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Evaluation and Characterization of sensors as part of a smart glove for monitoring wrist movements

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Abstract

This Project is about the Evaluation and Characterization of sensors as part of a smart glove for monitoring wrist movements. The smart glove includes two flexible sensors which measure flexion and extension movements of the wrist, and a pressure sensor which measures forces applied to the thumb. The Labview 2014 software was used to make the measurements from the sensors. The behaviour of the flexible sensor has been analysed for different bending angles while for the pressure sensors, different forces have been applied to their surface. The behaviour of the sensors has been characterized inside and outside the glove and the results were compared. When inserted in the glove, the flexible sensor allows more stable measurements with nominal values in their flat position of 10 kΩ ± 3 kΩ; however, when pressure sensors are inserted in the glove they move which interferes with the measurements.

Keywords

Flexible sensor, Pressure sensor, Resistor, LabView, Glove

Acronyms

MSDs: Musculoskeletal disorders
WMSDs: Work-related musculoskeletal disorders

Contents

1. Introduction

Musculoskeletal Disorders or MSDs are soft-tissue injuries caused by sudden or sustained exposure to repetitive motion, force, vibration and awkward positions. These disorders can affect the muscles, nerves, tendons, joints and cartilage in the upper and lower limbs, neck and lower back [1]. Musculoskeletal disorders are a complex issue which is not always easy to prevent, diagnose or treat. These disorders affect people from all over the world and have a considerable socio-economic impact. Musculoskeletal disorders have impact costs both directly (compensation of victims, medical care, etc.) and indirectly (work activity disruption, loss of production, replacement costs, absenteeism, etc.) which in turn affects workers, companies and society in general [2].

Although the causes of MSDs go beyond those related to the workplace, a considerable proportion of diagnosed Musculoskeletal disorders derivate from activities carried out at work and receive the name of Work-related musculoskeletal disorders (WMSDs). MSDs are the single largest category of work-related illness, representing a third or more of all registered occupational diseases in the United States, the Nordic countries and Japan. It is estimated that the prevalence of upper extremity symptoms (total number of WMSDs cases) is about 30% but may be higher, causing more work absenteeism or disability than any other group of diseases [3]. According to HSE statistics for the year 2016/17 [4], the prevalence in Great Britain was 507.000 out of a total of 1.299.000 for all work-related illnesses, which is 39% of the total and a rate of 1.550 cases per 100.000 workers; but the rate of total self-reported work-related musculoskeletal disorders showed a generally downward trend. The incidence (number of new cases of WMSDs) in 2016/17 was 159.000, with an incidence rate of 480 cases per 100.000 workers.

Since several WMSDs are not reported as work-related accidents, instead of evaluating WMSDs over the total number of accidents it would be more convenient to evaluate the number of days lost due to WMSDs. As reported by HSE report [4], 8.9 million working days were lost due to WMSDs in 2016/17 in Great Britain. This means that 35% of all working days lost due to work-related ill health correspond to work-related musculoskeletal disorders.

Hand, wrist and arm injuries are the most prevalent after lumbar spine/trunk injuries. In 2016/17, there were 3.9 million working days lost due to upper limb disorders in Great Britain [4]. This means that 43,8% of working days lost due to work-related musculoskeletal disorders correspond to hand, wrist and arm injuries.

Such a high prevalence of WMSDs has encouraged research about the causes, risk factors and practical solutions to prevent and palliate these disorders. It is known that some of the risk factors that can affect workers are: awkward postures, excessive efforts and musculoskeletal loads, static muscular work and repetition and invariability of work. Moreover, workers usually push themselves to the limits of their physical capacity. As a result, the lack of control that workers have over their work has a significant impact on the tension they can feel being a major factor in the development of a WMSD [2].

Rotation can reduce the exposure of the employees to risk factors [2], but it can be problematic to implement in line production or when a special formation is required. On the other hand, training the employees can be a prevention strategy to avoid WMSDs [2]. But it is necessary to consider that every worker will have different physical conditions and a "proper work method" cannot be taught as an only and general instruction. Therefore, it would be more effective to train employees in the early detection of symptoms. In combination with the training, the company should carry out an individualized follow-up with every worker.

Regardless, to avoid the occurrence of work related injuries it is necessary to perform ergonomic improvements of working conditions. Ergonomic improvements can be based on ergonomic studies and should incorporate the feedback from the workers. The process of improvement should include monitoring workers to assess whether the introduced changes are improving the working conditions of the employees.

Nowadays it is challenging to develop indicators to detect workers at risk of suffering a musculoskeletal disease. The development of wearables which monitor the movements and the consequent data analysis will allow researchers to establish reliable indicators. These indicators can be used to improve the detection of musculoskeletal injuries from the first symptoms. Furthermore, with the data collected from the wearable measurement systems, it would be possible to detect what movements or loads are originating certain musculoskeletal injuries.

The motivation of this project lies in being able to develop a glove that uses sensors to measure flexion and extension movements and loads applied to the thumb. Based on the technology selected for wrist angle measurement, a complete electrical, instrumental, contextual and positional characterization of each individual sensor that comprises the glove device will be made.

1.1. Aim and objectives

The aim of this project is to characterize the sensors of the glove, which is part of an automatic system of risk assessment tools in real time used for the prevention of MSD in the long term. The project has the following objectives:

- Determining the resistors values in different measurement conditions.
- Studying the differences in behavior when the sensors are measured outside and inside the glove, taking into consideration the possible interferences in the measurements due to the incorporation of the sensors to the fabric.

1.1. Limitations

- The sensors to be characterized are Spectra Symbol FSL-0095-103-ST flexible sensors and Interlink Electronics FSR Model 400 force sensing resistor. No other flexible or force resistors will be studied.
- The sample size: N=9 for flexible resistors and N=10 for pressure resistors
- Effects are only studied with respect to bending angle and force applied.

2. Background

2.1. Development of musculoskeletal disorders

Musculoskeletal disorders include a wide range of inflammatory and degenerative conditions affecting the muscles, tendons, ligaments, joints, peripheral nerves and supporting blood vessels [3]. In aging populations, workers are more vulnerable to musculoskeletal injuries, especially when unemployment rates are high and mobility is not encouraged. In these conditions, finding a new job can be arduous and workers will maintain their job position even though it leads to a work-related musculoskeletal disorder (WMSD). These injuries result from overuse, exceeding the body's recovery capacity, and occur because a structure is abused repetitively and is made to endure a work load that it cannot tolerate without negative consequences [2].

The development of WMSDs occurs over time and progress gradually with repeated overuse and inadequate recovery. The first symptoms can be early indicators of a more severe hurt condition. When WMSD is fully declared, the patient is suffering from discomfort and pain regardless of the absence of movement or effort. In this case, pain will be noticeable outside of work and people may need several weeks without performing their normal activity to recover from their condition. Even so, after a serious musculoskeletal disorder, full recovery is not guaranteed and affected tissues may remain susceptible to suffer from these kinds of injuries in the future. Hence early detection is essential to avoid further risk [2].

Because of the gradual appearance of WMSDs, the body will get used to the discomfort and pain and early detection can become a challenging task; but the gradual appearance of these conditions could be an advantage. With the help of wearables which monitor the movements of workers, musculoskeletal disorders could be anticipated through the detection of initial symptoms.

2.2. Common musculoskeletal disorders and structures affected

Repetitive movements involving the wrist and the elbow can be the cause of diverse injuries as tendonitis, tenosynovitis and the carpal tunnel syndrome.

Tendonitis is the inflammation of a tendon. Tendons are structures of fibrous connective tissue that connect muscles to the bones, allow the movement of the bone and stabilize the structures. In the upper limbs, the biceps are attached to the shoulder and the forearm by a tendon. When this muscle contracts and shortens, it pulls on the tendon and causes the forearm to bend [2].

