Catsuit : Technical Report

CatSuit is an easy-to-make e-textile platform. Fully integrated textile-based sensors detect touch, position, and meshes deformation. This project presents playful applications of e-textile. CatSuit aims to make e-textile technology more accessible to non-professionals.

Textiles were invented 27,000 years ago [1]. Their methods of designing, manufacturing, and processing assemblies have been optimized over millennia of technical innovations.[2]. **Smart textiles, or electronic textiles (e-textiles), are fibers, yarn, and fabric that sense and react to environmental conditions.** [3]

The first examples of electronic textiles date back to 1883. French dancers used illuminated headbands during the ballet La Farandole [4]. Academic settings paid attention to e-textiles in the late 1990s, after a series of publications from the Massachusetts Institute of Technology (MIT) and the Georgia Institute of Technology [5]. In 1997 Post and Orth made a Musical Jacket[6][7]. It is a wearable stand-alone musical instrument. The garment includes capacitive sensing on a MIDI keyboard embroidered directly into the fabric. In 2010 Coyle et al. realized the BIOTEX project[8]. They developed textile sensors to measure physiological parameters and the chemical composition of body fluids. In 2018, Skach et al. designed an embedded MoCap system for body-centric sonic performance [9]. The performers can manipulate sounds through gestural interactions captured by textile wearable sensors.

Despite the significant progress of research, either academic or industrial, in e-textile, the access to the **technology is restricted for non-expert users**. The most available form of e-textile is used by the cosplay/DIY community to enhance the visual aspect of their creations, which is far from the e-textiles' full potential. The difficulty of the technology lies mainly in the fact that almost everything has to be re-invented as the emphasis is placed on the seamless integration between the fabric and the electronic elements, such as cables, microcontrollers, sensors, actuators, and power supply. Today, **three generations of e-textile technologies exist**. The first integrates classical electronic devices (wires, integrated circuits, LEDs etc.). The second generation integrates modern electronics directly on the textile fibers of garments. The third generation refers to active garments where the fiber itself is built as a sensor or actuator (third generation).

CatSuit aims to make the first and second e-textile generation more accessible to the general public. This project focuses on fast-prototyping practices. Sensors/displays conception request sewing and electronics techniques. They are easily accessible for beginners in both fields. Electronic materials are available on the Adafruit website and are frequently used in the cosplay world. Electronic boards involved are widely used in DIY projects. Sewing materials are available in sewing shops and websites. CatSuit provides an essential understanding of electronics integration stakes. offers playful and artistic applications of e-textile. **This project gives everyone the necessary tools to build a garment producing music with movements**.

I Architecture detail:

Different mechanical movement sensors capture the movements of the wearer. The microcontrollers (ESP8266 Wemos Lolin D1 mini) sends this data. Audio-visual feedback is released when the information is transmitted.

The system architecture looks like this:

There are two stretch sensors placed on the right and left elbows to sense the stretch of the fabric when the elbow bends.

To measure the orientation of the arms and the torso, inertial sensors are placed respectively on the bottom of the right and left deltoids and the middle of the rib cage.

To measure the grip of the wearer's sleeve, crumple sensors were placed at the ends of both sleeves.

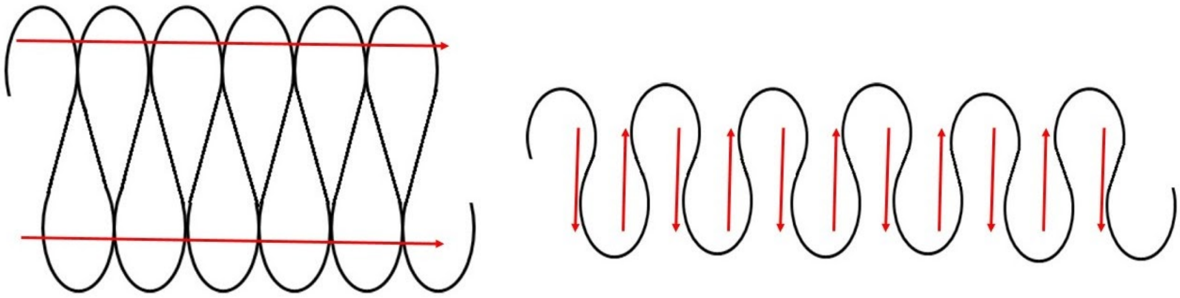
The microcontrollers are placed above each inertial sensor.
Headphones are embroidered into the hood so the wearer hears the music. LEDs are placed at the elbows

Sensing Interfaces :

- <u>stretch sensor :</u>

Stretch and crease sensors are very similar, as both have a resistance that will play out depending on the points of contact.

