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On the Development of a Hypermobile Joint Protection Assistant

Exploring eTextiles in the Health Area

In this report, we aim for the development of an eTextile that supports people suffering from hypermobility. As those people might hyperextend their joints above the common level painlessly, long-term damages on joints, tendons, and ligaments may occur. To protect the affected joints, bandages or splints usually come into play. Unfortunately, such splints should only be worn for a short period of time. We try to offer a long-term alternative to this problem with our so-called *Vibrotactile Joint Protection Assistan*t. The assistant comes in form of an elastic arm sleeve that acts as a flexible bandage. It is constructed to keep track of critical overextensions without affecting the overall joint mobility. The overextensions are detected with the help of a crocheted stretch sensor sewn in at the ventral side of the sleeve. An integrated microcontroller controls a vibrotactile and a visual actuator, immediately signaling overextensions to the user. Although we focus on elbow joints only, the presented principle can be easily adapted to the protection of other body regions such as knees, feet, as well as hands. We found that the overextension detection and the overall prototype concept seem to work reliably, but further effort should be put on the compactness of the designed prototype as well as on the vibrotactile feedback modality that is currently hardly noticeable.

Background

In 2017, the researchers Kumar et al. [1] claimed that at least 3% of the general population suffers from a hypermobility syndrome coming with joint instability and chronic pain. As this disease may strongly affect life quality in various ways, it is important to research on new technologies that offer some sort of support to this huge number of affected people. Such an approach is taken by our *Vibrotactile Joint Protection Assistant* which is based on an integrated stretch sensor.

You can find various instructions describing the construction of a crocheted, knitted, or felted stretch sensor online as they are applicable in very different projects such as for stretch sensitive bracelets [3], breath sensors [4], or interactive deco objects [5].

Based on the motivation of handmade sensors, Vogl et al. [9] examine stretch-based textile sensing technologies that enhance everyday objects. For that, they analyze yarns and ways of how to combine them with different elastic fabrics and stitch properties. Based on this, they conducted experiments to evaluate, e. g., the relevance of elasticity and length of the stretch sensor for the sensor design which is also a question we will face during construction.

Although there has not been made many research on the specific application of hypermobile joint protection, we can find many papers considering similar use cases such as hand pose estimation based on gloves equipped with multiple stretch sensors which was developed by Glauser et al. [6]. Two papers that come closest to our goal are the papers written by Enokibori et al. [8] and Liu et al. [7]. Enokibori discovers the general possibilities that stretch sensors offer within the health area, confirming that those type of sensors might be indeed applicable for our purpose. Five years later, Liu et al. further developed this idea by doing research on the development of a portable joint motion sensing system which is suitable for long-time wear. Thus, their research goal is closely related to ours. Especially interesting about this paper is that the authors try to use everyday fabrics to continuously and accurately display joint angular motions.

Thus, why not advancing this idea to support people suffering from a hypermobility syndrome?

For the vibration module construction, we refer to Kobakant [2] that offers an overview of easy-to-build vibration modules. Their simplicity and small size is what makes them interesting for the integration into our project.
Finally, I want to stress one artistic stretch sensor use that I found very nice and worth mentioning: Mika Santomi [10] designed a complete outfit for an artist having several cleverly integrated bending sensors, e. g., around the elbow and knee joints. The clothing is designed such that the artist can wear it during their live performances. The sensors then caption the joint movements in real-time and translate them into a signal. This signal is used to control some instruments that are part of the live act as well.

Project Concept

The *Hypermobile Joint Protection Assistant* is a wearable designed to support people suffering from hypermobility as well as artists and athletes that are naturally endangered of overextended joints. Thus, the design of the wearable is chosen such that it does not affect the overall mobility, but is able to give the user vibrotactile feedback when detecting overextensions. As a consequence, the user can fix their posture appropriately. If no overextension is detected, the wearable does not give any feedback and is just nothing else than a usual arm sleeve. Figure 2 illustrates the main idea.