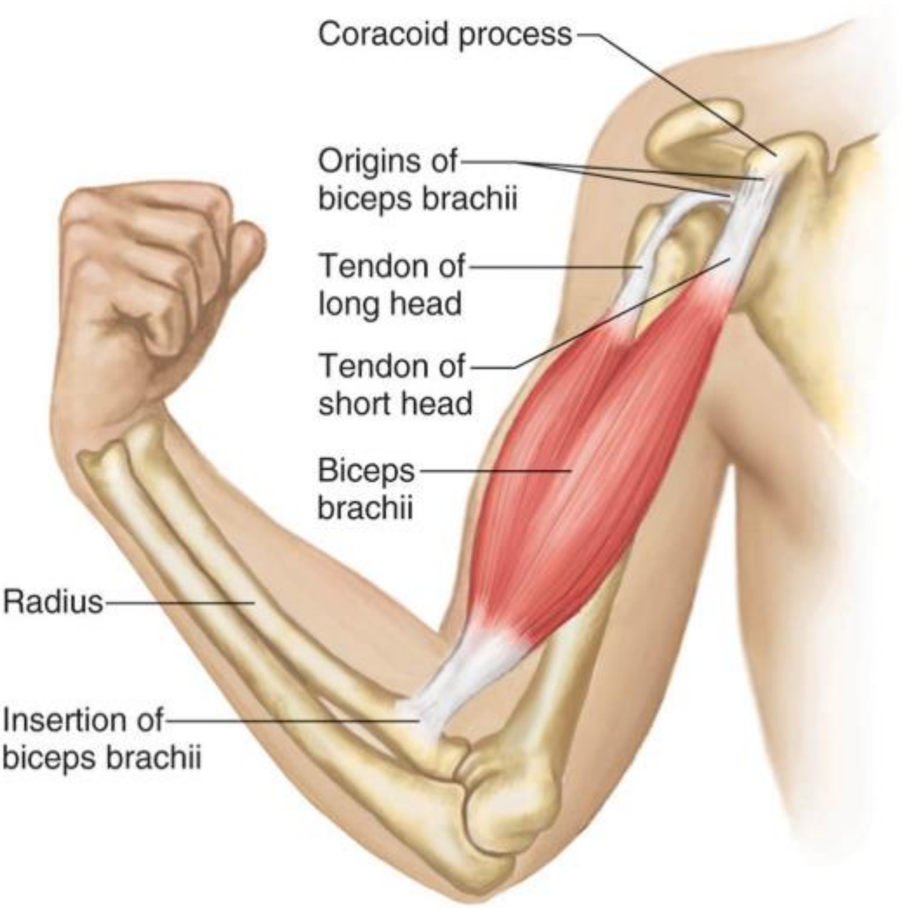


Figure 1. Tendon and muscle insertion in forearm [5]

Tendons work together with muscles. Therefore, if muscle overload occurs, the tendons will also be affected. When the tendon is damaged after an accumulation of microscopic injuries, the body's reaction to repair the damage will be inflammation with signs of swelling. If the overuse persists, an injured tendon, swollen by inflammation is even more susceptible to tendonitis [2].

Tendonitis in the upper limbs can affect the shoulder, elbow, wrist and fingers. The fine movements of the hand are controlled by muscles attached to the finger bones by long tendons. Production line workers, who repeatedly perform the same movements with their wrists, are more vulnerable to these injuries.

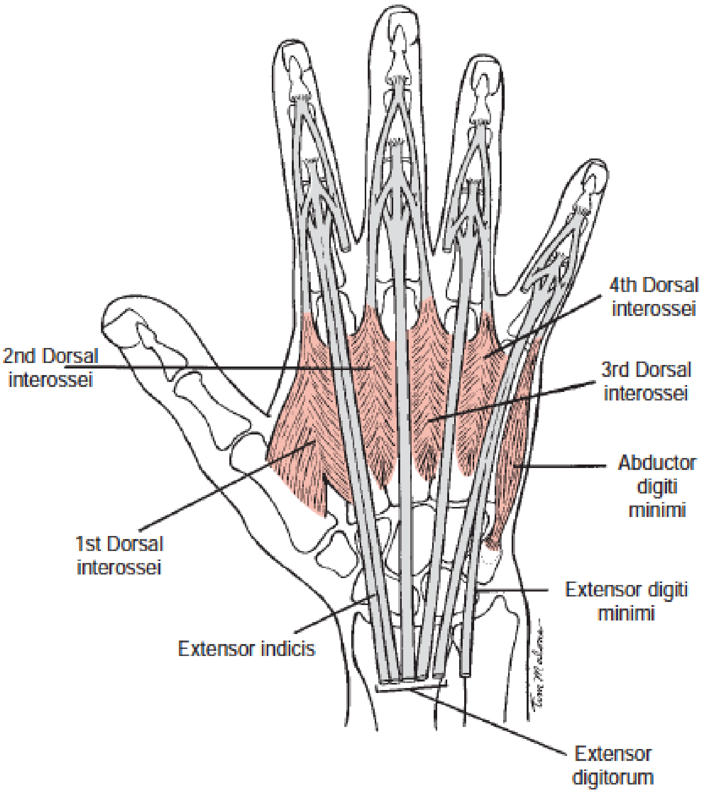


Figure 2. Extensor tendons attach the finger bones to the muscles [6]

Another common WMSD is tenosynovitis. Tendons are surrounded by a synovial sheath to be protected from excessive friction. These sheaths serve as lubricating covers that enclose the tendon in a space where it can glide freely in a lubricating fluid called synovia [2], but these tendons are still vulnerable to overuse. When the tendon swells due to tendonitis, the inflamed tissue compresses the tendon sheath which can become irritated and inflamed. The simultaneous inflammation of a tendon and its surrounding synovial sheath is known as tenosynovitis.

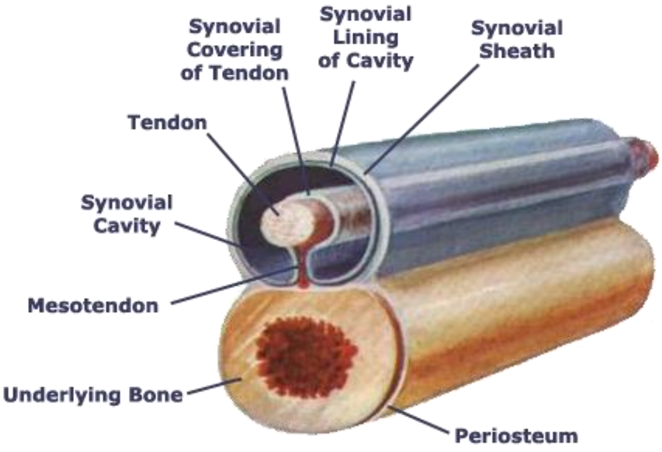


Figure 3. Anatomy of a tendon sheath [7]

The wrist joint is susceptible to WMSDs as well. This joint is made up of the carpus bones which form a cavity called the Carpal tunnel. The tunnel encloses different tendons, nerves and blood vessels. Carpal Tunnel syndrome occurs when the nerves inside the cavity are compressed due to swelling of the adjacent tendons. The symptoms associated with Carpal Tunnel are numbness and muscle weakness [2].