Stretch sensor [10] stretching the fabric increases the electrical resistance along the conducting wire. This is due to the opening of the mesh and thus the breaking of the parallel contact points, forcing the current to flow in series rather than parallel. This increase in the conductive path results in greater resistance as shown in the figure :



(a) (b)

Figure : Sketch of working principle of the stitch-based sensors with relaxed (a) and stretch (b) state

- <u>crumpling sensor</u>

Using the contact points, we suppose that other types of sensors (e.g. crumpling sensors) can be created. Instead of breaking the contact points to obtain a positive change in the resistance, we can use the contact points created by a crumpled textile, thus creating a negative change in the resistance, to detect a grip for example.

While the stretch sensor uses the break of contact points to create an increase in the resistance, the crumpling sensor uses the creation of contact points to create a decrease in the resistance. When the fabric is crumpled, voluntary "short circuits" are created : the current flow is not following the conductive path and parts of it are left out, therefore creating the decrease in the conductive ran through path.

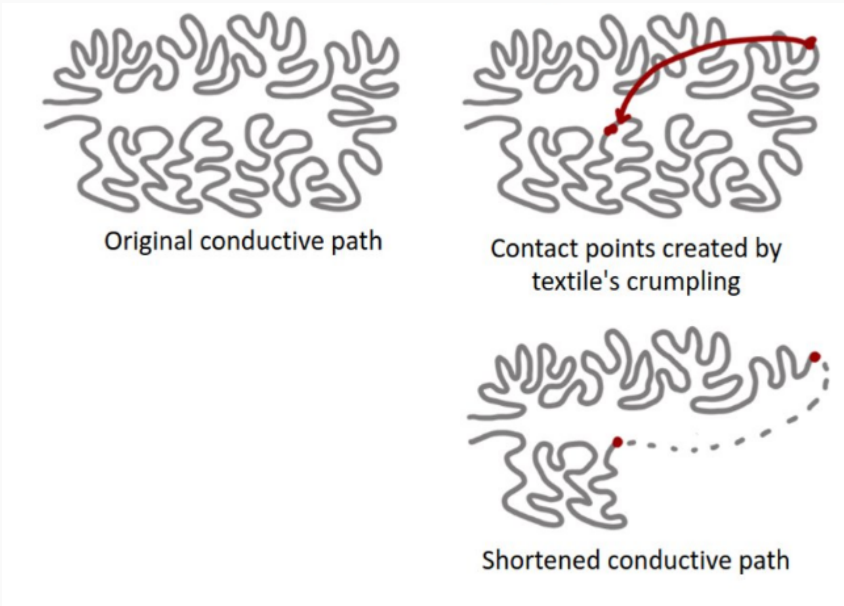


Figure : Sketch of working principle of the crumpling sensor

- <u>accelerometer sensor</u>

A 3-axis accelerometer tells which direction is down the earth. We used an off the shelf component from adafruit. The product is designed to be easily sewable with its large mountable hole and large plates [15].