From a more technical viewpoint, the decision when to activate the vibrotactile module is based on the measurements of an integrated stretch sensor on the ventral side of the sleeve. A microcontroller uses these sensor measurements to activate the vibe module iff the measured values are smaller than an initially determined threshold (more details can be found in the section *Project Implementation*). It ends vibration if the stretch measurement exceeds this threshold. In turn, this means that the microcontroller is required to periodically take and interpret the current state of the stretch sensor. We propose a possible design for the *Hypermobile Joint Protection Assistant* with its main technical elements within Figure 1 and 3. Throughout the implementation, we will stick to this main design concept

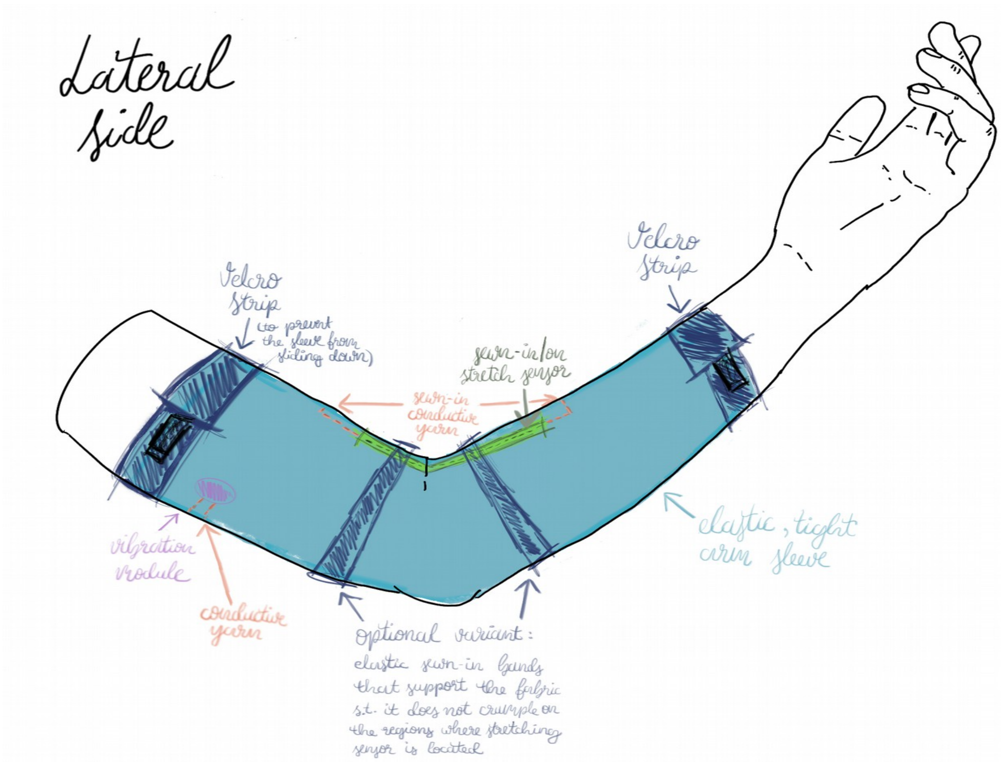

Figure 1: The image depicts a lateral view on our prototype. The stretch sensor is sewn at the ventral arm side. The actuator is added on the inside of the upper arm but, e.g., positioning it on the ventral side of the lower arm would be possible as well.

