eSkin

Extended Body / Perception.
Wearables for real world cyborgs.

Prof. Eva Hornecker
Dipl. Hannes Waldschütz
Michaela Honauer

Anton Brams	118026
Aziz Niyazov	119029
Constantin Noack	116068
Diarmuid Farrell	119751

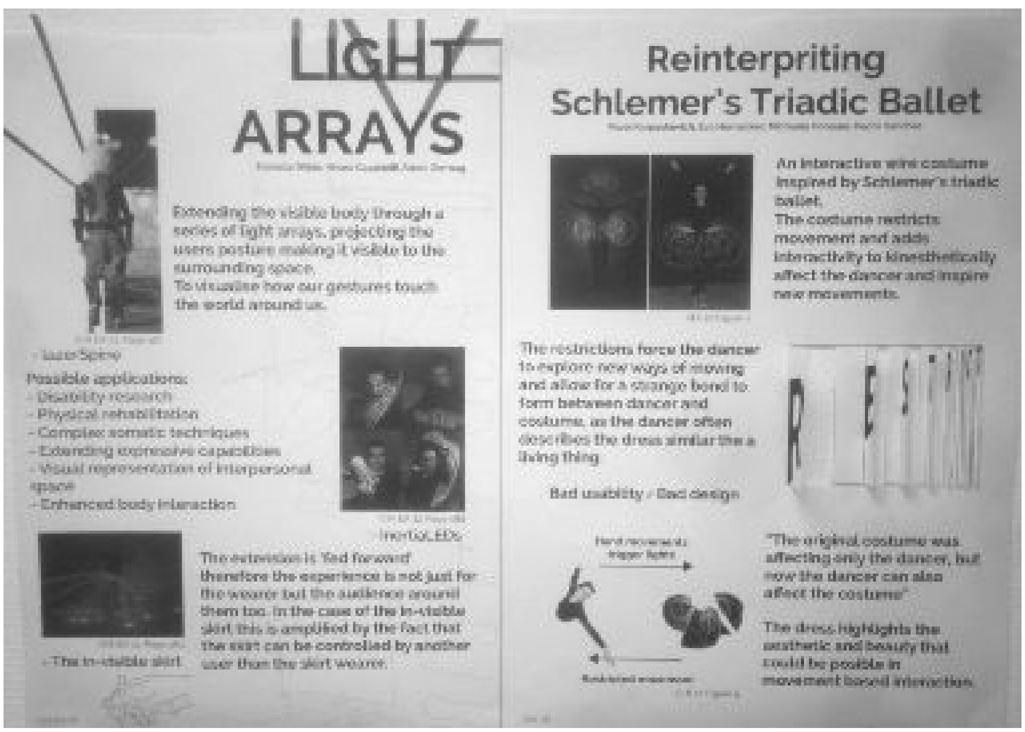
Index

Introduction

Related works

At the beginning of the project, we first became familiar with the subject of cyborg and robotic. We read several articles that touch on the topic and produced research posters on the topic, which summarize the core ideas of the papers.

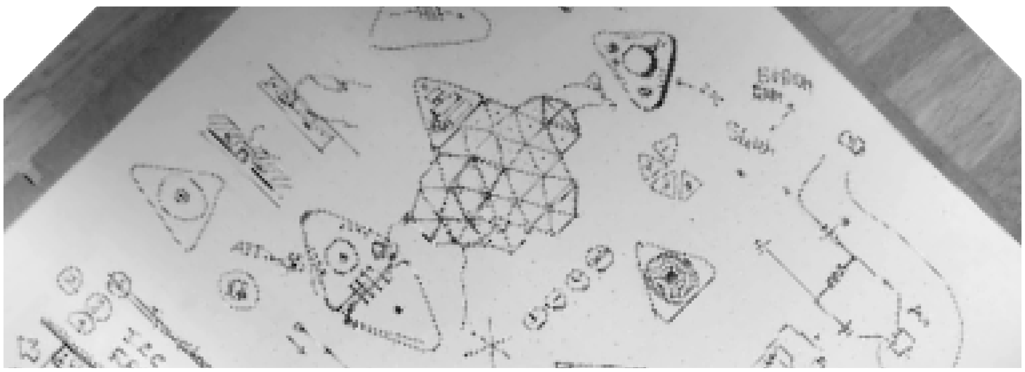
Valeriia Shakhova looked at **Emotional Expression / Sensory Augmentation** [1, 2] Papers. The **Extended Body** [3, 4] topics were Diarmuid Farrell's subject. Aziz Niyazov and Anton Brams worked on **Extended Mind/Body** [5, 6, 7]. And the **Prostheses Research** [8, 9] was presented by Constantin Noack.



This scientific papers gave us an overview and some ideas on the state of art of cybernetic area.

Inspiration

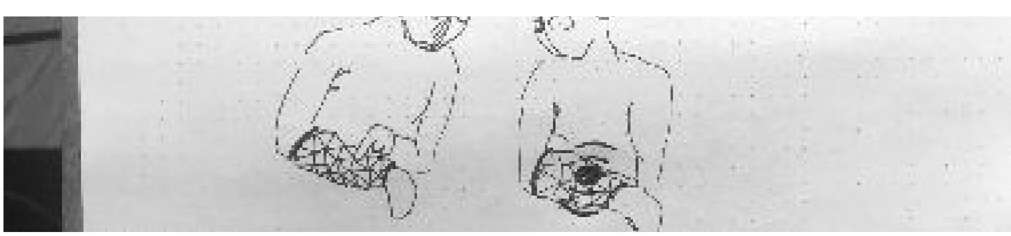
In the next step the project team had a group brainstorming session where the team explored the relation between materials and the body. The brainstorming was recorded in a number of sketches to substantiate experiments into tangible ideas.



One of the ideas was based on the **Low-fi skin vision** [6] paper. The HCI british group used computer vision to drive haptic motors placed on the back of a blind user to provide a dermal vision.
Our group, consists of Anton, Aziz, Constantin and Diarmuid, wanted to move this concept into a different context by creating a special skin that transmits haptic input. We called it e**Skin**.

Concept

The Idea was to create a new P2P device that acts like a second skin and transmits haptic interactions between two people. So if one person touches his own arm, the position and force of the touch is transmitted to the second user and replayed as pressure or a vibration. Additionally the touch's position and force has to be represented visually on the receiver's patch. The e**Skin** is a flexible freeform patch that can be worn on every body part. In this project we decided to concentrate on the forearm area.

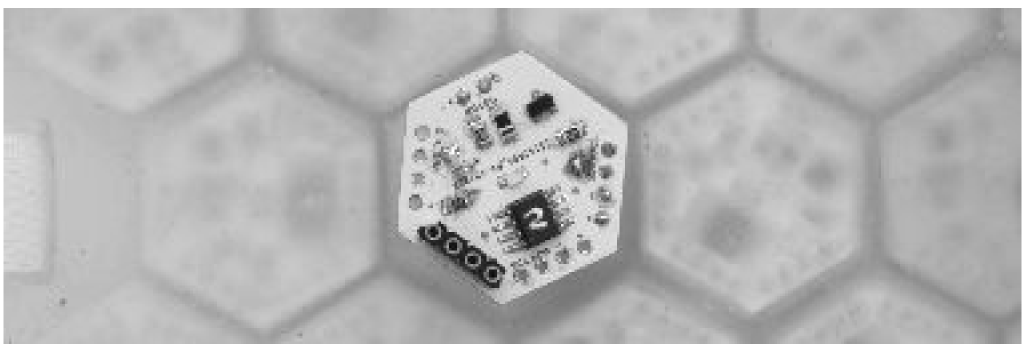


Documentation

Technical Abstraction

The patch contains multiple sensors that transmits pressure information to a **M**ain **C**omputational **U**nit and is transferred wirelessly to another unit. The message received by the MCU is sent to a corresponding actuator & LED.