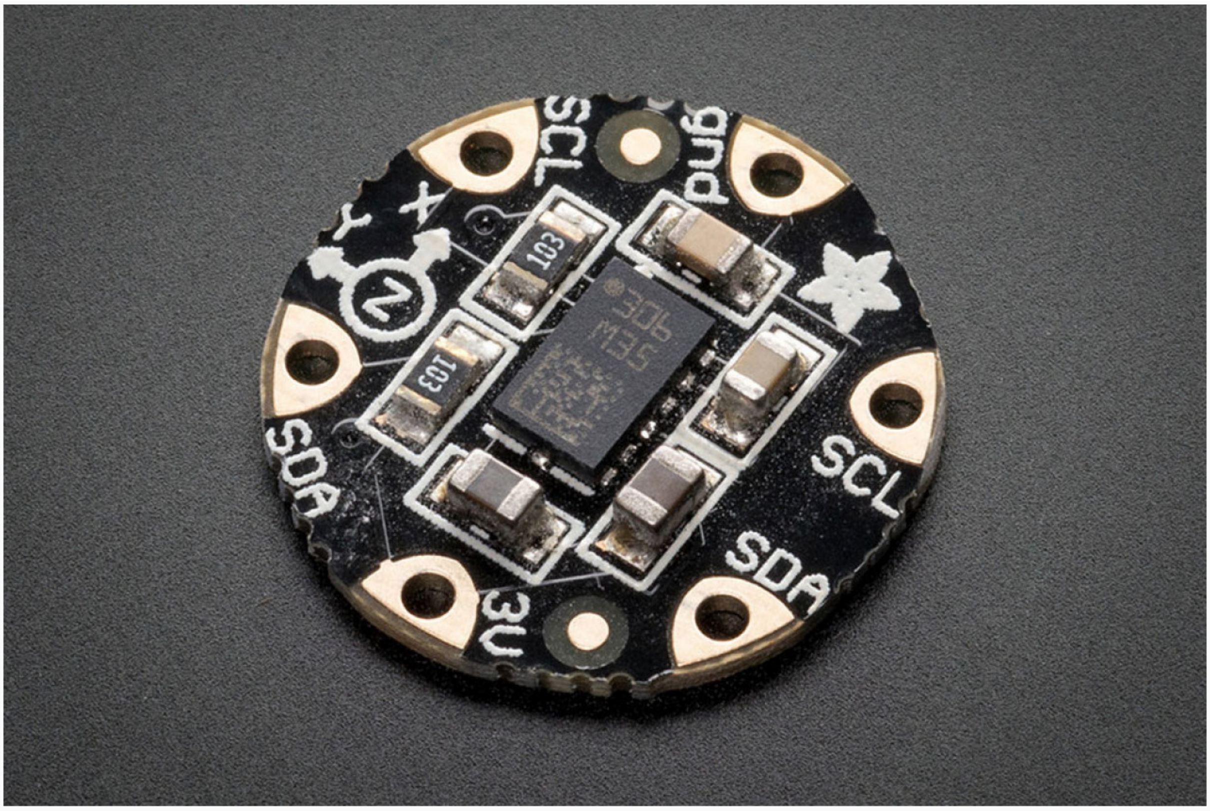
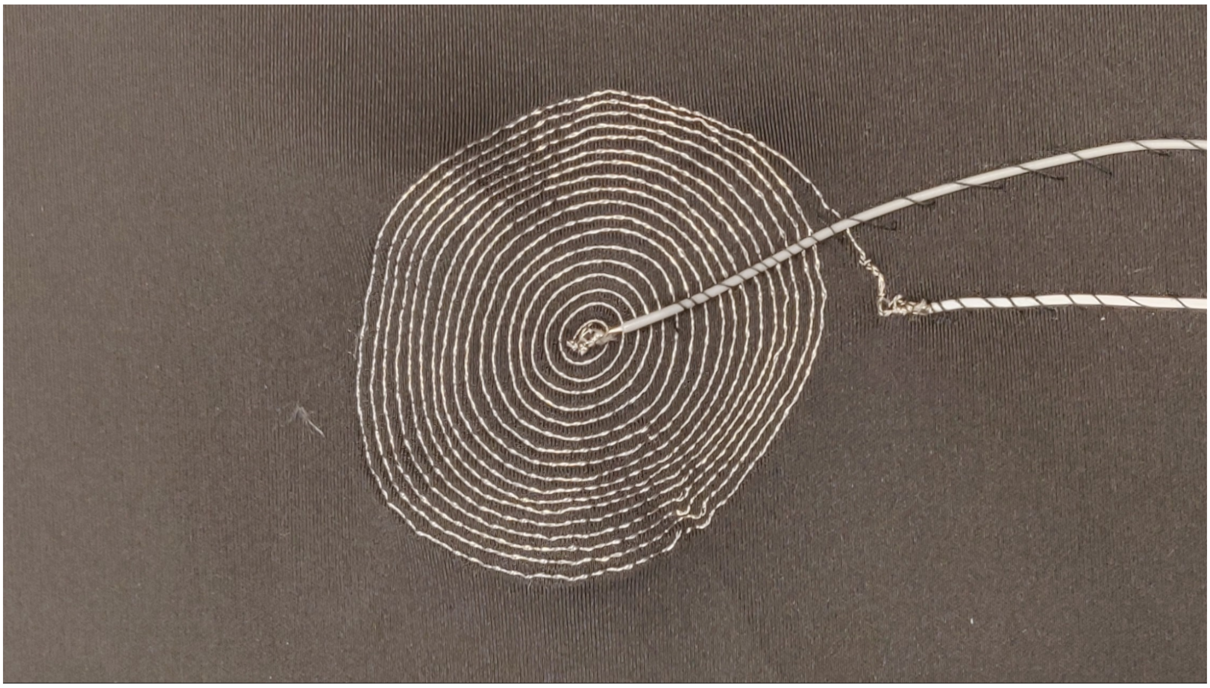