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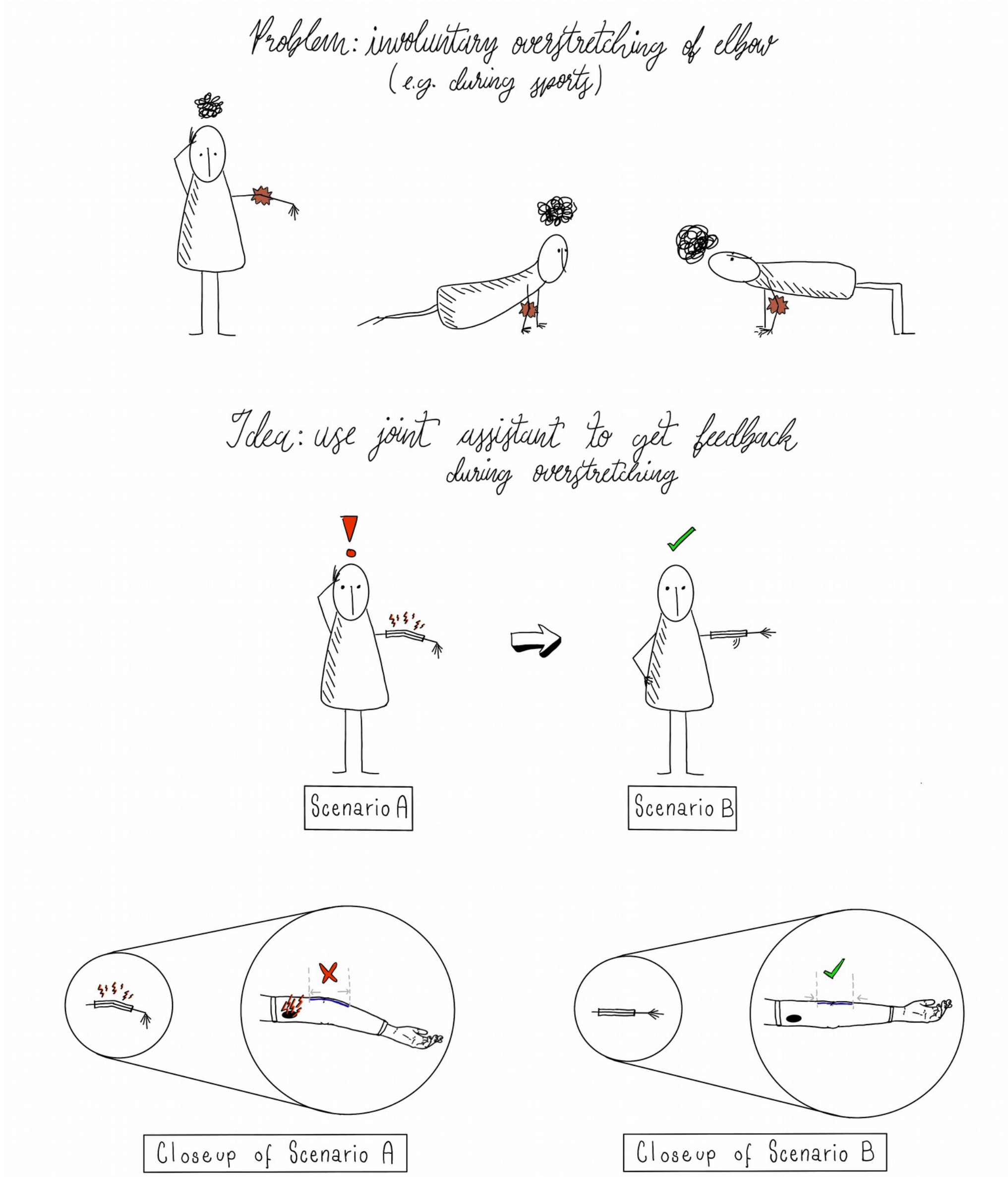
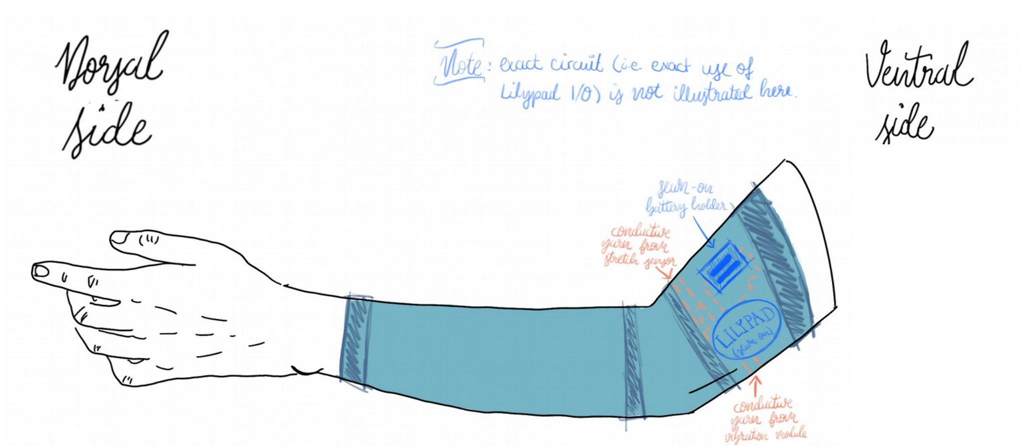


Figure 2: On the top, we show some scenarios in which joints might be overextended involuntarily. The images below illustrate how our project could help to prevent those situations.