Because the sensor on the **patch A** has an actuator & LED agent on the **patch B** exactly in the same position, we have to combine **sensor A** with the **actuator & LED A** spatially together into one cybernetic cell.



Due to experimentation we have found out that the distance of a human arm nerves varies from 1 to 2 cm. So it gives us a clue as to what distance between the cell's actuators should be.

This cell can be replicated in big amounts to build a patch. Every cell contains its own microcontroller and is connected to a MCU with wires. Due to a big amount of cells we decided to use a parallel **I^2C** protocol that requires only four parallel pins - power, ground, clock and data.

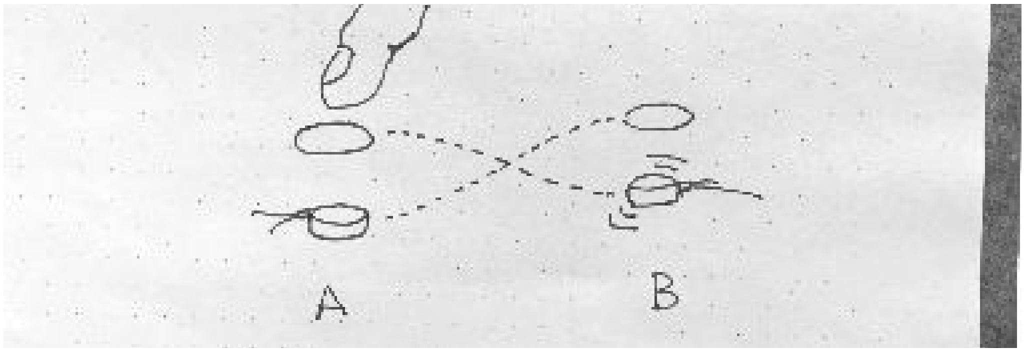
Project Planning

All Through the e**Skin** device has to transmit only a haptic interaction as a pressure/vibration and a visual feedback, this project is technically challenging due to interplay of different domains like hard & software, construction & surface finish of the patch and assembling.

Our team had to make a lot of decisions to connect these domains into one system:

- finding the right surface of the e**Skin** patch (flat, convex, concave)
- looking for the right cell shape to space motors according to a nerve resolution (triangular, square, hexagon)
- checking the I^2C connectivity between cell's microcontroller and a MCU
- establishing real time wireless transmission (data type, speed)
- selecting the right haptic motor for our application (ERM, LRA, Linear Motors)
- selecting the right touch/force sensors (capacity, **F**orce **S**ensing **R**esistor)
- getting the right pin arrangement to connect cells in parallel
- making a working electrical circuit
- making a compact electrical circuit
- programm cell and MCU
- making a construction flexible
- making the cell easy to assemble

In order to cover the most of aspects of our design, we had to go iteratively in three stages.



The main evaluation of our prototypes was a configuration of two against two cells connected to their MCU units and transmitting pressure to each other in a cross-over manner.

Proof of concept

- choosing the right haptic technology
- build the first cell prototype and connect it to the MCU via I^2C
- build 3 more and transmit signal between pairs of cells from one MCU to another (*2 vs. 2 cell test*) via serial cable
- *2 vs. 2 cell test* over the air

Prototyping the circuit

- experimenting with silicone molds, shapes and pin arrangement
- building a first **P**rinted **C**ircuit **B**oard prototype
- *2 vs. 2 cell test*

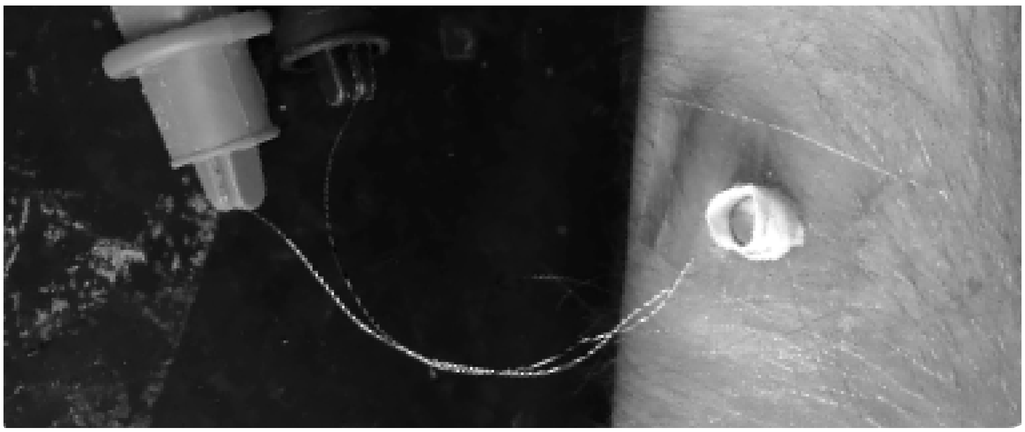
Final stage

- design a cell
- design MCU base
- scale up the mold patch
- assemble cells
- connect cells
- embed into a mold
- refeinment

Proof of Concept

A Very important aspect in this project was to choose the right sensor and actuator to transmit the pressure with the highest resolution. The most straight forward approach is to use FSR to read the finger's pressure and map the value to a linear motor that pushes a valve against the user's skin.

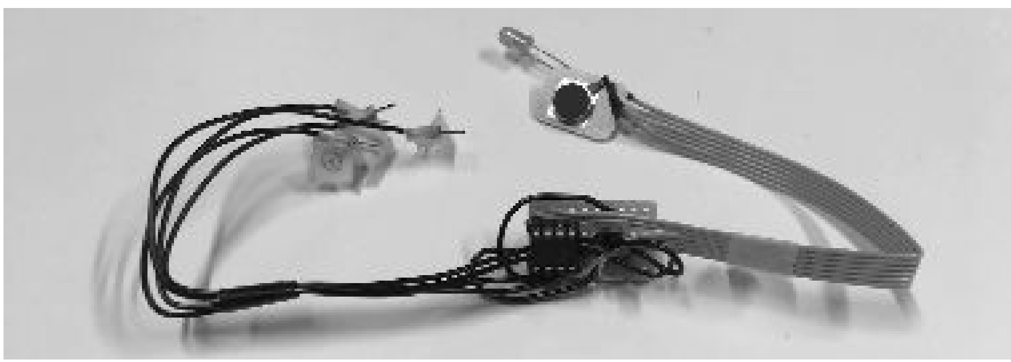
We started to experiment with different permanent magnets and voice air coils. If the current running through the coil creates an electromagnetic field and pushes the magnet in one direction. This approach is very promising but has one downside. In practical experiments we have found out that the coil due to the high current heats up, dissipates the heat to a permanent magnet that contacts the skin. The actuator feels very hot after a while. The factory made linear motors have less heat dissipation but are not easy to buy in a right size.