Figure : Picture of accelerometer connected to Wemos D1 mini

Interactive Interfaces :

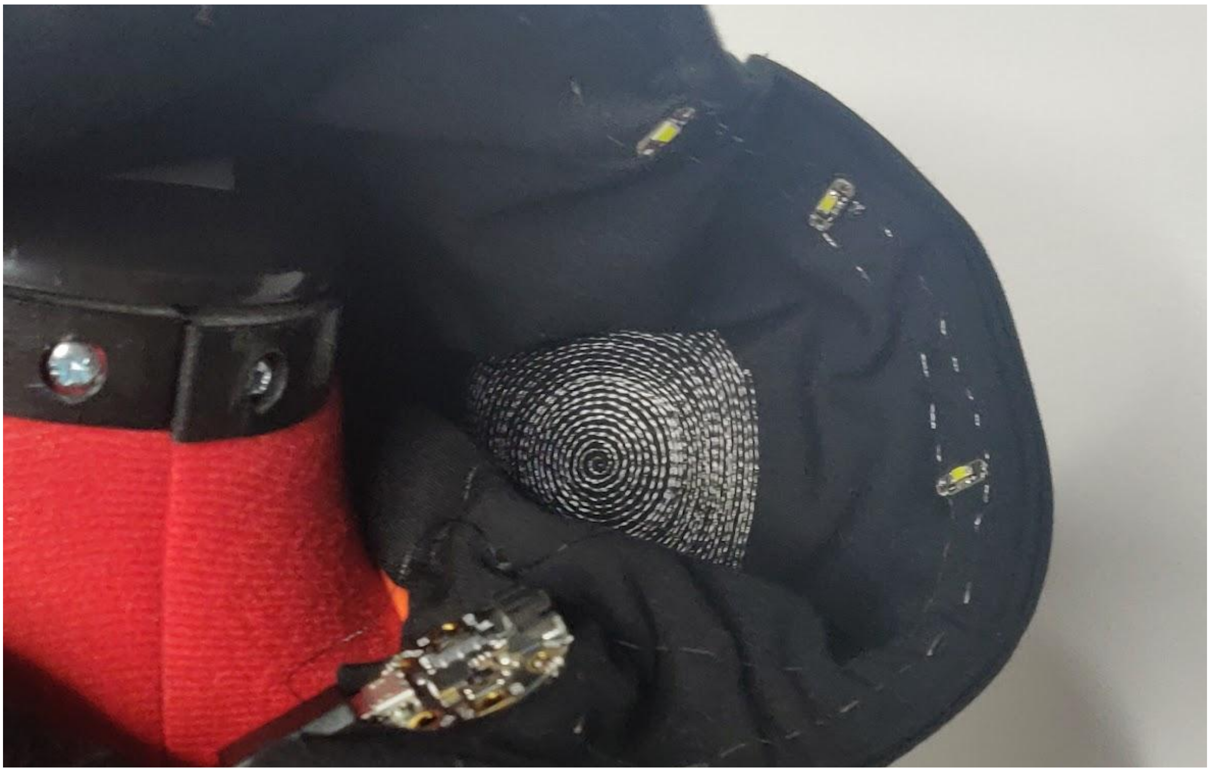
- <u>Soft Speakers :</u>

The speaker works with an electromagnet (the embroidered coil) mounted to a membrane [12][13][14](the fabric) with a permanent magnet. A fluctuating magnetic field is formed around the electromagnet (coil) when an audio signal is connected to either end of the loop. The magnetic field attracts and repulses the membrane repeatedly to the permanent magnet. The membrane moves the air locally around it. This mechanical perturbation creates hearable sound waves.



Picture of embroidered speaker with cables attached

For this part the Janome MB4S embroidery machine is used. since we are going to make a complex diagram that would require a lot of time at the sewing machine.



Picture of hood with embroidered speaker

- <u>Led Interfaces</u>

The LEDs are here used for the aesthetic part. Led sequins [16] are used. They are small and easy to sew on the garment

Lighten up LEDs on CatSuit

- <u>Cables.gl</u>

Cables.gl is a new WebGL-based tool for building out and compositing real-time VFX looks. It runs right in the browser, but with features and performance normally associated with standalone software. The data are sent to a local server and cables.gl gets the data and processes them.