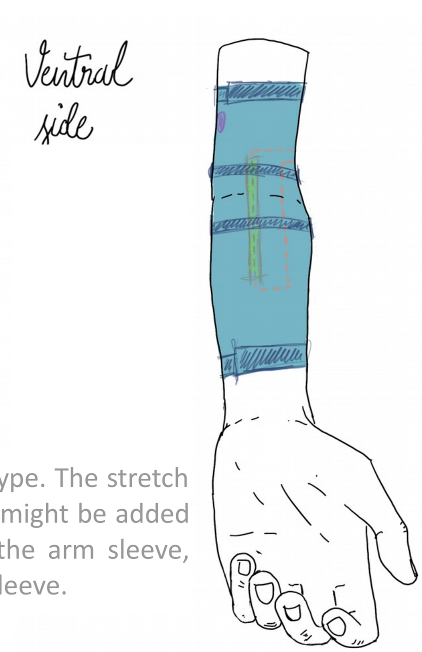


Figure 3: The images depict a dorsal, and ventral view on our prototype. The stretch sensor is sewn at the ventral arm side. The microcontroller might be added on the dorsal upper part. Depending on the elasticity of the arm sleeve, additional velcro strips might be added to avoid a crumpled sleeve.

Project Implementation

In this section, we give an overview over materials that are needed for the project as well as subdivide the projects into three parts: The construction of the stretch sensor, the construction of the vibe module, and the part in which we put everything together to a working prototype similar to the one depicted on the sketches in the last section.

List of Materials

You can retrieve the list of materials from the *Prerequisites* section of the README in the Git repository. The list contains additional annotations if the proposed material is not a hard requirement in order to build a working prototype.

Constructing the Stretch Sensor

For the construction of the stretch sensor, use the wool and the crochet hook while following the instructions of this video - but start with five chain stitches only. Stop after finishing the fifth row. Now, take the conductive yarn in addition to the wool on your hand but leave around five centimeters of loose unused yarn at the end. Continue crocheting according to the technique presented in this video. Crochet 20 rows such that you get ten "ribs" on each side of the cord. We will need this rib-like structure to make the cord elastic. Finally, crochet again five normal rows of wool only on top, exactly as we have done it in the beginning. Cut the conductive yarn such that you get again a loose end of around five centimeters.

To make the sensor stretchy, sew some elastic yarn or elastic band with a needle and some non-conductive yarn on the left and right backside of the rib-like sensor part, pulling together the ribs on each side. When doing it correctly, the distance between the ribs increases when stretched and pulls together when released.

Finally, pull the loose ends of the conductive yarn through the non-elastic part of the sensor towards the sensor's ends.

Figure 4 shows how an outcome of the above instruction could look like.

You can verify that your sensor works correctly by measuring its resistance while stretching. For that, use the multimeter. You should observe that the resistance significantly decreases during stretching and goes back to its initial state almost immediately after the end of stretching. One exemplary video of such an experiment can be found in my Git repository. In this repository, you can also find a simple prototype setup consisting of a microcontroller and a stretch sensor only. Information on how to build a simplified prototype on Tinkercad can be retrieved from the repo, too.

Figure 4: On the left side, we can see the frontside of the stretch sensor. The right side shows its back with the elastic bands.

Constructing the Vibe Module

The construction of the vibe module is fully inspired by the corresponding kobakant vibe module website [2].

First, cut a small piece of plastic in an oval form large enough to add the vibe module and two snaps on it. This will be the module's solid base. Next, glue the vibe motor at the center of the oval and make two holes for the snaps on the left and on the right side. The snaps should help you to easily detach the vibe module again from the circuit and add it on another one. As the conductive ends of the vibe module (via which we connect it to the rest of the circuit) are really short, knot some conductive thread around each. We now have a much easier and larger point of connection to the vibe module than before. The result may look as depicted in the left image of Figure 5. Finally, to hide and solidify the technical components and the copper knot, add some insulating Sugru around them, resulting in a hard and robust vibe module encapsulating its technique inside. See the right part of Figure 5 for reference.