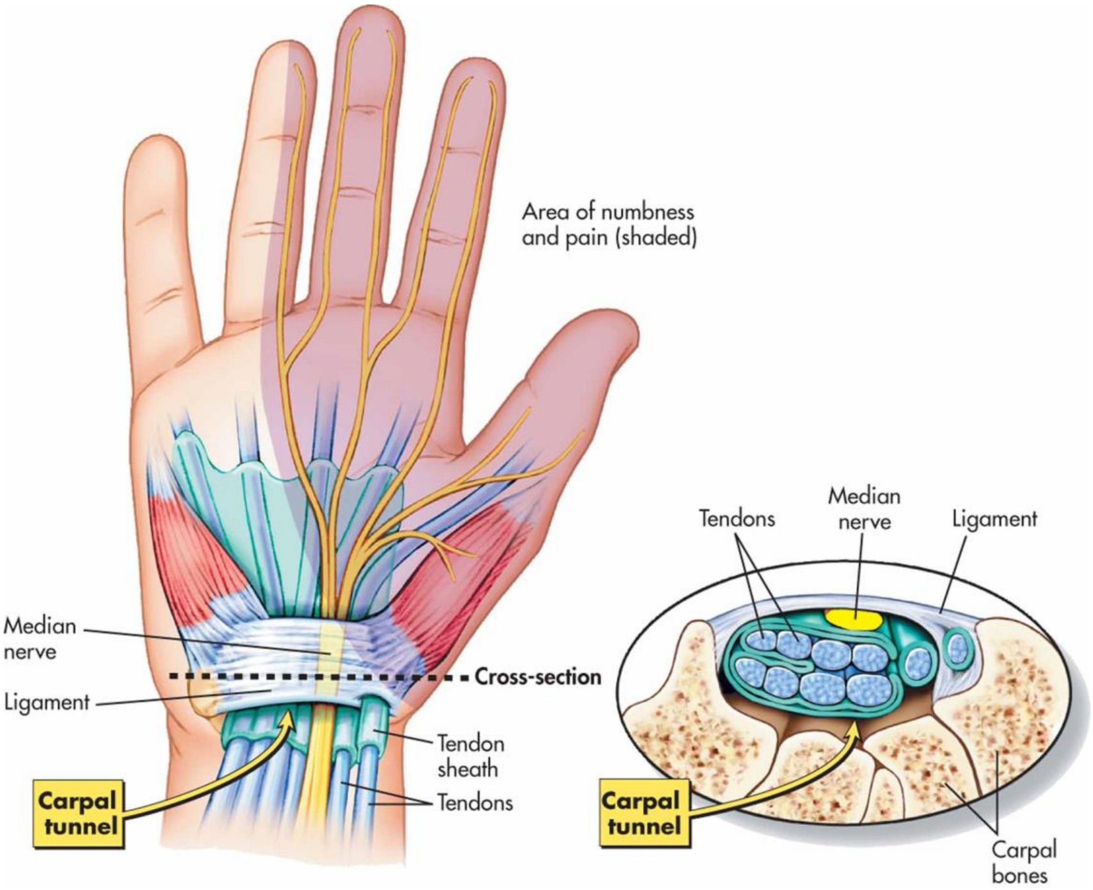


Figure 4. Affected areas of Carpal tunnel syndrome [8]

2.3. Detecting Work-related musculoskeletal disorders

To detect musculoskeletal disorders potential causes must be evaluated. Working conditions are often the cause of these disorders. Therefore, evaluation of working conditions will help to establish risk factors.

Other effective ways of detecting WMSDs are collecting data directly from workers. Companies can provide their employees with pain questionnaires where workers can indicate the regions of the body where they feel pain. These questionnaires can be combined with clinical evaluations that can estimate a limitation of movement.

Because musculoskeletal disorders are mainly caused by repetitive movements, they produce pain in a progressive way. Neither establishing a clear list of possible risk factors or having pain questionnaires and clinical evaluations a few times every year will completely avoid the appearance and progress of a WMSD. Therefore, new monitoring and early detection measures must be developed.

Some new monitoring techniques have emerged and are based on data analysis. However, the information collected about the workers' movements must be as exact as possible so that the analysis will be reliable. Hence, new devices such as sensor gloves are being developed to collect data from the employees. It is also important that these devices do not disturb the employees while they are performing their normal activities at work.

3. Methods

The glove to be characterized has been developed by the Unit of Ergonomics from the School of Engineering Sciences in Chemistry, Biotechnology and Health (KTH). This glove is part of an automatic system of risk assessment tools used for long term prevention of MSDs.

The glove has integrated two different sensors: FSL-0095-103-ST flexible sensors and FSR Model 400 force sensing resistor. Flexible sensors measure flexion and extension movements of the wrist while the pressure sensor measures forces applied to the thumb.

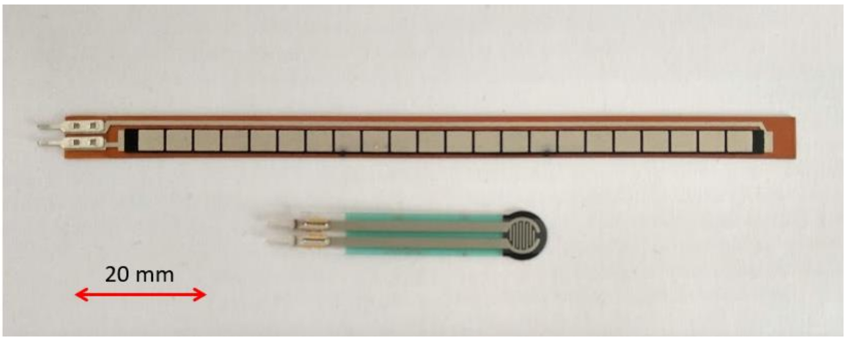


Figure 5. FSL-0095-103-ST flexible sensor and FSR Model 400 force sensing resistor

Figure 6. Glove with integrated sensors

The selected flexible sensors just behave linearly in one bending direction. Therefore, two of these sensors have been integrated in the glove with the conductive inks on different sides of the glove. The first measures flexion movements and the second measures extension movements.

Figure 7. Flexible sensors positioned in opposite sides

According to the manufacturer's electrical specifications [9], the flat resistance of the sensor is 10 kΩ ± 30% while the value for a 180° bending will be at least twice the value of the flat resistance (see *Figure 8*).

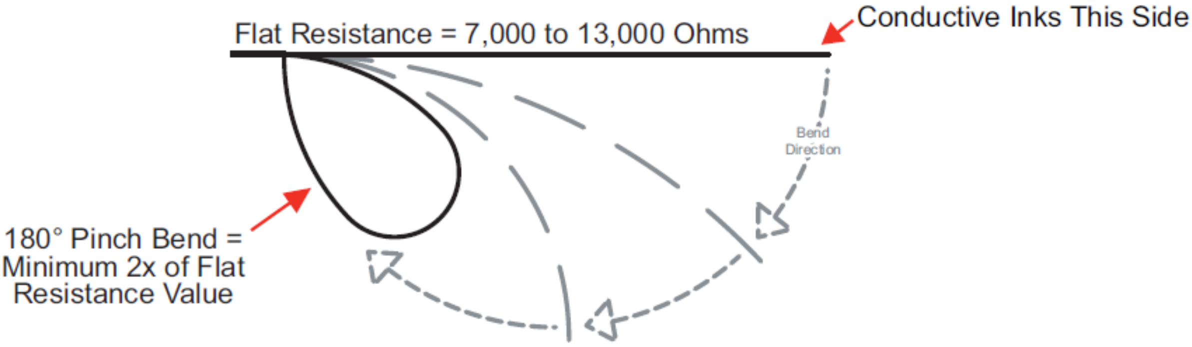


Figure 8. According to the manufacturer [9], bending behaviour of Flexible sensor FSL-0095-103-ST

Regarding the force sensing resistor FSR Model 400, it exhibits a decrease in resistance when the force applied to the surface of the sensor is increased [10].