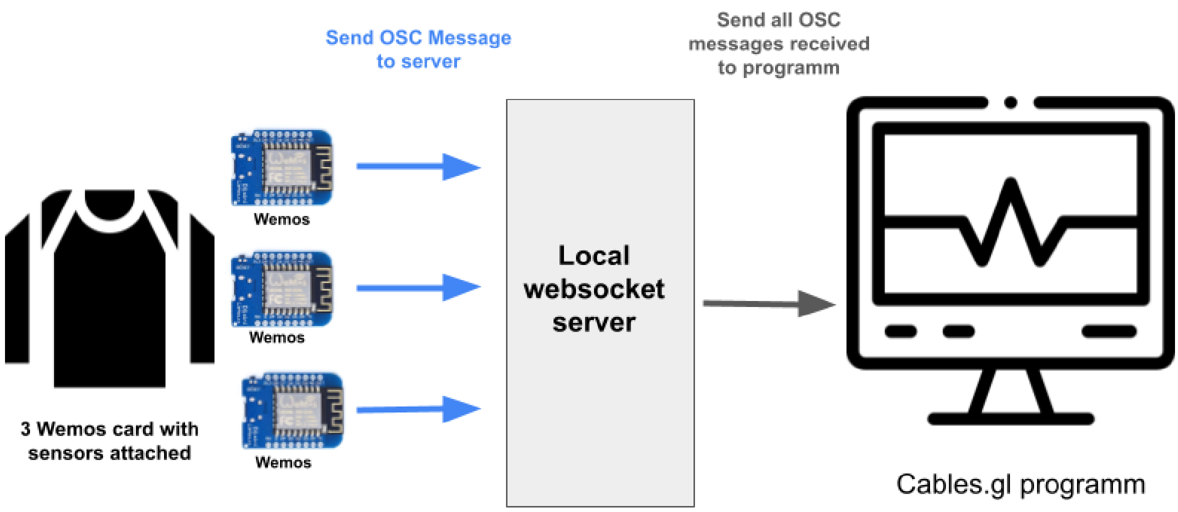


Figure : System architecture

II Materials & Manufacturing

As we're aiming for facilitating access to technology, we're focusing on DIY / crafting tools. For sewing we use a Brother CS6000i Sewing and Quilting Machine and for embroidering a JANOME MB-4S. Adafruit Stainless Thin Conductive Thread and Suzhou TEK's Anti-static Silver Coated Conductive Thread were chosen for the applications.

We use Lolin Wemos D1 mini for prototyping. The boards are affordable and have Wi-Fi support, which allows us to send data via Wi-Fi or create a server, I2C port - to connect the gyroscopic sensors and analog I/O port stretch and crease sensors.
A bi-stretch 1 mm thick jersey fabric (72\% Polyester, 23\% Viscose, 5\% Elastane) is used as support to make the garment.

Conductive thread is slightly stiffer and more fragile than normal polyester thread when exposed to the mechanical stress of the sewing and embroidering machines. Therefore, several threads were tested to evaluate their practicality: Adafruit Stainless Thin Conductive Yarn / Thick Conductive Thread, Stainless Thin Conductive Thread - 2 ply, Stainless Medium Conductive Thread - 3 ply, as well as Anti-static Silver Coated Conductive Thread from Suzhou TEK Silver Fiber Technology Co., Ltd. Each thread was used as top spool and bottom bobbin in both the sewing and embroidering machines, and hand-sewn.

Board connection

The Lolin Wemos D1 mini is directly sewn onto the garment. Using Stainless Medium Conductive Thread - 3 ply. The connections are hand sketched and imported in DRAWings as .png file. The image is vectorized, rescaled and transformed in a ISO 301 stitch (2 mm stitch length). The other elements (sensors) are added to the design and embroidered upside-down using the same stitch on the outside surface of the sleeve.