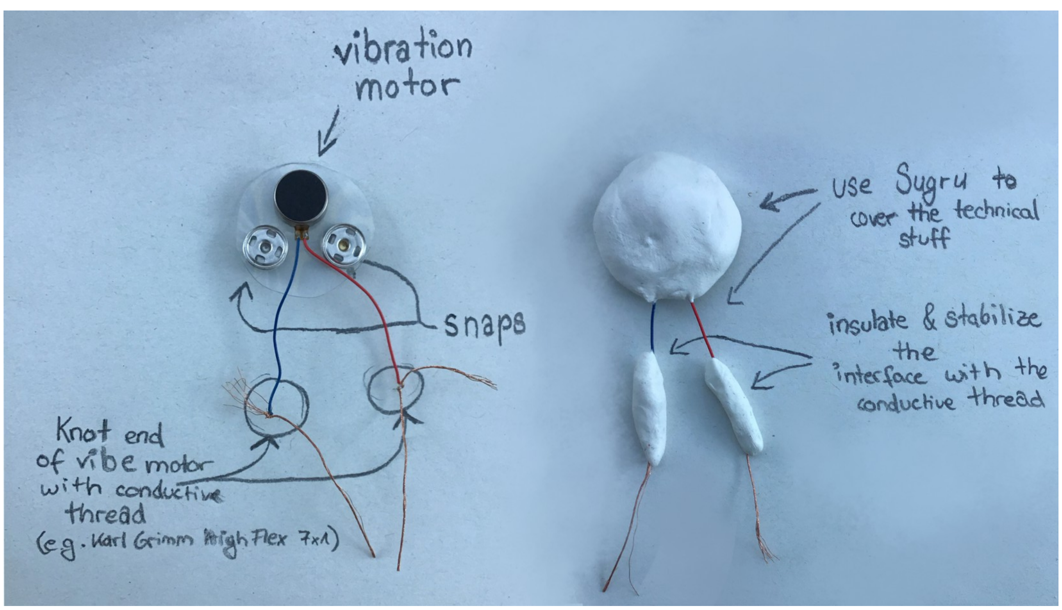


Figure 5: On the left side, we can see the final vibe module without Sugru. On the right side, some Sugru has been added on top of the technical parts and around the yarns' knots.

Putting It All Together

In contrast to our initial prototype design, we will add some visual output on top of the vibrotactile feedback. The reason for that is that during the final tests of the prototype, I found that the vibration feedback is very weak and cannot be visibly presented in a demo video. Hence, we use an additional LED that is always activated in combination with the vibe module.

With that, we can subdivide the circuit into three main parts: one for the LED, one for the stretch sensor, and one for the vibe module.

The circuit schematic is depicted in Figure 6. You can find the whole Fritzing file in the Git repo.