For this reason we had to fallback to the ERM technology that is more conventional and reachable in a short timeframe. So we used coin motors to arise the skin nerves and simulate a pressure.

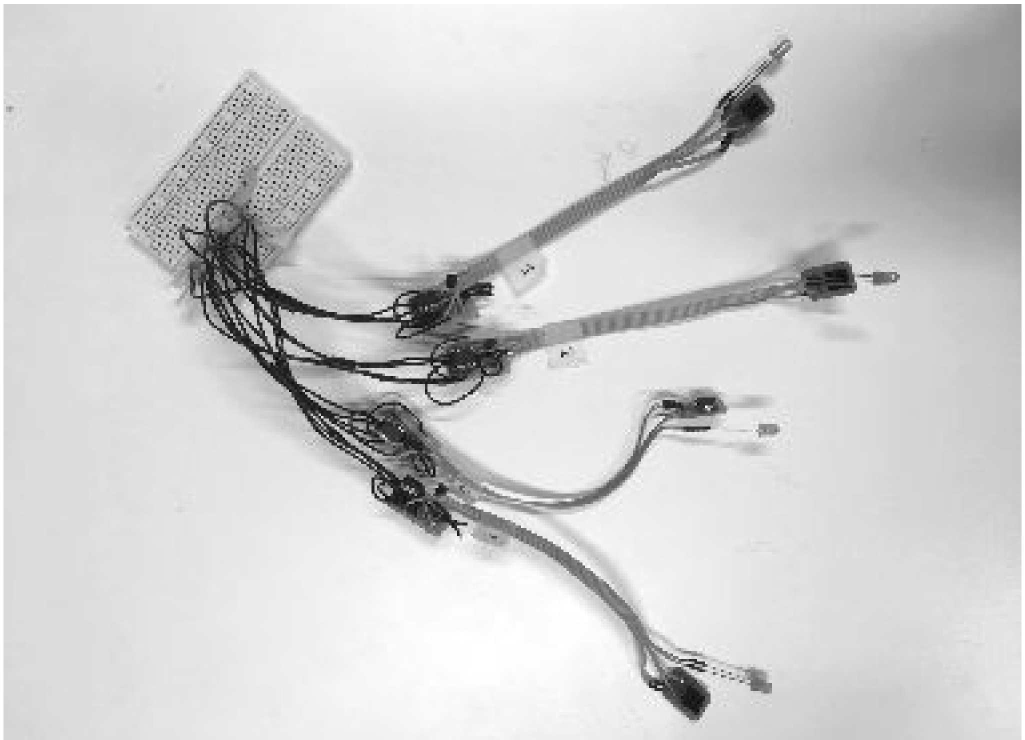
In order to be flexible in a FSR design we decided to use velostat conductive material and dedicated PCB design. So we can build free shaped FSR's in different sizes to measure the finger pressure by a resistance change.

The first cell was made on a prototype PCB. Due to small design requirement we had to choose a small ATTiny85 microcontroller that drives the cell. ATTiny drives a coin motor over a transistor with **P**ulse **W**idth **M**odulation. ATTiny has only 8 legs, so the last free pin was not capable of PWM to dim a LED. This had to be fixed in a software.



As an evaluation test of this setup the value from the self designed FSR was received over I^2C by the Arduino Uno MCU, mapped, and sent back to the motor and LED of the same cell.

In the next step we had built 3 more cells to make sure that everything works through I^2C as planned. Two cells were connected to a MCU A and two others to a MCU B. The communication between MCUs happened over a serial connection. Every cell had a corresponding clone on another side and its sensor has driven the clone's actuator & LED.



The last important proof of the technical concept was the wireless transmission between MCUs. To transmit a haptic data, we have to send a package containing an ID of a cell and the intensity of the pressure.

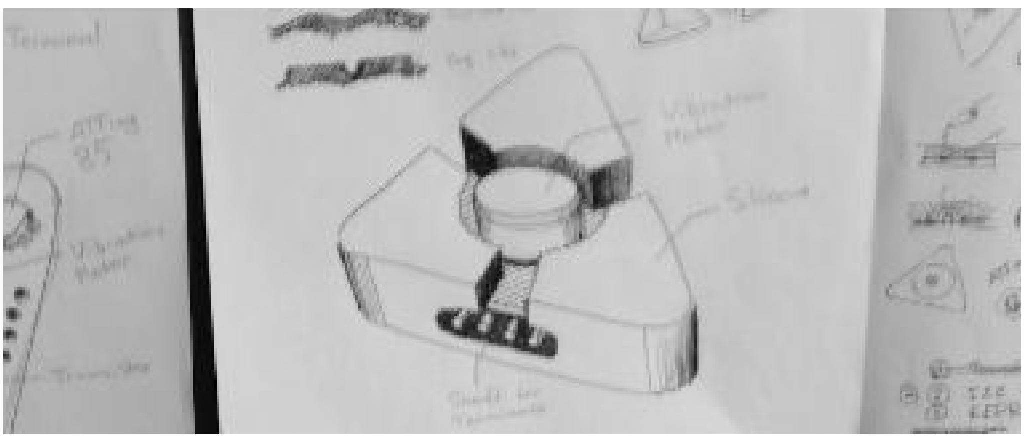
The first idea was to work with an ESP8266 and transfer data over the WiFi Mesh Network and communicate in a broadcasting mode. The packet has to be sent as a string value. While doing technical tests we have realized that this approach is too slow. The distance between packages was approximately 300ms, was interrupted every 5 seconds and was not suited for our application.

Next we decided to change to an Arduino Nano with NRF24L01 module. This wireless module is less complex in usage but unfortunately, due to the configuration of the SPI protocol, it has only half-duplex data transmission. That means, the data can be sent in both ways from device A to device B and vice versa, but sequentially in time. This approach was omitted due to the latency of the switching between modes.

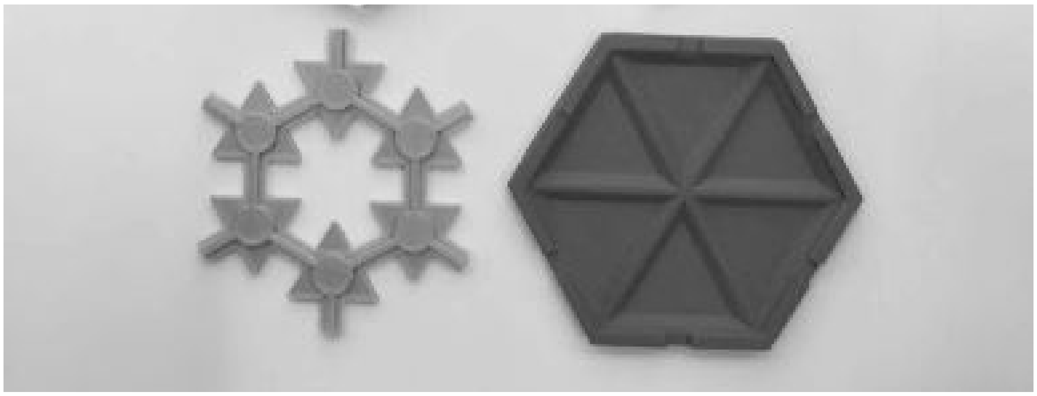
Another solution was a 433MHz antenna for sending and receiving the data packages. In order to achieve a higher bandwidth we had to reconfigure the antennas and sent self formatted packages.