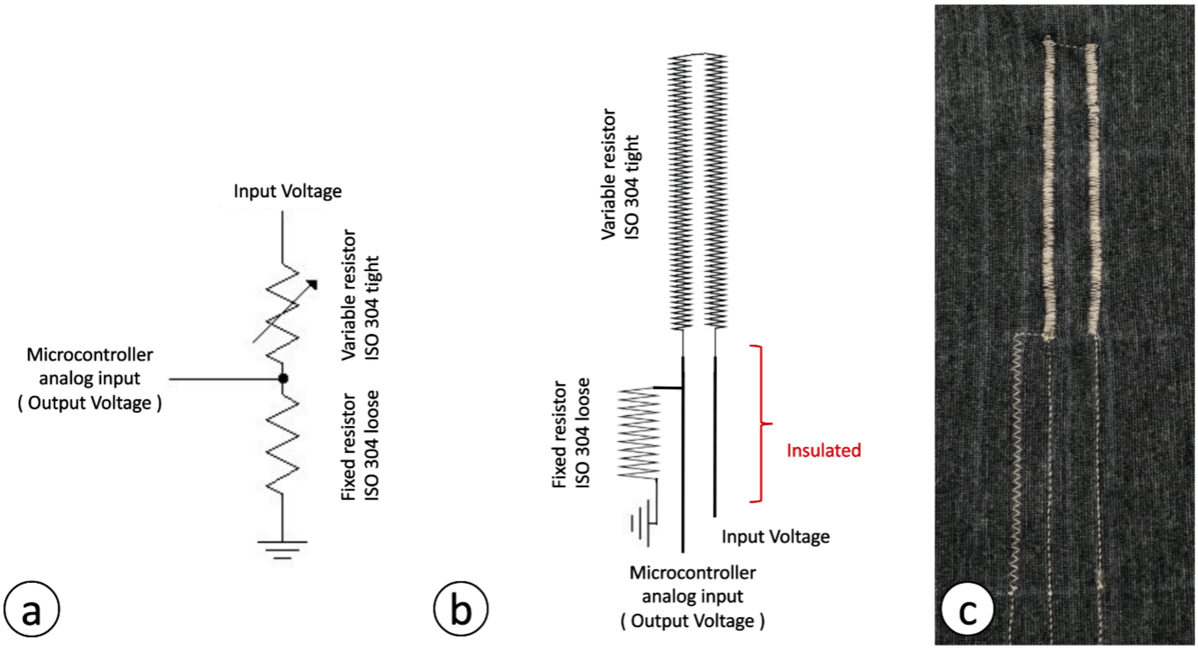
Sensors interfaces

Stretch sensor

- Manufacturing & Tools

The stretch sensor (Fig. \ref{fig: stretch}) is the textile analogy of a variable resistance voltage divider that uses the conductive path length change created by the stretch of the ISO 304 tight stitch as a variable resistor and a loose ISO 304 stitch as the fixed resistor. The connecting stitches and the fixed resistor are embroidered upside-down, while the ISO 304 tight stitch is done using the sewing machine using a stitch length of 0.3 mm and a stitch width of 4 mm. The design of the variable resistor allows the fabric to stretch in both directions, while the design of the insulated stitches allows only perpendicular stretching of the fabric.

- Connector & Integration



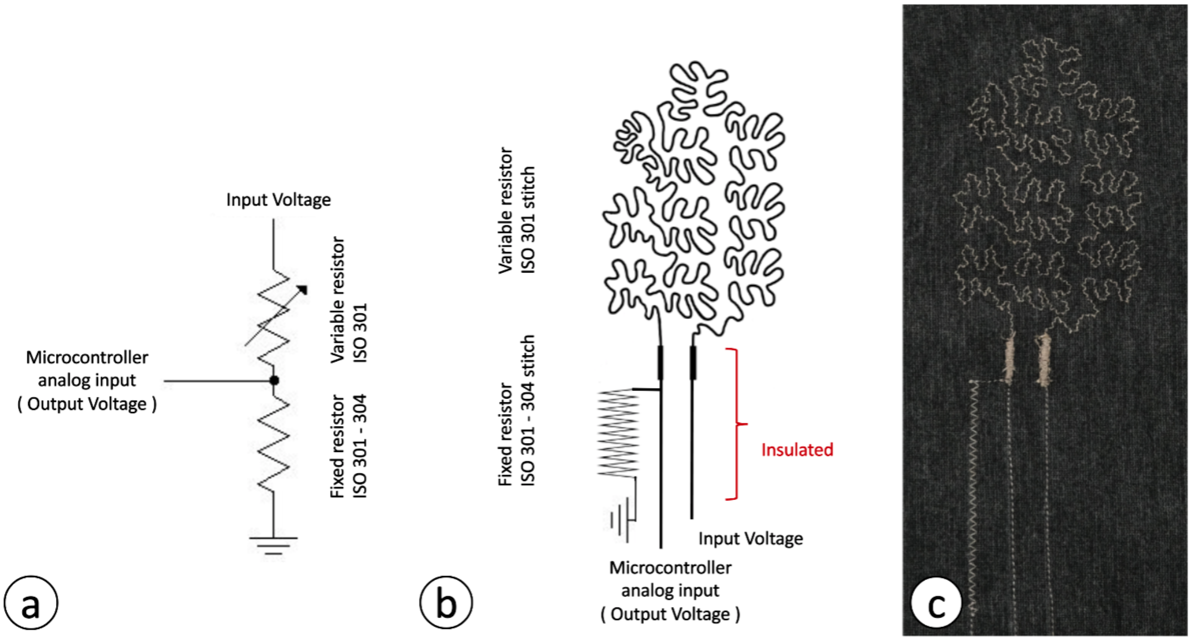
In this example the fixed resistor was measured at 65 Ω (6cm long, ISO 304 1.4 mm long x 4 mm wide stitch) and the variable resistor ({ISO 304 0.3 mm long x 4 mm wide stitch) at 460 Ω in normal state (7.5cm long each side) going up to approx. 695 Ω when stretched (10.8 cm long measured at the base of the sensor).