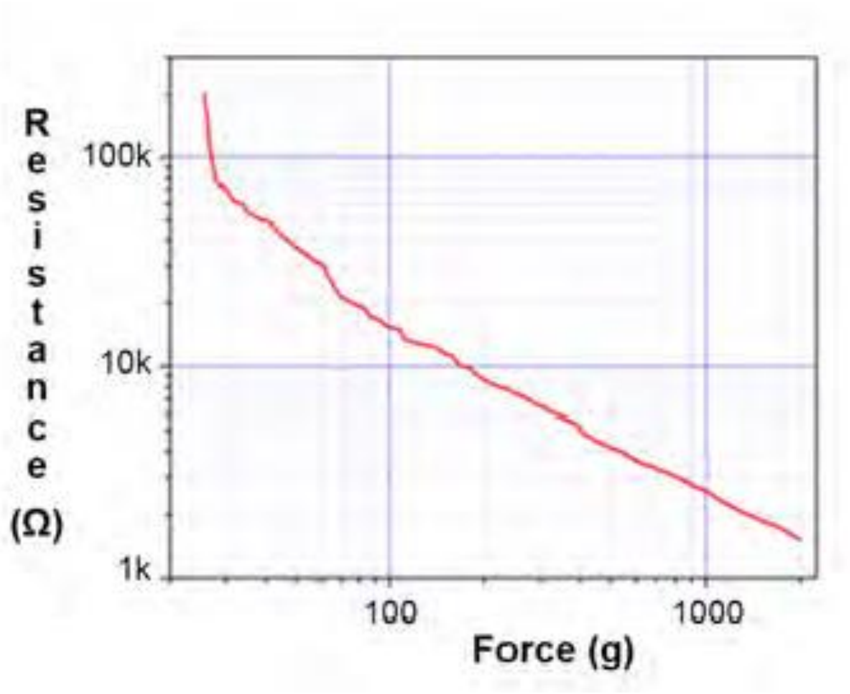


Figure 9. According to the manufacturer [10], *resistance behaviour of the FSR Model 400 sensor when a force is applied to the surface. The manufacturer uses force in Grams instead of Newtons to evaluate the resistance behaviour when a force is applied.*

The glove incorporates a box which contains a printed circuit board. A printed circuit board is used to measure the voltage output for each of the sensors and sends their signals via Bluetooth to another device for transformation and analysis. To connect the box to the glove, six snap buttons are used: the female component of the snap button is attached to the fabric while the male component is fixed to the box. From the male components of the snap buttons, conductive threads are connected to the printed circuit.

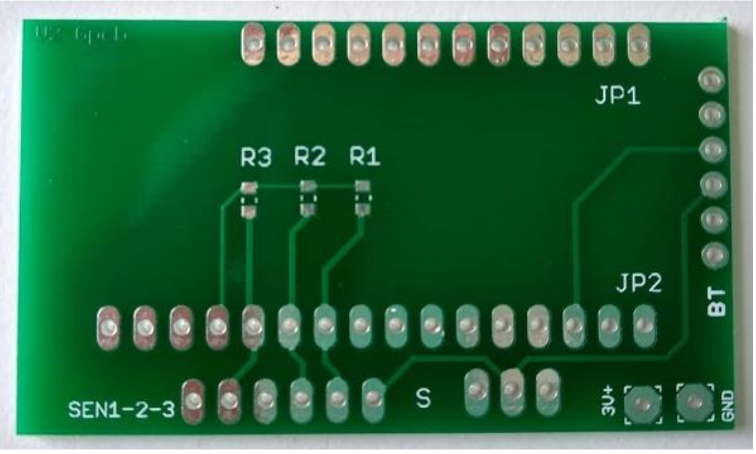


Figure 10. Printed circuit board

To measure the voltage output, a voltage divider is used for each of the sensors. The first impedance of the voltage divider (Z_1) corresponds to the sensor resistance. The second component (Z_2) corresponds to a resistance of 10 kΩ so that the output voltage can be measured as:

$$V_{out} = \frac{Z_2}{Z_1+Z_2} \cdot V_{in} \qquad (1)$$

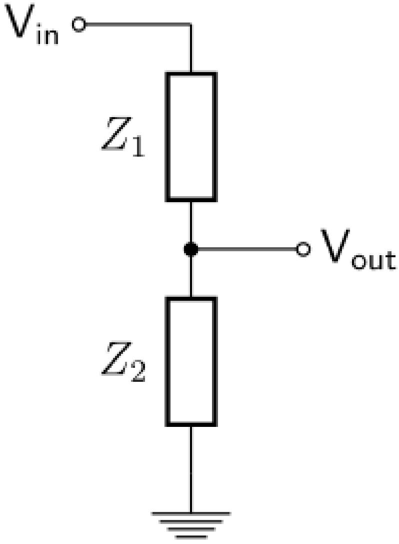


Figure 11. Voltage divider

To characterize the sensors, an independent measurement of the values of the resistances will be carried out in the following way.

First, the electronic circuit incorporated in the glove's box will be simulated using National instruments LabVIEW 2014 software. To generate the LabView code of the VI (Virtual Instrument), the LabView DAQ assistant will be configured with three virtual channels, one for each of the sensors. To acquire the signals, the sensors will be physically connected to the LabVIEW simulation through a NI USB-6218 device.