The proof of concept was done successfully. Now was the time to bring the hardware into a desired shape.

After some initial design explorations for the shapes of our individual cells we decided to explore the idea of using a triangular design. We researched a wide variety of possible designs and thought the poly design seen in digital 3D objects could be an interesting approach, exploring how these triangles linked together in different patterns are used to create such interesting 3D shapes and worlds. From a functional approach this could be useful as the large amount of triangular cells linked together would easily bend into abnormal shapes like a users arm and would be helpful with this device being able to be used by a wider variety of users with different arm sizes and shapes. From a circuit side this approach would work too as this would allow for a modular approach with every side being able to link up with another cells corresponding side allowing for freedom when it comes to the design of the full patch.

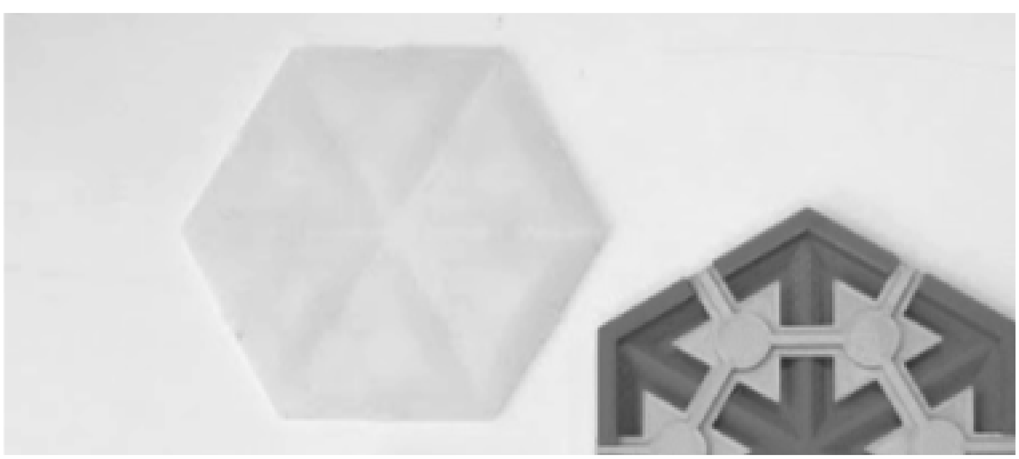


After deciding on the initial triangular form for each cell we went about prototyping this concept. This prototyping took form in 2 varieties, making paper prototypes of our full scale patch to test the scale, possible pattern designs and see how these patches wrapped around various parts of the body. Secondly we produced silicone patches with these triangular forms, to test how this form works with the material and also see how this material feels and how a user would interact with it. During the production of these patches we also explored methods of how we could embed the cells into the silicone. Because the measurements and shapes of the cells and components on the cells such as the motor were so specific and needed to be consistently accurate we felt that 3D printing a mould for the silicone was the best approach. We first 3D printed a base form, made up of 6 triangles joined together to make one large hexagonal patch. Each triangle had a distance of 5 mm apart from each other in order to allow for the wires to be able to bend enough without putting strain on them and breaking. This base print was design to produce a 5mm thick silicone patch this was based on rough measurements around how much space would be required to house all electronic components while still being thin enough to not be heavy for a user to wear. A wall surrounded these triangles creating a 5mm thick bath needed to create the silicone.



After designing and printing this base form we then had to explore how we could house the cells and their connecting wires in the silicone securely. We explored the idea of simply pouring half the silicone into the bath letting it dry, then placing the components on the silicone and then pouring the rest of silicone over the cells, completely embedding them in the mould however we felt this was not a good approach as it left a lot of room for human error in terms of lining up the components accurately as well as not allowing for easy repairs. We instead decided on a different approach 3D printing a second component which would mimic the form of the cells connected together in a patch, this would then be placed in the base and using bridge like structures designed into this form, this would allow for this form to hang freely 1.5mm above the bottom of the base. In order to allow for us to remove this form from the silicone a 1mm thin bridge was extruded from each bridge that connected the triangles. These bridges were extruded 5mm, along with a 10mm diameter circle in the center of each triangle to allow for the motor in each cell to not be encased in silicone and free so that it would be pressed against the users skin, rising above the walls of the base meaning the silicone never joined at these points allowing for this printed form to be removed and the actual patch to be placed in. For the actual pouring of the silicone, we first poured a portion of the silicone into just the base shape, we then placed the 3D printed triangle form into the still wet silicone and base, with the bridges being supported by the walls. We then poured the rest of the silicone into the base and over the triangle form this meant that the silicone enclosed the form securely and thus would securely house the cells.

These early explorations were very successful, the method we devised for producing our silicone worked successfully, we could easily take out the 3D printed form and place in some test cells and have them be housed securely in the silicone while still being easy to physically take out. The silicone itself also worked well giving us the flexibility needed to wrap around a users skin while also giving us durability and strength needed to cope with the stretching and rough use by users. However we did run into issues due to using the triangular form, we realised that when all of these 6 triangle cells connect with each other there is a large gap of freespace in the center of the Hexagon patch. This would cause a large break in the haptic feedback and cause for a big pain point with the user experience and greatly alter how a user would interact with our device. We decided instead , after exploring a number of options, to go with a hexagonal design instead. The patch would still be based on the idea of poly tesselation but would now use hexagons instead of triangles. The hexagons would still allow for freedom in the pattern design while also eliminating the empty space created from the triangles. Going with hexagonal cells would mean that there would be a slightly less bend available to us however this was not a major issue for our device.

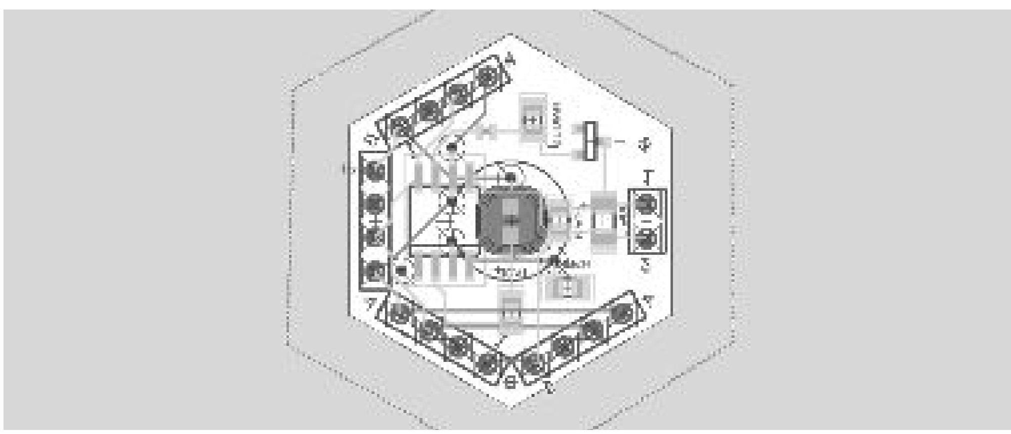


Prototyping the Circuit

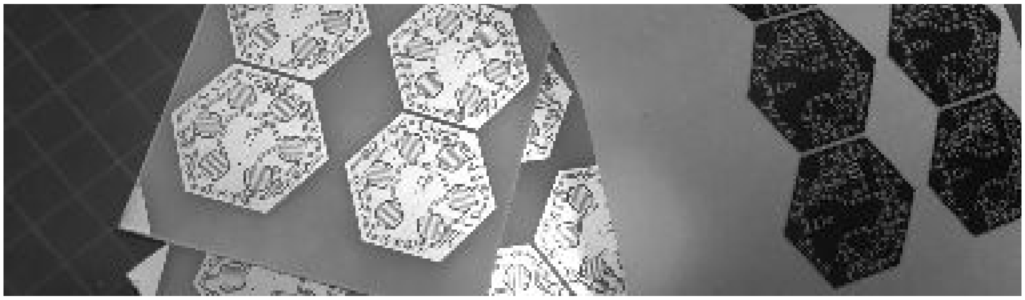
Now it was time to minify the project and switch to **S**urface **M**ounted **D**evices. For every used component we have found a SMD analog. In order to test our SMDs we had to edge a small series of PCBs.

