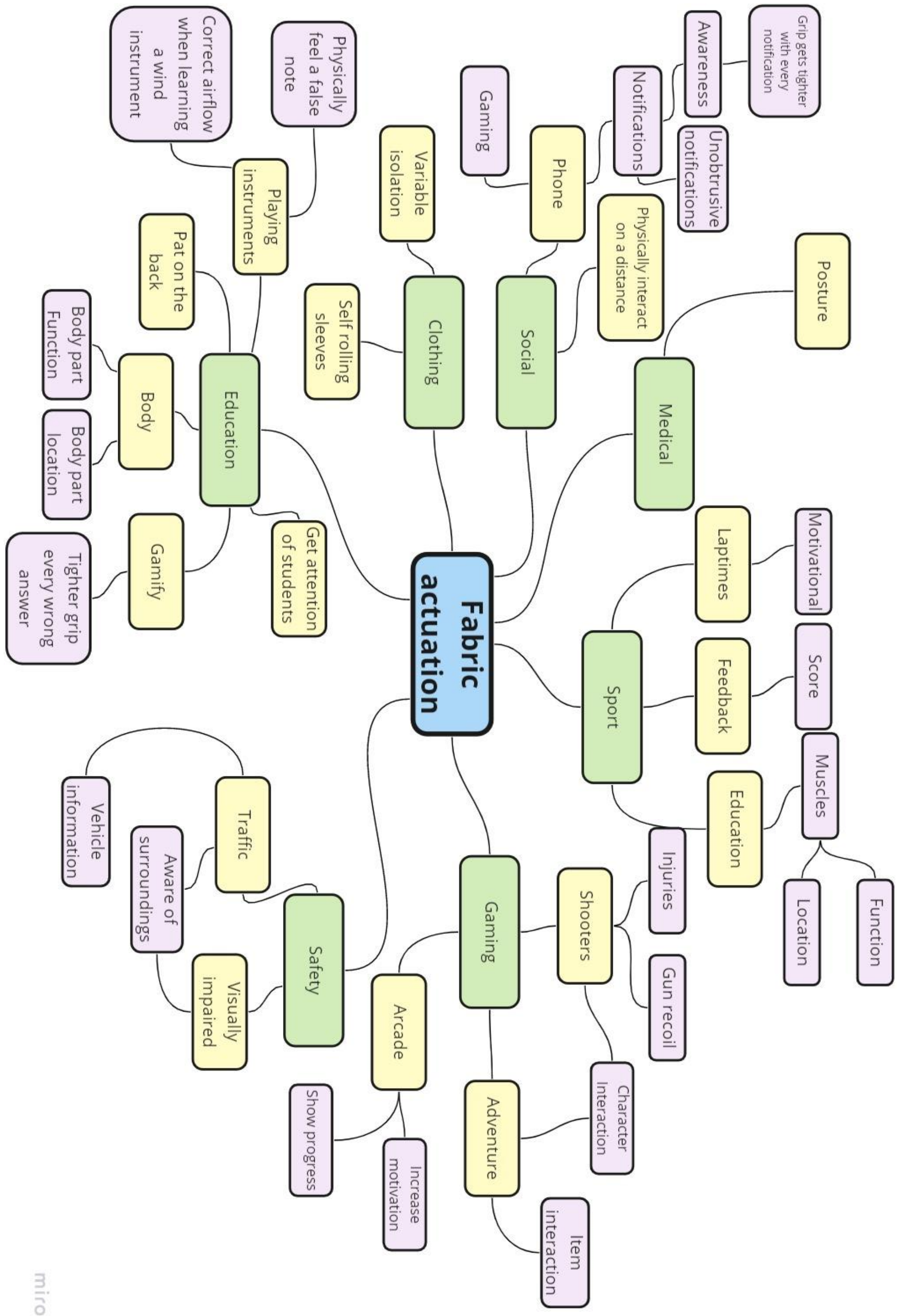
11. Appendices

11.1. Ideation mind map



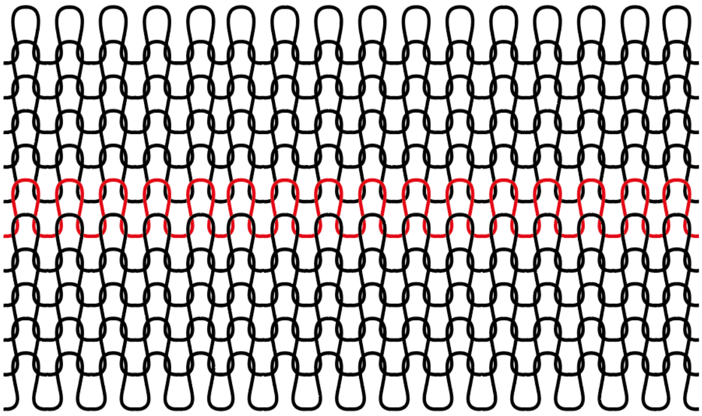
11.2. Code Arduino 1 (Current sensor and Strain gauge

```
/*Combined code for strain gauge and current sensor
   code of current sensor based on the code of EG projects from:
   https://www.engineersgarage.com/arduino/acs712-current-sensor-with-
arduino/
*/

unsigned long time;

void setup() {

  Serial.begin(9600);
  Serial.println("start");
}

void loop() {
  time = millis();
  unsigned int x = 0;
  float AcsValue = 0.0, Samples = 0.0, AvgAcs = 0.0, AcsValueF = 0.0;
  int sensorValue = analogRead(A3);
  int gram = map(analogRead(3), 23 , 780, 0, 423);

  for (int x = 0; x < 150; x++) { //Get 150 samples
    AcsValue = analogRead(A1);     //Read current sensor values
    Samples = Samples + AcsValue;  //Add samples together
    delay (3); // let ADC settle before next sample 3ms
  }

  AvgAcs = Samples / 150; //Taking Average of Samples

  AcsValueF = ((AvgAcs * (5.0 / 1024.0)) - 2.48 ) / 0.185;

  Serial.print(time);
  Serial.print("\t");
  Serial.print(gram-13);     // print the number
  Serial.print("\t");
  Serial.print(AcsValueF);//Print the read current on Serial monitor
  Serial.println();
  delay(50);
}
```