Crumpling sensor

- Manufacturing and tools

The sensor's design is hand-sketched and imported in DRAWings as a .png file. The image is vectorized, rescaled, and transformed in an ISO 301 stitch (2 mm stitch length). The other elements (fixed resistor and a part of the connecting wires) are added to the design and embroidered upside-down using the same stitch on the outside surface of the sleeve. Therefore, the design of the variable resistor allows the fabric to stretch in both directions, while the insulated stitches allow only perpendicular stretching of the fabric.

- connector and integrations



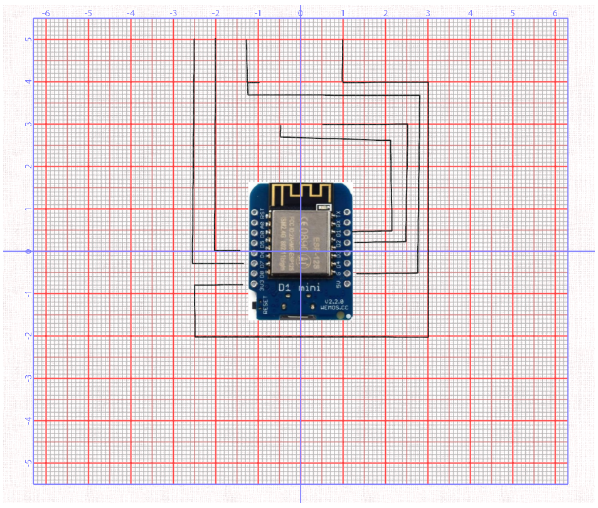
In this example the fixed resistor was measured at 67 Ω (6cm long, ISO 304 1.4 mm long x 4 mm wide stitch) and the variable resistor (ISO 301 2 mm stitch) at 590 Ω in normal state going down to approx. 115 Ω when the textile is grabbed (measured at the base of the sensor).

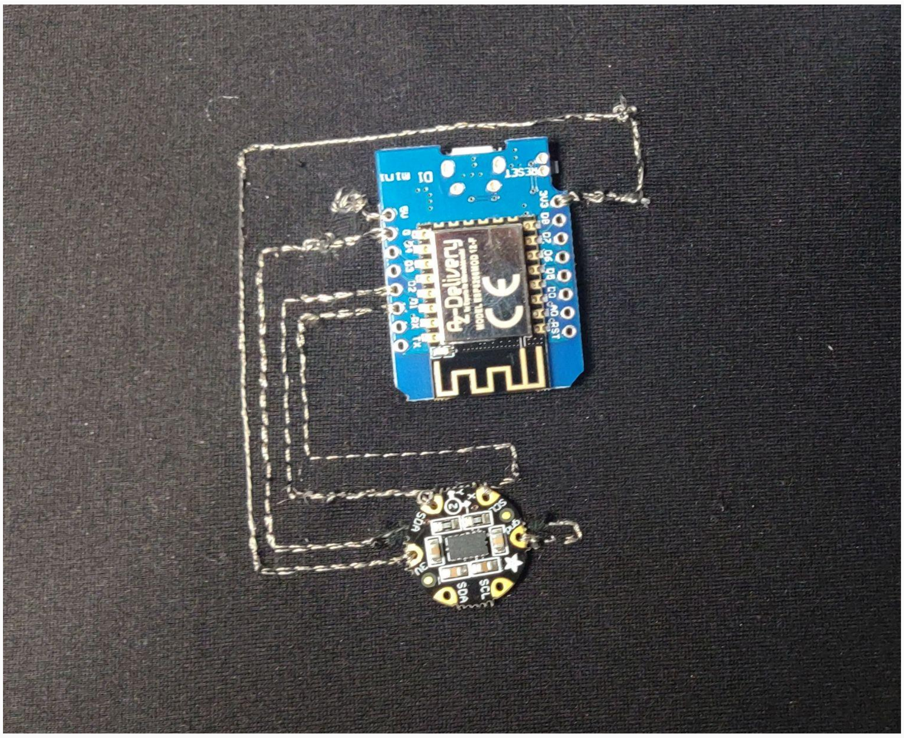
Please find below a step by step tutorial to create the sensors:
https://dvic.devinci.fr/tutorial/capteurs-textiles