ATTiny85 with a 8000 bytes memory had to be replaced with ATTiny25 with 2000 bytes memory due to a lower price. Our sketch could handle this limitations.

We used EAGLE to create a layout design. The PCB had to be double sided because the sensory part & a LED had to be on the top and an actuator on the bottom layer. The LED was placed exactly in the middle of the PCB surrounded by 6 velostat contact traces. On another side the actuator was placed in the middle and was surrounded by an ATTiny, a transistor, capacitor and diode for the actuator and a voltage divider resistor for the LED. Every side of the hexagon shape had 4 contacts for connection.

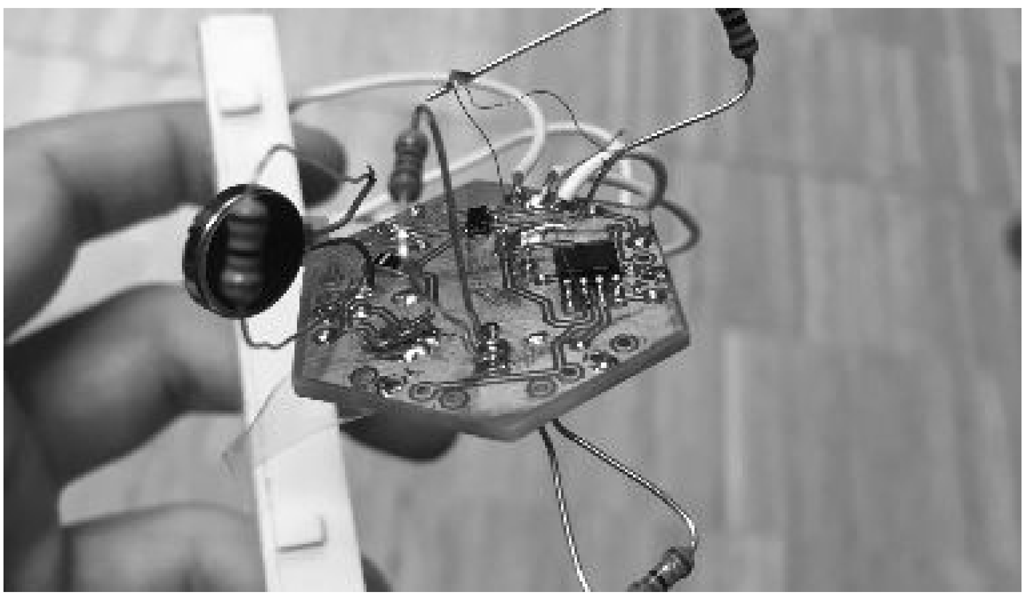


To develop the PCB we went to Leipzig to Hannes Waldschütz's lab. After printing and applying a 2-sided negativ mask to the epoxy photoplates, we exposed it to UV radiation to remove the copper in between traces with the acid later in a process. Finally the PCBs contacts and vias had to be drilled and the vias soldered.

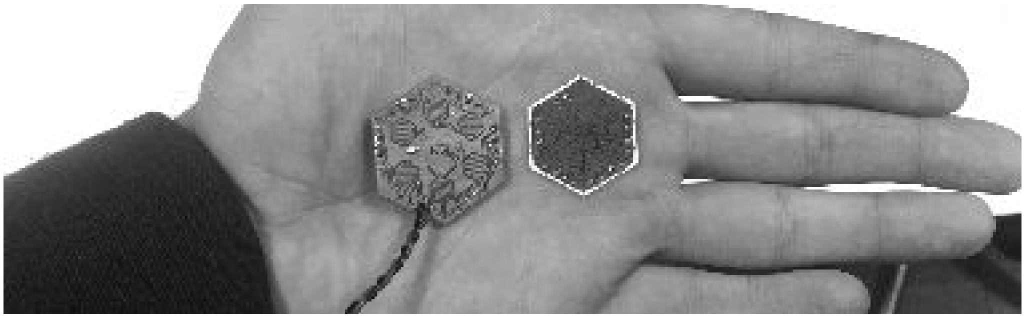


Now we had a good foundation to test out our SMD parts and their connection.

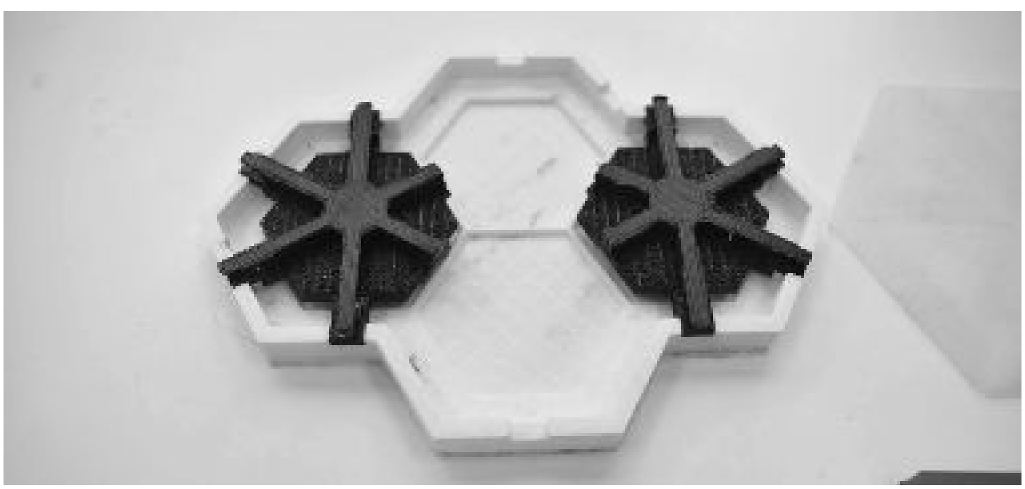
After the mounting of SMDs on the PCB we were faced with a number of different problems. Imprecise soldering, lack of voltage dividers on some parts, missing pull-down resistors on a transistor and a lack of pull-up resistors on the I^2C rails were fixed one after another.



We realized the design with 6 Velostat patterns and pressure points is not the optimal way to get a good value for pressure because the velostat contact traces were connected parallely and impossible to calibrate individually. Additionally due to the placement of components on both sides the PCB size was to big and also not easy to assemble in a batch process. Therefore, the PCB design was redesigned again.