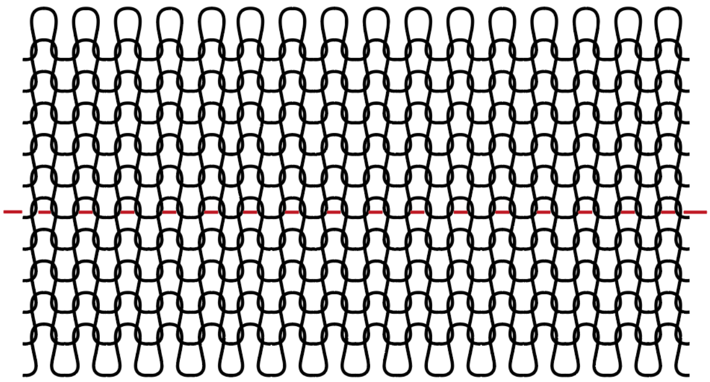
11.3. Code Arduino 2 (Voltmeter and thermistor)

```
/*
Code of voltmeter and thermistor combined
Code comes from https://www.circuitbasics.com/arduino-thermistor-
temperature-sensor-tutorial/
*/

unsigned long time;
int ThermistorPin = 0;
int Vo;
float R1 = 10000;
float logR2, R2, T;
float c1 = 1.009249522e-03, c2 = 2.378405444e-04, c3 = 2.019202697e-07;

void setup() {
  Serial.begin(9600);
  Serial.println("start");
}

void loop() {
  time = millis();
  int input = analogRead(A3);
  float voltage = (0.0049 * input)*2;

  Vo = analogRead(ThermistorPin);
  R2 = R1 * (1023.0 / (float)Vo - 1.0);
  logR2 = log(R2);
  T = (1.0 / (c1 + c2 * logR2 + c3 * logR2 * logR2 * logR2));
  T = T - 273.15;
  //T = (T * 9.0)/ 5.0 + 32.0;
  Serial.print(time);
  Serial.print("\t");
  Serial.print(T);
  Serial.print("\t");
  Serial.println(voltage);

  delay(520);
}
```

11.4. Fabric specification first knitted sample

FABRIC SPECIFICATION TEMPLATE_ GARTER STITCH	
FABRIC CHARACHTERISTICS:	
PRODUCT:	Sample 1 for test setup
STITCH NAME:	Garter Stitch
EFFECTIVE FABRIC WIDTH and HEIGHT (in cm):	8,5 x 4,5 cm
TYPE OF KNIT: weft/warp/jacquard etc.	Weft knit
GAUGE (stitches per inch)	4 stitches per inch
RAW MATERIAL COMPOSITION Co/Pes or Wool/Acril etc.	Acrylic yarn + NiTiCu shape memory wire
FABRIC WEIGHT (in g/m2):	9,88/38*100= 26 g/m2
DENSITY nr of needles and rows:	16 needles, 11 rows (8,5 x 4,5 cm)
YARN NUMBER (Nm or Ne):	5 Nm
FABRIC THICKNESS (In mm):	3 mm
DYEING:	☒ Fibre dyed ☐ Yarn dyed ☐ Fabric dyed ☐ Garment dyed
KNIT STRUCTURE	PHOTO KNIT
 Front + Back	
DATE: 6-6-2020	

11.5. Fabric specification second knitted sample

FABRIC SPECIFICATION TEMPLATE_ GARTER STITCH	
FABRIC CHARACHTERISTICS:	
PRODUCT:	Sample 2 for test setup
STITCH NAME:	Garter Stitch
EFFECTIVE FABRIC WIDTH and HEIGHT (in cm):	8,5 x 2,5 cm
TYPE OF KNIT: weft/warp/jacquard etc.	Weft knit
GAUGE (stitches per inch)	4 stitches per inch
RAW MATERIAL COMPOSITION Co/Pes or Wool/Acril etc.	Acrylic yarn + NiTiCu shape memory wire (only in row 8)
FABRIC WEIGHT (in g/m^2):	9,88/38*100= 26 g/m2
DENSITY nr of needles and rows:	16 needles, 16 rows (8,5 x 4,5 cm)
YARN NUMBER (Nm or Ne):	5 Nm
FABRIC THICKNESS (In mm):	3 mm
DYEING:	☒ Fibre dyed ☐ Yarn dyed ☐ Fabric dyed ☐ Garment dyed
KNIT STRUCTURE	PHOTO KNIT
 Front + Back (red line = NiTiCu shape memory wire)	
DATE: 6-6-2020	