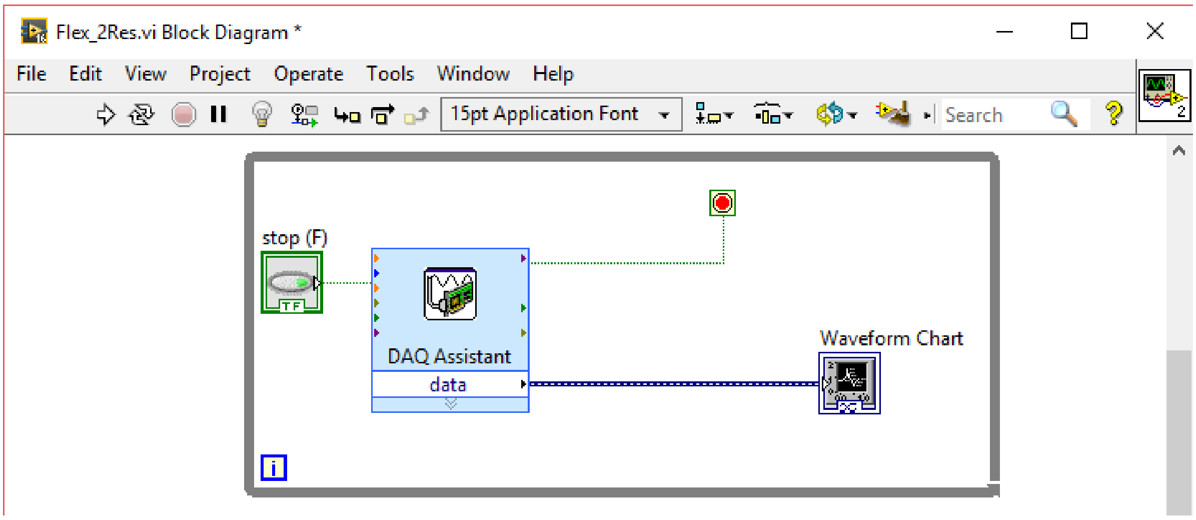
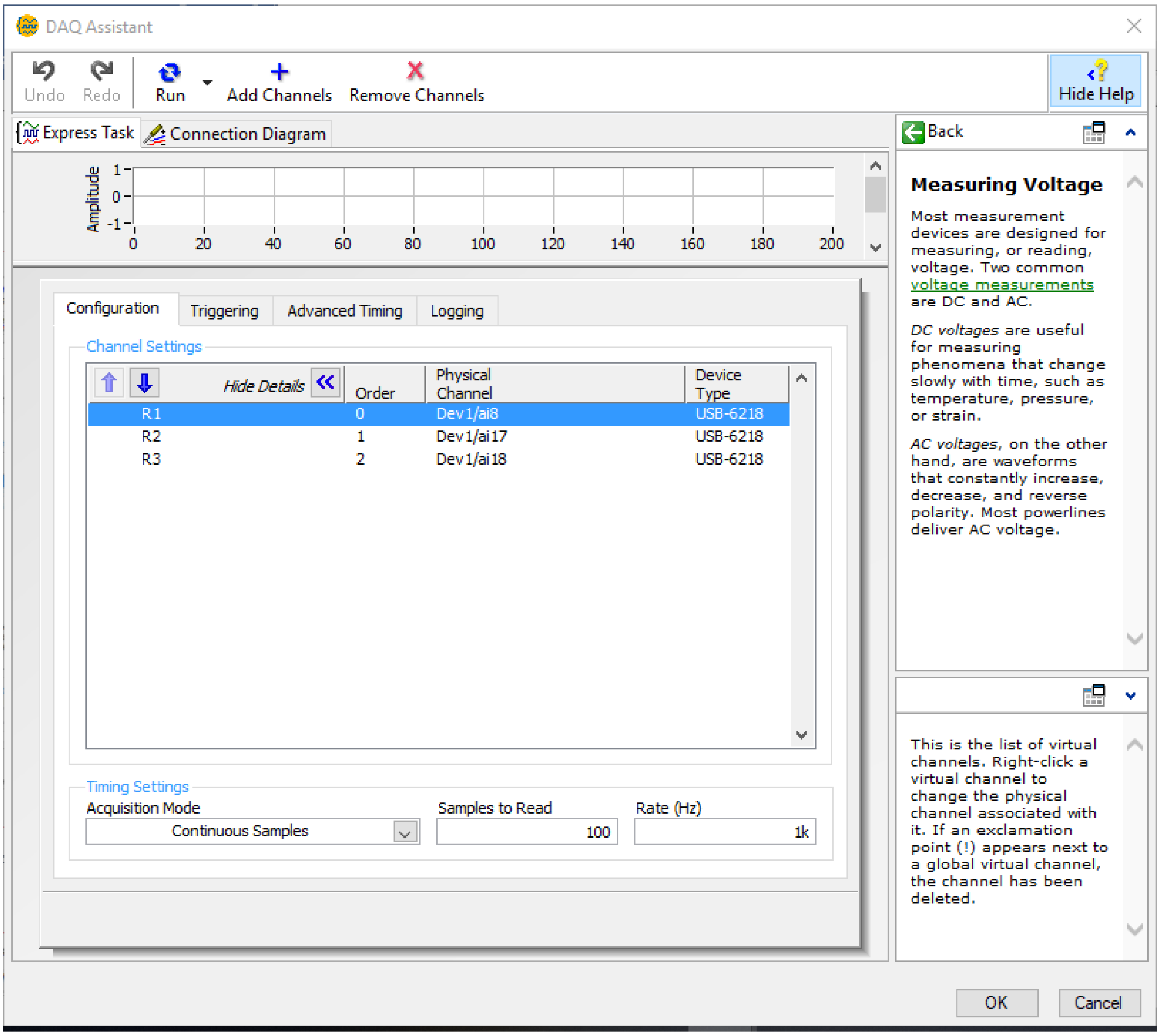


Figure 12. VI Block diagram. It contains the DAQ assistant and a Waveform Chart to measure and visualize the output voltage values



	Order	Physical Channel	Device Type
R1	0	Dev1/ai8	USB-6218
R2	1	Dev1/ai17	USB-6218
R3	2	Dev1/ai18	USB-6218

Acquisition Mode: Continuous Samples

Samples to Read: 100

Rate (Hz): 1k

Measuring Voltage

Most measurement devices are designed for measuring, or reading, voltage. Two common voltage measurements are DC and AC.

DC voltages are useful for measuring phenomena that change slowly with time, such as temperature, pressure, or strain.

AC voltages, on the other hand, are waveforms that constantly increase, decrease, and reverse polarity. Most powerlines deliver AC voltage.

This is the list of virtual channels. Right-click a virtual channel to change the physical channel associated with it. If an exclamation point (!) appears next to a global virtual channel, the channel has been deleted.

Figure 13. DAQ Assistant configuration

Figure 14. NI USB-6218 device, National Instruments

In the same way as in the glove’s box, the code generated with the DAQ Assistant will obtain the voltage output signals from each sensor through a voltage divider. To facilitate the connections between the resistors and the sensors to the NI USB-6218 device, a printed circuit as the one shown in Figure 10 board will be used.

The NI USB-6218 device will have the following inputs connected to the printed circuit:

- +5 V (Voltage input)
- DGND (device ground)
- AI GND (Analog Input ground)
- AI 8 (Analog Input 1)
- AI 17 (Analog Input 2)
- AI 18 (Analog Input 3)

The three 10 kΩ resistors corresponding to the second impedance of the voltage divider (Z2) will be soldered directly to the printed circuit. For the sensors (Z1), a male-female cable will be soldered to the printed circuit allowing the connection of the sensor on the contrary end.

To characterize the FSL-0095-103-ST flexible sensors, nine individual sensors will be measured separately. Once each sensor is connected to the cable coming from the printed circuit, it will be bent in two points of attachment to different angles. Bending in two different points of the length of the sensor will allow to study if the amount of bent surface affects the measurement. The first clamping point will correspond to L=1/3=32 mm while the second clamping point will correspond to L=2/3=63,5 mm, where L is the longitude of the active length of the sensor.

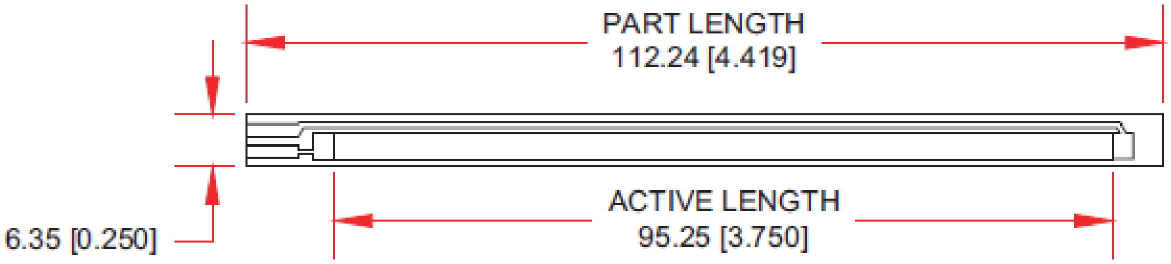


Figure 15. Dimensional diagram of FSL-0095-103-ST flexible sensors [9]. The measurements outside the brackets is in millimetres and the measurement inside the brackets are in inches.

The voltage output of the sensor will be measured to the following bending angles: 0°, 15°, 30°, 45° and 60° using a digital goniometer (Powefix Digital Angle Finder); for each angle, five measurements will be performed at both clamping points.

Table 1. Voltage measurements of FSL-0095-103-ST flexible sensors

	0°	***15°***	***30°***	***45°***	***60°***
L=1/3	5 measurements	5 measurements	5 measurements	5 measurements	5 measurements
	Average value	Average value	Average value	Average value	Average value
L=2/3	5 measurements	5 measurements	5 measurements	5 measurements	5 measurements
	Average value	Average value	Average value	Average value	Average value

An average value will be calculated for each angle at each clamping point, and this value will be used to calculate the resistor value of the sensor.

To compare the behaviour of the sensor outside the glove with the sensor incorporated in the glove, the same voltage measurements specified in Table 1 will be done with the sensor inside the glove as shown in Figure 16.