Gyroscopic sensor

- Manufacturing and tools

The sensor is an off-the-shelf gyroscopic sensor, so it is directly sewn on the fabric.
The design of the connector is hand-sketched and imported in DRAWings as a .png file. The image is vectorized, rescaled, and transformed in an ISO 301 stitch (2 mm stitch length). The design is embroidered upside-down using the same stitch on the outside surface of the sleeve.





- connector and integration :

This sensor has a digital (I2C) interface. It is connected to the Wemos D1 mini through SDA/SCL pin (D1/D2 on the Wemos). The sensor is lined up to the wemos, adjacent to the D1/D2 pins, and sews conductive thread from the 3V, SDA, SCL, and GND pins. The connections are sewn using Stainless Medium Conductive Thread - 3 ply to ensure the data flow along the thread.

Interactive Interfaces

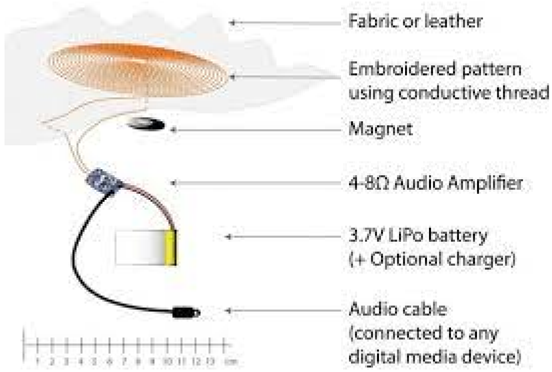
<u>Soft Speaker</u>

- Manufacturing and tools

The sensor's design is hand-sketched and imported in DRAWings as a .png file. The image is vectorized, rescaled, and transformed in an ISO 301 stitch (2 mm stitch length).
Cables are attached at the center and the extremity of the coil for better signal transmission.

- Connector and integration

Cables are attached to the center and the extremity of the coil to conduct the signal.
A neodymium magnet is sewn to the center of the speaker to create the magnetic field. Then a Bluetooth amplifier is connected to the cables to get the sound from the computer.



LEDs

- Manufacturing and tools

The LEDs are off-the-shelf sewable LEDs, so it is directly hand sewn on the fabric.
The design of the connector is hand-sketched and imported in DRAWings as a .png file. The image is vectorized, rescaled, and transformed in an ISO 301 stitch (2 mm stitch length).
The design is embroidered upside-down using the same stitch on the outside surface of the garment.

- Connector and integration

They are powered by Gemma microcontrollers and receive a 3.3V current. They are sewn on the sleeves and hood.

Cables.gl

To collect and process the data using Cables.gl, please find on the GitHub CatSuit repository all the code.
To transmit the data a server is launched on the computer [17].
All the .ino files are uploaded on their respective microcontroller, they allow them to connect to the wifi and the server, and send the data to the server as OSC Message.
If there is any problem with connection to the server, make sure the server is active and the address in the .ino code corresponds to the one displayed at the launch of the server.

Experimentations and Evaluations

A CatSuit prototype was made and presented to a group of people.
The program connected to the CatSuit produced music according to the movement of the garment.
The program did not indicate to them the results of specific movements. The only feedback the users had was audio feedback.

Since the electronic boards were visible, the group quickly understood that they had to interact. However, they did not understand that sound was coming out of the hood.

Moreover, the changes in the music according to the movements of the garment were not noticeable. So the users did not notice that the music reacted to the activities.

The garment was modified according to the reaction of the group. LEDs were sewed onto the sleeves and around the hood to indicate the presence of the sensors and actuators.
Moreover, the code that changes the music according to the movements of the clothing has been modified.

Conclusion

The cards are much smaller than the adafruit circuit playground used before, but they are still uncomfortable. However, the placement of the cards depends on how the garment is used. If the SmartSuite is used for a ground fighting sport like judo, the cards will not be on the shoulders but in places with little grip and contact with the mat.

Though the ESP8266 Wemos Wifi development board is small and widely used, they are rigid and hardly sewable.
Designing and manufacturing sewable and flexible micro-controllers or adapting the development board by creating flexible sewable breakout boards will be a step further towards increased wearability.

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