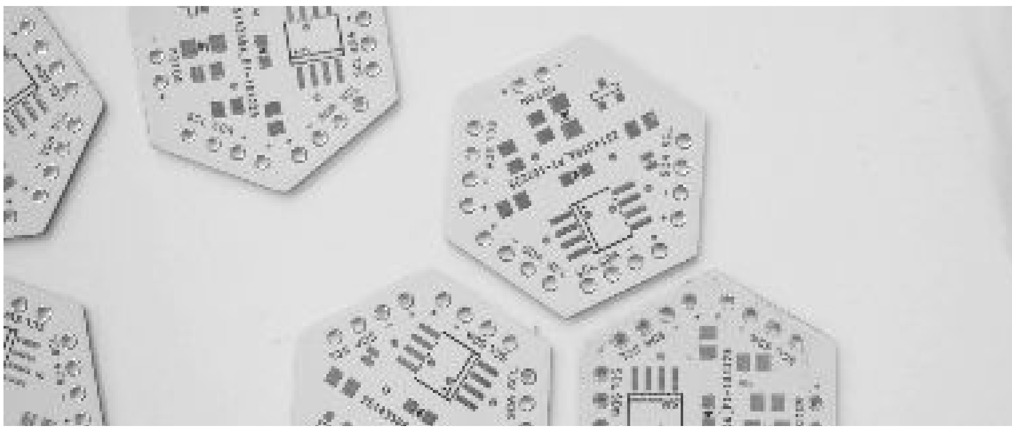


After deciding to go with a hexagonal cell design we made a second silicone prototype patch again to see how this form would look feel and be interacted with. There was also some additional changes we made to this patch such as, changing the gap between each cell from 5mm to 2mm, increasing the overall thickness of the silicone from 5mm to 7.5mm and increasing the size of the cells to 30mm in diameter. Some of these changes were made to increase the user experience while others were to test how a user interactions with a variety in scales. This patch was made with the same method as the first triangular patch except now with only 4 hexagonal cells. After producing this patch we got a number of new findings, firstly the 30mm diameter hexagon cells were much too large for a users arm and caused a number of issues. Another issue that arose was the 2mm gap between each cell, this small gap meant it was impossible to take out the ridged 3D printed filler form without breaking it . Although this did improve the user experience and cause a more consistent haptic feedback, we would still have to change the design of our filler form to take this into account as we did not have time to break and reprint our filler forms.



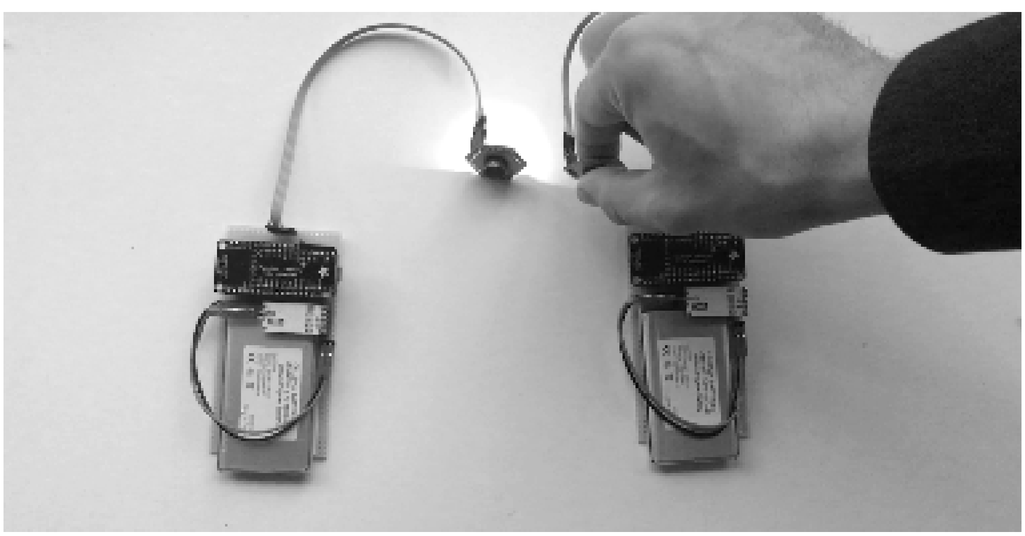
Final stage

In the final design the sensory part was moved to the button layer and integrated between the actuator and a PCB. SMDs around the actuator were moved upstairs around the LED. This strategy made the PCB way smaller and easier to solder in only one go. The design was sent to a chinese factory named JLCPCB.

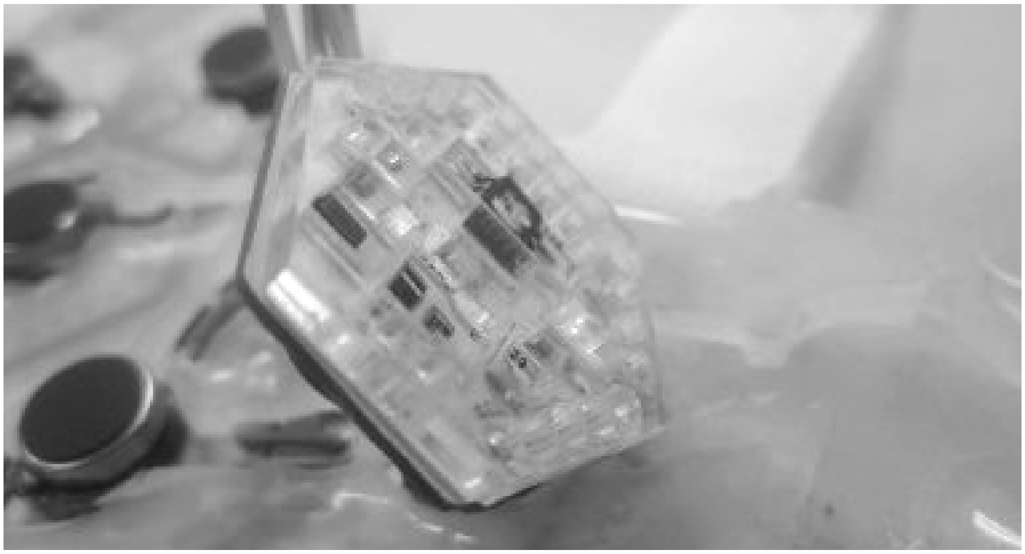


As the PCBs had arrived, the *2 vs. 2 cells test* was necessary to make sure that the circuit functions as its supposed to. While the SMDs were soldered on PCBs, we designed two Server units that cells are connected to.