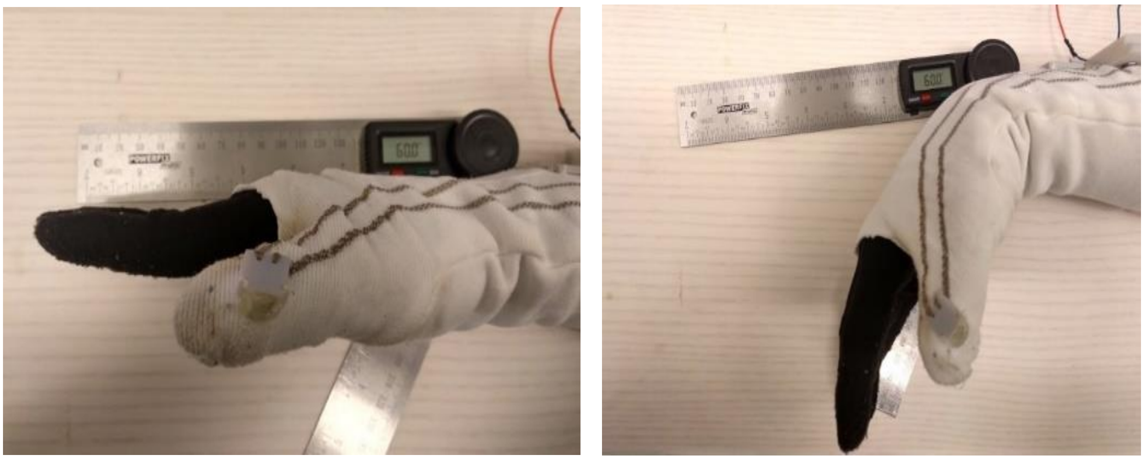


Figure 16. Measurements of FSL-0095-103-ST flexible sensor inside the glove

Once the voltage average values are obtained, the resistor values can be calculated as:

$$Z_1 = \frac{Z_2 \cdot V_{in}}{V_{out\ (average)}} - Z_2 \quad (2)$$

To calculate the sensor resistance values Z1 it will be necessary to obtain the nominal values of the resistors Z2 and the voltage input (Vin). To obtain the nominal values of the resistors Z2 a conventional multimeter can be used, and the voltage input (Vin) provided with the NI USB-6218 device is 5V.

Next, the percentage change will be calculated to characterize the difference in behaviour between the tested flexible sensors. This value will provide information about the performance of the sensors when they are being bent. The percentage change represents the relative change between the old value and the new one. If V1 represents the initial value of resistance and V2 the new one:

$$\text{Percentage change} = \frac{\Delta V}{V_1} = \frac{V_2 - V_1}{V_1} \text{ x } 100 \quad (3)$$

The behaviour of the pressure sensors will be characterized by applying several force values to their surface. A scale (SilverCrest SNAW 1000 C1) will be used to measure the incremental forces applied to the sensors; each measurement will be performed 5 times, calculating the average value afterwards.

Table 2. Voltage measurements of FSR Model 400 force sensing resistors

	200g	***400g***	***600g***	***800g***	***1000g***
Sensor identification number	5 measurements	5 measurements	5 measurements	5 measurements	5 measurements
	Average value	Average value	Average value	Average value	Average value

To compare the behaviour of the sensors outside the glove with their behaviour when they are incorporated inside of it, the same tests will be performed with the glove. In this case, the sensor will be introduced in the glove and the force will be applied with the hand using the same scale.

As it is done with the flexible sensors, the impedance value of the pressure sensors (Z1) will be calculated with the equation (2). Once the resistance values are obtained, the percent relative difference will be calculated for both the individual sensors and the sensors integrated into the glove.

Finally, the resistors values obtained for the flexible sensors FSL-0095-103-ST in both measurement conditions will be compared with respect to the bending angles. For the FSR Model 400 force sensors, the resistor values in the two measurement conditions will be compared with respect to the applied force.

4. Results

First, the nominal value of the resistors welded to the printed circuit have been obtained.

Table 3. Nominal values of the resistors Z2 welded to the printed circuit

Nominal values of impedances Z_2 (kΩ)	
R_1	10,00
R_2	9,97
R_3	9,99

Secondly, the measurements of the flexible sensors FSL-0095-103-ST have been made. The average voltage measurements of the different flexible sensors (Table 4) have been taken with the sensor connected to the physical channel three, where the impedance Z2 was R3=9,99 kΩ. All the values used to calculate the average voltages of Table 4 are collected in Table I of the Appendix.

Table 4. Voltage average values in volts (V) obtained after the measurement of flexible sensors FSL-0095-103-ST outside the glove

Sensor serial number		***0º***	***15º***	***30º***	***45º***	***60º***
0118-18	**L 1/3**	1,55	1,38	1,16	1,04	0,92
	L 2/3	1,55	1,32	1,24	1,18	1,10
0118-5	**L 1/3**	1,41	1,25	1,07	0,91	0,81
	L 2/3	1,41	1,33	1,16	1,07	0,99
0417-17	**L 1/3**	2,36	2,17	2,02	1,88	1,88
	L 2/3	2,36	2,20	2,14	2,02	1,94
0817-11	**L 1/3**	1,16	1,08	1,01	0,95	0,97
	L 2/3	1,16	1,08	1,09	1,04	0,97
0817-13	**L 1/3**	2,35	2,21	2,09	1,82	1,75
	L 2/3	2,35	2,24	2,15	1,92	1,77
0817-2	**L 1/3**	2,07	1,97	1,87	1,49	1,39
	L 2/3	2,07	1,91	1,78	1,63	1,43
0817-7	**L 1/3**	2,56	2,45	2,37	2,29	2,09
	L 2/3	2,56	2,45	2,43	2,25	1,99
0817-15	**L 1/3**	2,49	2,38	2,31	2,16	2,09
	L 2/3	2,49	2,35	2,26	2,17	2,01

0817-23	**L 1/3**	2,29	2,16	2,10	1,91	1,67
	L 2/3	2,29	2,21	2,18	1,99	1,72

From the equation (2), the resistance values of the different flexible sensors have been obtained. These values have been collected in *Table 5*.

Table 5. Resistance values (kΩ) of flexible sensors FSL-0095-103-ST outside the glove

Sensor serial number		***0º***	***15º***	***30º***	***45º***	***60º***
0118-18	**L 1/3**	22,32	26,15	32,92	37,86	44,30
	L 2/3	22,32	27,97	30,42	32,27	35,34
0118-5	**L 1/3**	25,54	29,97	36,69	44,90	51,53
	L 2/3	25,54	27,68	33,15	36,78	40,57
0417-17	**L 1/3**	11,14	13,01	14,79	16,52	16,52
	L 2/3	11,14	12,76	13,33	14,79	15,81
0817-11	**L 1/3**	33,00	36,09	39,37	42,59	41,29
	L 2/3	33,00	36,09	35,67	37,86	41,72
0817-13	**L 1/3**	11,23	12,59	13,93	17,40	18,52
	L 2/3	11,23	12,27	13,29	16,03	18,23
0817-2	**L 1/3**	14,16	15,42	16,75	23,53	26,00
	L 2/3	14,16	16,22	18,10	20,69	24,94
0817-7	**L 1/3**	9,49	10,41	11,05	11,82	13,89
	L 2/3	9,49	10,40	10,55	12,17	15,09
0817-15	**L 1/3**	10,10	11,02	11,63	13,09	13,93
	L 2/3	10,10	11,30	12,11	13,03	14,86
0817-23	**L 1/3**	11,82	13,16	13,82	16,16	19,88
	L 2/3	11,82	12,63	12,94	15,14	19,09

The percentage change of the nine sensors (*Table 6*) has been calculated from the data collected in *Table 5* with the equation (3).