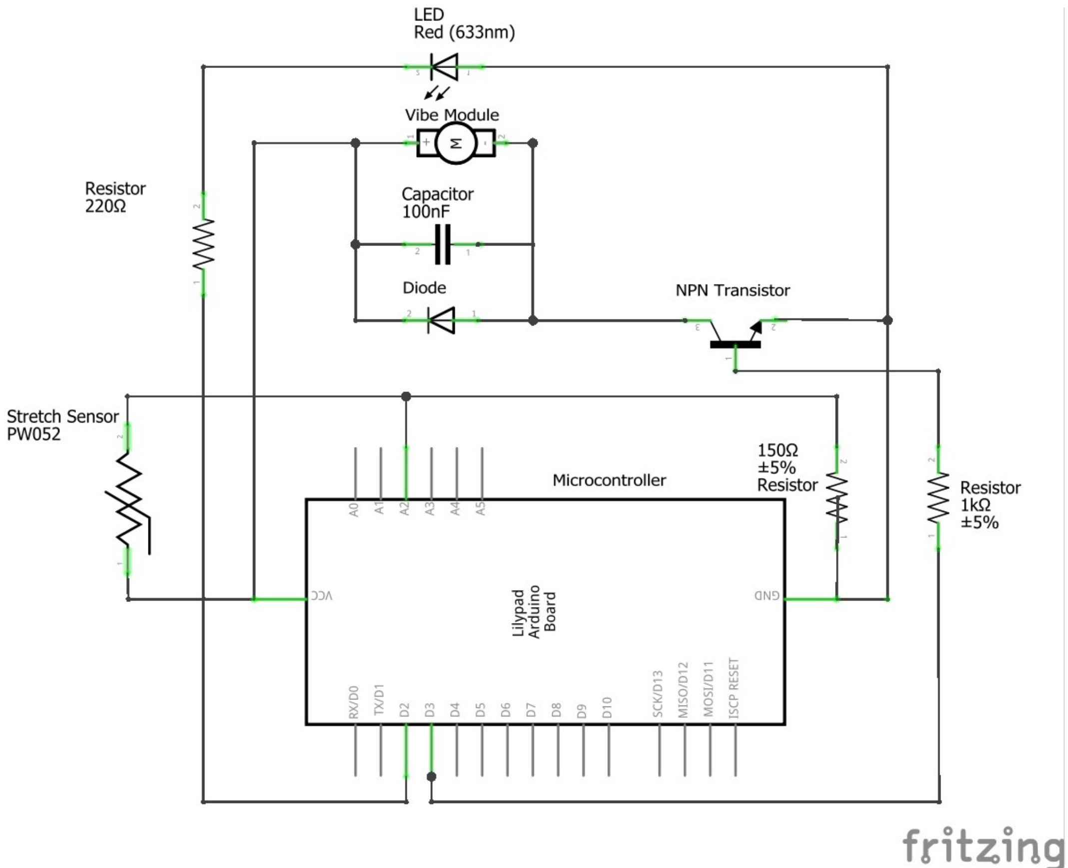


Figure 6: The schematic was created with Fritzing and depicts our prototype's circuit.

In this resource, it is carefully explained how a circuit containing a vibe module must be constructed and why a diode and a capacitor may be needed.

The NPN transistor that is used in the circuit above serves as a switch/control to power on the vibration module if its base (middle) pin gets the corresponding impulse from digital pin 3. This impulse is controlled by the microcontroller. We will have a look at when to start this impulse at the end of this section.

To incorporate the stretch sensor into the circuit, we must be aware that the sensor gives us a variable resistance resulting in a variable voltage divider. To connect the sensor successfully to the microcontroller, connect one end to the power source and the other end to an analog input. Next, connect an additional wire T1 to this connection. T1 will be used as the voltage divider that, hence, must be connected to a resistor of 150 Ohm. The other resistor's end is connected to ground.

Figure 7: Some predrawings of the final circuit were added onto the sleeve.

To connect the LED, we must add a resistor in between of the digital pin and the LED's anode. With that, we ensure to protect it from inappropriate voltage. The cathode is connected to the ground.

To realize the Fritzing circuit, first predraw the circuit on your sleeve as depicted in Figure 7. Then, sew the stretch sensor on its intended position. Sew the non-elastic ends of the sensor tightly at the designated locations and the elastic part a bit more loosely on the space in between. Next, sew the microcontroller, the vibe module, and the LED on the sleeve. Afterward, place the resistors, diode, capacitor, and transistor on their positions and stitch their metallic ends through the fabric such that they stick to their positions.

Sew or stitch the conductive yarn according to your predrawing on the stretched arm sleeve. It is important to stretch the sleeve while sewing as the conductive yarn itself is not elastic and could otherwise tear while wearing.

To connect two yarns, just knot one yarn's end around the other one and make sure that this knot is tight. This already suffices for a working connection. On locations where several yarns cross each other (which might be inevitable), make sure to insulate those points, e. g., by using Sugru or carefully adding some hot glue (which is insulating as well). Finally, there should not be any uninsulated yarn crossings left.

To connect the conductive yarn to the electrical components such as resistors or the transistor, form their small metallic pins into little loops around which you can easily knot the yarn. As the LilyPad already offers holes for their I/O pins, you can easily wrap them through the intended holes several times to establish a connection. You may fix all those connections again by carefully applying hot glue. Some detailed close-ups are shown in Figure 8.

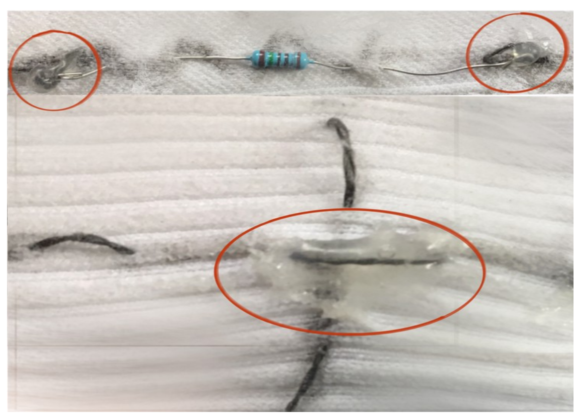


Figure 8: The red circled parts show parts of the circuit that were carefully isolated with some hot glue.