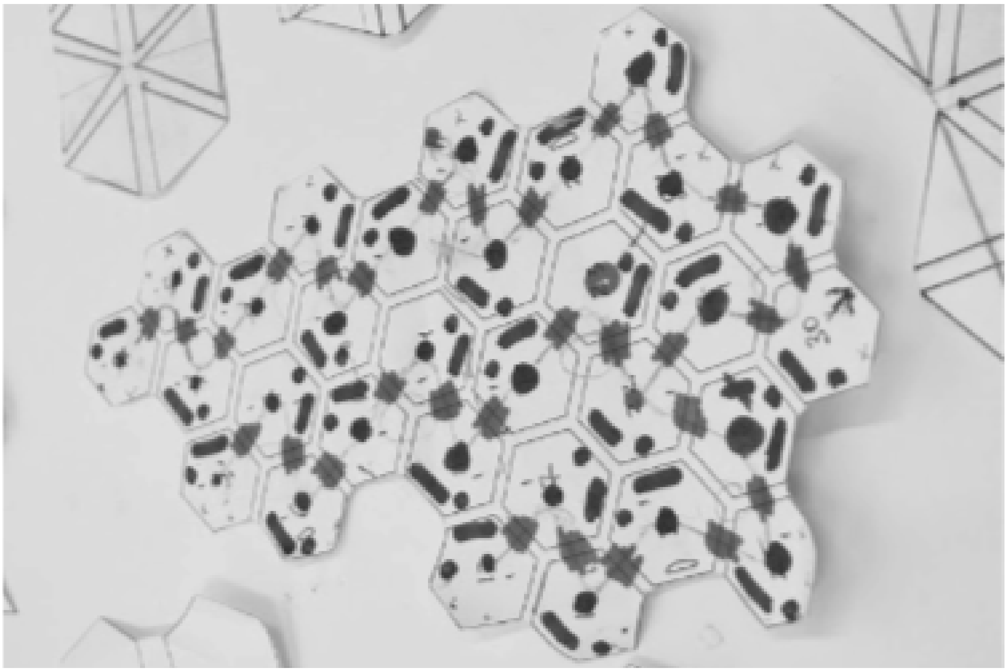
One server unit contained pull up resistors, antenna and a battery. For the battery we decided to take a lithium polymer battery with 3.7v and 1500mAh in order to have enough energy for several hours of use.



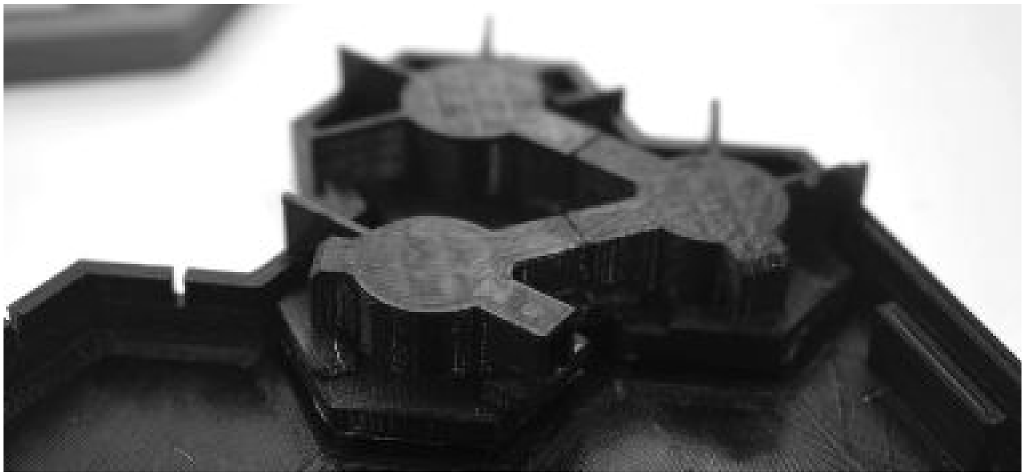
Because the surface of the cell was very bumpy due to all the components on the upper layer, it was perceivable through a silicon layer. So the plastic stencil was necessary to even out the surface of the cell.



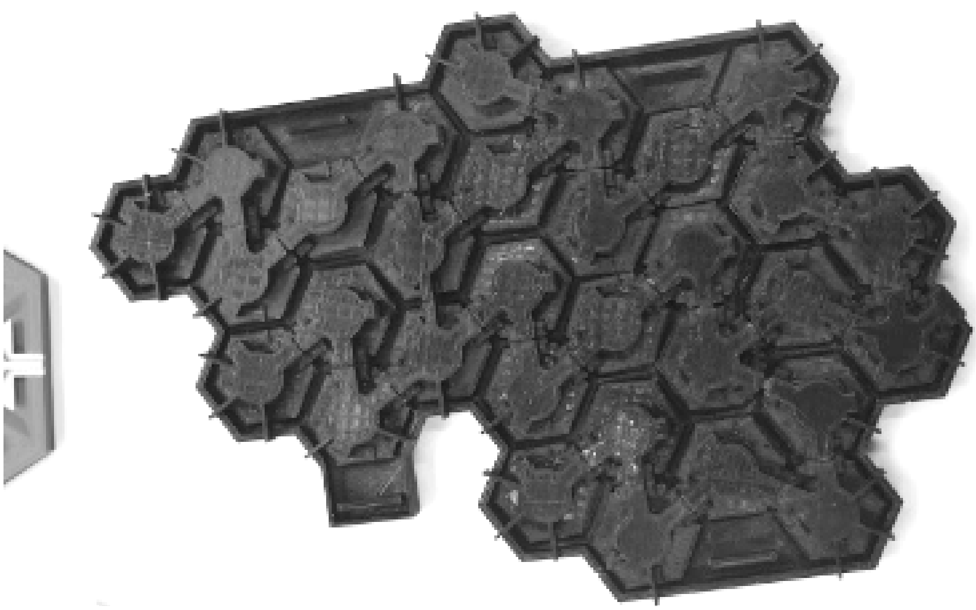
After producing these test moulds and gathering all the needed findings from these test patches, it was time to scale up. Before actually producing a final silicone piece we first had to decide on a pattern design. It was important that the pattern had to be modular and be as universal as possible so it could fit on a wide variety of users arms. We first decided on a way to connect a small number of cells together that could then be easily scaled up to make a 31 cell pattern that all connected correctly. We found that connecting 3 cells together in a triscle like pattern worked best for this. These sets of threes were then connected together in a number of different pattern designs to test which best fit on a users arm. We ultimately decided on a pattern which got skinnier as it approached the wrist and fatter as it went up the users arm.



Now that we had our pattern design we could produce our silicone moulds. The method of producing the mould remained the same for our final silicone patches however there were a number of small changes required now that we would be producing a full wearable patch such as adding an additional space with a slit in it to allow for a velcro strap to be attached at both ends of the patch so that the patch would be secured on the users arm, and reducing the size of the cells to 25mm diameter hexagons. The biggest change was made to the 3D printed hexagon filler form, due to the scale of the 31 cell patch and the problems with the size of the gap between each cell meaning one large rigidly connected form was not an option. We instead went with a modular approach printing 31 individual hexagon pieces which corresponded to their respective cell. In order to connect each cell and still have them hang above the base of the bath, we still went with the bridging approach, instead opting for a modular method to it.



The bridges were cut in half and then had a piece extruded out so it acted similar to a male head while other cells had a hole placed in their bridge half having it act like a female head. This allowed for all of the cells to be joined together securely and hang above the base of the bath while also still being able to remove the filler form from the silicone without breaking it meaning we could produce a large number of silicone patches just from these 2 printed components.



Due to time constraints we had to opt for a very functional approach to the housing of the battery and arduino components, housing them in a separate armband pouch which was strapped onto the users bicep, with a wire connecting the hexagon cell patch to these components.

Software

The main complexities in the software part were wireless communication between MCUs and a signal processing.

The value read from the FSR had resolution of 16 bits. The I^2C has a bandwidth of 8 bits byte. In order to keep the communication as fast as possible, we used only one byte to collect pressure values from cells. So the first stage was the downsampling of the FSRs signal.