Table 6. Percentage change of the resistance values of the flexible sensors FSL-0095-103-ST outside the glove

Sensor serial number		**0º**	**15º**	**30º**	**45º**	**60º**
0118-18	**L 1/3**	0%	17%	48%	70%	99%
	L 2/3	0%	25%	36%	45%	58%
0118-5	**L 1/3**	0%	17%	44%	76%	102%
	L 2/3	0%	8%	30%	44%	59%
0417-17	**L 1/3**	0%	17%	33%	48%	48%
	L 2/3	0%	15%	20%	33%	42%
0817-11	**L 1/3**	0%	9%	19%	29%	25%
	L 2/3	0%	9%	8%	15%	26%
0817-13	**L 1/3**	0%	12%	24%	55%	65%
	L 2/3	0%	9%	18%	43%	62%
0817-2	**L 1/3**	0%	9%	18%	66%	84%
	L 2/3	0%	15%	28%	46%	76%
0817-7	**L 1/3**	0%	10%	16%	25%	46%
	L 2/3	0%	10%	11%	28%	59%
0817-15	**L 1/3**	0%	9%	15%	30%	38%
	L 2/3	0%	12%	20%	29%	47%
0817-23	**L 1/3**	0%	11%	17%	37%	68%
	L 2/3	0%	7%	10%	28%	61%

To obtain the voltage values of the flexible sensors integrated in the glove, a first analysis of the results from *Table 5* has been made. As it can be observed, only resistances with serial number 0417-17, 0817-13, 0817-7, 0817-15 and 0817-23 have a nominal value within the interval given by the manufacturer (10 ±3 kΩ). Therefore, only these resistances will be analysed inside the glove.

As mentioned before, the sensors are integrated in the glove with the conductive inks on different sides. The first of them will be denominated Rflex1 and the second of them Rflex2. Rflex1 is connected to the physical channel 1 (AI8, Analog input 1) where Z2=R1=10 kΩ. Rflex2 is connected to the physical channel 2 (AI 17, Analog Input 2) where Z2=R2=9,97 kΩ. While Rflex1 will measure flexion movements, Rflex2 will measure extension movements.

In *Table 7* only the voltage average values are shown. All the measured data is collected in *Table II* of the Appendix.

Table 7. Voltage average values in volts (V) obtained after the measurement of the flexible sensors FSL-0095-103-ST inserted in the glove

	0º	15º	30º	45º	60º
$Rflex_1$ 0817-7	2,53	2,36	2,27	2,17	2,04
$Rflex_2$ 0817-15	2,44	2,32	2,17	2,05	2,01
$Rflex_1$ 0417-17	2,26	2,11	2,03	1,91	1,83
$Rflex_2$ 0817-13	2,32	2,19	2,07	1,98	1,82

With the equation (2) and the Voltage average values collected in *Table 7*, the resistance values of the flexible sensors inside the glove have been calculated.

Table 8. Resistance values (kΩ) obtained after the measurement of the flexible sensors FSL-0095-103-ST inserted in the glove

	0º	15º	30º	45º	60º
$Rflex_1$ 0817-7	9,75	11,22	12,05	13,06	14,56
$Rflex_2$ 0817-15	10,44	11,54	13,02	14,32	14,81
$Rflex_1$ 0417-17	12,14	13,74	14,58	16,18	17,26
$Rflex_2$ 0817-13	11,54	12,79	14,16	15,23	17,48

The same process carried out to analyse the behaviour of the flexible sensors will be done to analyse the FSR Model 400 force resistors. First, the voltage output of the sensors outside the glove has been measured. The average voltage measurements of the different pressure sensors (*Table 9*) have been taken with the sensor connected to the physical channel three, where the impedance Z2 was R3=9,99 kΩ. All the output voltages are collected in *Table III* of the Appendix.

Table 9. Voltage average values in volts (V) obtained after the measurement of FSR Model 400 force sensing resistors outside the glove

Sensor identification number	0g	200g	400g	600g	800g	1000g
1	0,00	2,51	2,95	3,20	3,41	3,47
2	0,00	2,55	2,90	3,29	3,38	3,45
3	0,00	2,44	3,08	3,36	3,36	3,52
4	0,00	2,48	3,02	3,26	3,43	3,61
5	0,00	2,32	3,07	3,23	3,40	3,48
6	0,00	2,54	3,06	3,38	3,37	3,48
7	0,00	2,43	2,75	3,17	3,40	3,51
8	0,00	2,63	2,86	3,17	3,42	3,48
9	0,00	2,48	2,82	3,23	3,40	3,51
10	0,00	2,44	2,86	3,22	3,39	3,41

With the average voltage values from *Table 9* and the equation (2), the resistance values in kΩ can be calculated. When there is no force applied to the sensor, the voltage output is 0 V. Therefore, neither the resistance value or the percentage change for an applied force of 0 g will be calculated.

Table 10. Resistance values (kΩ) of FSR Model 400 force sensing resistors outside the glove

Sensor identification number	200g	400g	600g	800g	1000g
1	9,91	6,94	5,60	4,68	4,41
2	9,63	7,25	5,21	4,79	4,47
3	10,45	6,21	4,86	4,88	4,21
4	10,17	6,53	5,35	4,56	3,85
5	11,54	6,27	5,47	4,71	4,36
6	9,64	6,31	4,77	4,85	4,36
7	10,60	8,19	5,75	4,70	4,26
8	9,00	7,45	5,77	4,62	4,36
9	10,12	7,72	5,49	4,68	4,23
10	10,45	7,48	5,52	4,74	4,68

The percentage change of the ten sensors (*Table 11*) has been calculated from the data collected in *Table 10* with the equation (3).

Table 11. Percentage change of FSR Model 400 force sensing resistors

Sensor identification number	200g	400g	600g	800g	1000g
1	0%	-30%	-44%	-53%	-56%
2	0%	-25%	-46%	-50%	-54%
3	0%	-41%	-54%	-53%	-60%
4	0%	-36%	-47%	-55%	-62%
5	0%	-46%	-53%	-59%	-62%
6	0%	-35%	-51%	-50%	-55%
7	0%	-23%	-46%	-56%	-60%
8	0%	-17%	-36%	-49%	-52%
9	0%	-24%	-46%	-54%	-58%
10	0%	-29%	-47%	-55%	-55%

To compare the behaviour of FSR Model 400 force sensing resistors inside and outside the glove the output voltage measurement for the different values of applied force has been done with the sensor inserted in the glove. In this case, only one sensor has been measured and it has been connected to the physical channel 3 (AI18, Analog input 1) where Z2=R3=9,99 kΩ.

In *Table 12* only the average output voltages are shown while full data is collected in *Table IV* of the Appendix.

Table 12. Voltage average values in volts (V) obtained after the measurement of a FSR Model 400 force sensing resistor inserted in the glove

	0g	***200g***	***400g***	***600g***	***800g***	***1000g***
Vout(average)	0,00	2,50	2,81	2,98	3,25	3,34

With the equation (2), the resistance values of the sensor inside the glove has been calculated (*Table 13*).

Table 13. Resistance values (kΩ) of a FSR Model 400 force sensing resistor inserted in the glove

	0g	***200g***	***400g***	***600g***	***800g***	***1000g***
R(kΩ)	0	10,01	7,76	6,75	5,39	4,97

5. Analysis

5.1. Flexible resistors FSL-0095-103-ST

In a preliminary analysis of the obtained nominal values of resistors outside the glove, four of them can be discarded. Resistors with the serial numbers 0118-18, 0118-15 and 0817-2 have a nominal value with an error over the 30% established by the manufacturer. Also, the resistor with serial number 0817-11, has a nominal value over 30 kΩ because the conductive ink was partially broken.

To determine if bending the flexible resistors in the two clamping points affects the voltage output, two-sample T-test assuming unequal variances (*Table 14*) has been carried out. T-test has been done with the resistances which have not been rejected in the preliminary analysis. These resistances have the following serial numbers: 0417-17, 0817-13, 0817-7, 0817-15 and 0817-23.