The resulting prototype is depicted in Figure 9.

Figure 9: Top left:Dorsal view on the prototype. Top right: Lateral view. Bottom: Ventral view.

Next, we must consider the working principle (code) of the prototype. For that, we need to find a threshold to which we will compare our sensor measurements. We propose to add an initial calibration phase to the system that starts when powering the wearable. The calibration phase begins with a double vibration signaling that we may now adjust our arm with the stretch sensor such that it is extended to a level that is close to overextension. Simultaneously to the vibration, the LED must blink. After a five seconds time frame in which we could adjust our elbow appropriately, we measure the stretch value. This is used as the reference value to which all further measurements are compared. There is again a double vibration and LED blinking signaling the end of the calibration phase. From that point in time, the microcontroller measures the sensor's value once in a second. If it is smaller than the initially set reference value, the vibration motor vibrates until a subsequent measurement finally exceeds the reference. In the code, we decided to add an error tolerance of 10% to the reference value as the measurements may not always be completely accurate.

The corresponding code can be retrieved from the [repository](). A demonstration video of our working prototype can be found [here]().

Lessons Learned

- The incorporation of the vibration motor into the circuit was a bit more complicated than initially thought. The reason for that are the voltage spikes that such a motor might generally produce. Those uncontrolled spikes may damage the microcontroller. Thus, prevention might come in form of a transistor, diode, and a capacitor which complicates the circuit slightly (see here for reference).
- Based on the point above, I discovered that there is a large variety of different transistor types. We not only differentiate between NPN and PNP transistors, but also between many different models. Some of those models slightly differ in their functionality, some are equivalent, and some are even outdated and cannot be bought anymore. In other words, one should carefully chose the right transistor.
- For crocheting the sensor, it is important to use conductive yarn that *really* works. While conducting some experiments, I found that some 'conductive' yarns did not show any reaction when connecting it to the multimeter. Thus, we should always first test the conductivity of the material before using it inside the prototype. Additionally, we must also ensure that the incorporated conductive yarn does not tear during crocheting as this destroys the functionality. Unfortunately, some yarns are very prone to tear.
- Another important aspect to consider is the correct use of the multimeter. Sometimes, I was wondering why the measured values are fluctuating although I am not touching the measured sensor. One reason for that might be the multimeter's low quality. Another one could be eliminated by having a closer look at the alligator clips I used to connect the multimeter to the sensor. When clipping the alligator

clips on/around the conductive yarn, one has to be very careful with their small teeth. I. e., the yarn should be wrapped closely several times within one tooth hollow. If not wrapped tight enough or if the upper and lower parts of the clip do not fit perfectly on each other, we trigger a loose connection. This may significantly distort the measurements. A video demonstrating this undesired behavior can be found in the repository.

- Currently, I am troubling with the power supply for the vibe module. As too few volts arrive at the vibration motor, its vibration is hardly perceivable. Thus, I must still find a way how to boost the voltage before arriving at the motor.

Vision and Outlook

First of all, we found that the vibration feedback is too weak. This should be the next point on which work must be done.

Next, the design could be improved. We should try to hide technical parts and use an elastic conductive yarn to make the sleeve more comfortable to wear. We could further advance the design by trying to integrate the stretch sensor directly inside the elastic sleeve instead of sewing a sensor on top.

Instead of using a fixed reference value and error tolerance of 10%, we could integrate an IMU into the prototype and an Exponential Weighted Moving Average into the code to achieve more precise measurements. The reason for that is, inter alia, that the elasticity of the sensor could decrease while in use (which should definitely be considered) leading to incorrect pose estimations.

Finally, to improve user experience, we may think about replacing the sleeve by a stretchable plaster or a wearable “tattoo” that sticks on the skin and carries our stretch sensor technique inside.

Resources

- Repository: https://github.com/zitos97/InterSys20
- Crochet Video 1: https://www.youtube.com/watch?v=aAxGTnVNJiE
- Crochet Video 2: https://www.youtube.com/watch?v=g86s0c9NzB0
- Vibe Module: http://www.learningaboutelectronics.com/Articles/Vibration-motor-circuit.php

Video

This is the link to the demonstration video: https://youtu.be/dP-_t6vw2Vw

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