In the second stage we had to pass a value only if it was updated. Additionally we had to calibrate values because all the sensors had different sensitivities and baselines. In the first go we just used a fixed threshold and mapping. It didn't work because by putting the patch on the skin, some sensors were already activated even though the user hadn't pressed them. The system had to be smart enough to adjust itself dynamically. So we tried different approaches like floating baseline or sending just a change. The second option worked out the best.

Because the wireless communication had a slower pass through rate, we built a circular buffer to accumulate excited cell's IDs.

Another complexity was a missing error checking on the wireless communication. This created false positives and high latency. We had to simplify our communication protocol by sending just raw bytes. The byte represented an ID that was arised. On another side the received ID excited the actuator & LED for just 50ms.

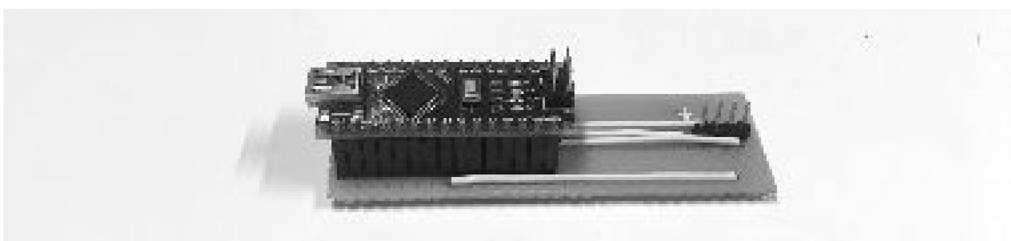
Assembling

The assembly of the 62 PCBs for the two devices proved to be a very time-consuming and error-prone part of the project.

We baked the SMD components on the circuit boards for days and then provided each one with velostat and the motor.

There were many bugs because the components were not soldered properly. After that we decided to solder most of the boards by hand again. This was time consuming, but still easier than soldering everything by hand from the very beginning. Even though most components were not soldered after baking process, at least they left on designed slots.

All clients were individually tested for functionality. For this purpose we made a I^2C tester.



This should eliminate faulty boards that should be integrated into the e**Skin**. During the assembly process, instead of soldering everything together, we decided to make small patches just for several cells and then connect the patches together. The rationale for this is to spot the error at an early stage. Otherwise, we would have to do a “binary search” for the whole setup, thus separating cells and soldering them again, which requires more time and work.

Unfortunately, we have not yet managed to get all the clients in the two devices to work. Adding every single pattern caused unforeseen bugs.

Furthermore, we have soldered with too stiff wire (solid) to connect the individual modules together. This has made it very difficult to insert the panels into the silicon mold. On the other hand, if we would use stranded wire, there will be more chance to break the connection.

Reflection

Future Steps

As for the possible improvements, we could have used RGB LEDs to decode some messages using visual feedback together with haptic one. Potentially, the colors of LEDs could be set by the pressure applied to force sensors. Also, it would be possible to build such kind of system with different shape and size with regard to its application.

Overall the silicone patches worked really well for this project, the material was flexible enough to wrap around a users hand without tearing and protected the inner cells, meaning it had a long lifespan. Conceptual it worked well too due to its similarities with skin. The method of producing the silicone I feel also worked well for the most part, the bridging technique worked well and allowed for easy repairs however due to the scale of the project it was very time consuming designing and printing 31 individual hexagon cells. 3D printing the moulds was perhaps also not the best options as the finish on prints was not great and thus picked up by the silicone, if we were to do this again we would try CNC our mould pieces from high density cibatool and then finely sand down these pieces for a top grade finish. A big pain point from the patches we produced was how we secured the patches using velcro straps. Due to time constraints we went with the quickest most functional use, however upon reflection this choice greatly affected both the design and the user experience making it clunky and difficult to put on as you needed an additional person to help you put on the patch. For future developments we would possible think about using magnet strips embedded in the silicone so they could easily join together. Another approach could be to potentially explore a material which sticks to a users skin having no need to have straps. These pain points and solutions also extend to our housing of the battery and arduino components in a separate armband pouch.

Possible Research Design

In order to make a good research design, it is necessary to understand how usable and useful the system that we are building. To test how usable our development is, we would need a usability study by working with statistics, thus we could be sure that our prototype has a good enough quality.

Another aspect to test is how useful our product is. To do this, we would need to consider **U**ser **C**entered **D**esign. We could consider the UCD that consist of three parts: Discover, Design, Evaluation. First, we would need to discover the user needs and their requirements for our projects. Next, since we have already had an idea what to build, we would need to consider aesthetics of the prototype and its use cases, e.g. what the application of it and the area of where it could be used. The last step of UCD would be to evaluate of how people use e**Skin** to perform particular task.

To understand users better, it is necessary to choose an appropriate methodology. In our case a better way could be to use mixed method combining qualitative and quantitative techniques, thus having a clear picture of who the users are and what they want. To do so, first we need to set a research question, which could be: "How do people use e**Skin** for communication?".

To conduct the study, in our opinion would be good to have a survey and an overt observation. The survey would give us an overview of demographic information of potential users, whereas by observing how people use e**Skin** to communicate, we could see how can we improve the setup. The improvement could be done, for example, using "think aloud" technique. Also, by having feedback from different users, we could alternate the setting of the prototype to better suit user requirements and expectations.

Summary Visitors Reaction

During the exhibition, there were different types of visitors: around half of the visitors were just passing by the stand with our projects, few of them were looking from the side, showing some interest, but those who came closer were excited and asked a lot of questions and even some proposal.

The questions varied from how we designed the device to how we assembled everything. When we explained the concept and the idea behind it, the visitors were amazed even more. When they got more familiar with the e**Skin**, they started to propose their own ideas of where it could be used and how to improve it. Some people were saying that it would be a good idea to decode information and send them to another part of the device, so only the receiver could understand the hidden message, whereas the others said that color coding of each cell would be of great benefit for silent communication. Yet another suggestion was to place touch screens inside each cell in order to use them as a map for navigation.

Personal Reflections

The whole assembly process took a long time. Also, there were a lot of point of failure, which requires time.

As it was mentioned previously, we tested each cell separately to avoid failures when assembling them in a designed pattern. Nevertheless, after assembling a patch of several cells, some of them did not function properly; for example, when one cell is touched, the signal was received by multiple cells on the other hand.

Having more time and considering all the limitations and user feedback, we could make the development process more iterative. Thus, repeating the whole process of Discover, Design, and Evaluation, would lead to a better outcome.

Conclusion

At the beginning of this project we set out with the task of exploring the theme of the cyborg, looking at how we can design to improve our current world by looking through the lens of a cyborg exploring what it means to be a cyborg and how we can become a cyborg through a mixture of design and technology. We wanted to explore how we could extend a users sense of the world and explore how they interact with and experience the world is different now due to their cyborgification.

Although we explored this through a very conceptual lens we feel that this device has a number of very functional uses such as simply being a physical and visual communication device, it has uses in the world of sex, a way to experience haptic feedback in a virtual world, a visual interface that interacts with it's world, the possible real world implementations are broad and endless.

By enabling the user to feel what another user was feeling and vice versa we extended their perception of the world that surrounds them interlinking these two users through technology thus enabling both of them to become cyborgs.

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