Table 14. Two-sample T-test assuming Unequal variances

	L 1/3 0°	***L 2/3 0°***	***L 1/3 15°***	***L 2/3 15°***	***L 1/3 30°***	***L 2/3 30°***	***L 1/3 45°***	***L 2/3 45°***	***L 1/3 60°***	***L 2/3 60°***
Mean	10,76	10,76	12,04	11,87	13,04	12,44	15,00	14,23	16,55	16,61
Variance	0,88	0,88	1,54	1,00	2,60	1,36	5,79	2,51	7,24	3,69
Observations	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00
Hypothesized Mean Difference	0,00		0,00		0,00		0,00		0,00	
df	8,00		8,00		7,00		7,00		7,00	
T Stat	0,00		0,23		0,67		0,60		-0,04	
P(T<=t) one-tail	0,50		0,41		0,26		0,28		0,48	
T Critical one-tail	1,86		1,86		1,89		1,89		1,89	
P(T<=t) two-tail	1,00		0,82		0,52		0,57		0,97	
T Critical two-tail	2,31		2,31		2,36		2,36		2,36	

For all the bending angles, p-value is less than T Critical two-tail. Therefore, there is not a significant difference between bending the resistor at 1/3 of their active length or bending them at 2/3 of it.

Regarding to the average values of the resistor's percentage change at the two clamping points (*Table 15*), in both cases the increasing percentage is very similar. Thus, no significant differences can be found.

Table 15. Average percentage change at two clamping points of flexible sensors

Average percentage change	**15°**	**30°**	**45°**	**60°**
L 1/3	10%	18%	32%	44%
L 2/3	9%	13%	27%	45%

When analysing the resistance values of flexible sensors inserted in the glove, it can be observed that there are minor differences between flexion and the extension movements. These differences in the resistance values are due to the differing flat resistance nominal values in the flexible sensors.

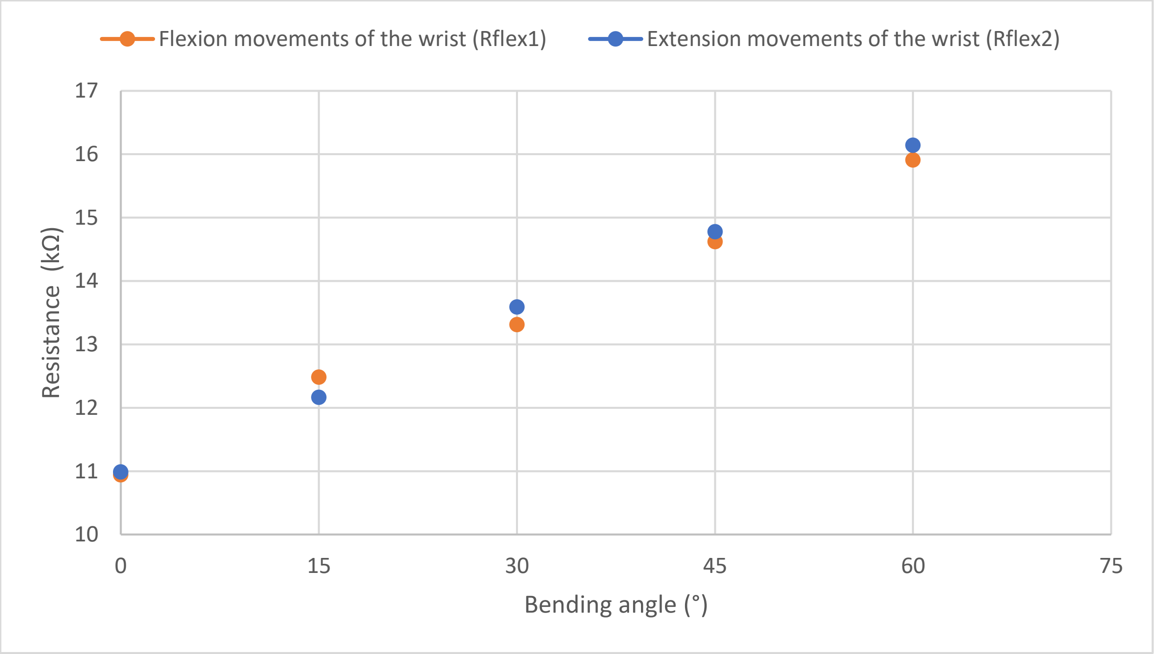


Figure 17. Resistance values (kΩ) obtained for the sensors inserted in the glove. Values from Rflex1 (flexion movements) and Rflex2 (extension movements) are compared

All the resistance values, for the different measuring conditions, have been compared in *Figure 18*. It can be observed that there are no significant differences between the various measuring conditions. Also, their behaviour is in accordance with the behaviour established by the manufacturer meaning that it increases as the bending angle increases.

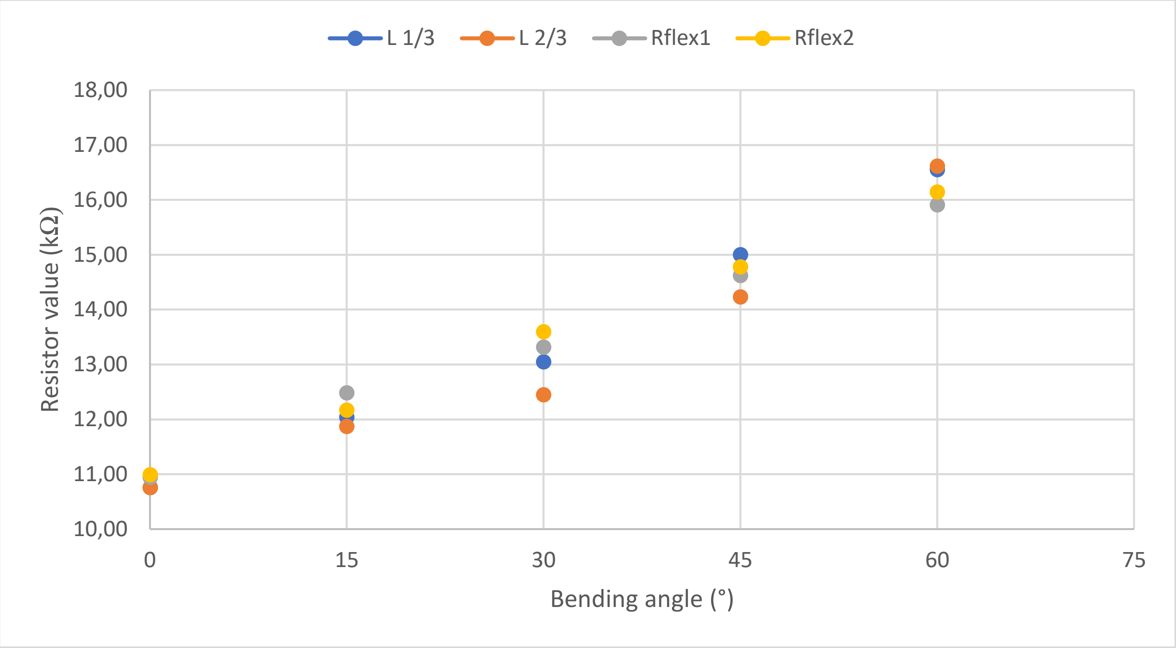


Figure 18. Resistance values (kΩ) obtained for the all FSL-0095-103-ST flexible sensors. The graph shows the results of the measurements of sensor outside the glove at both clamping points and the results for the sensors inside the glove for extension and flexion movements

Even though the results agree with the values of the manufacturer's data sheet, it must be considered that four of the sensors have been eliminated from the study for having an error greater than the 30% in its nominal value.

Furthermore, when making the measurements of the sensors outside the glove, there are stability problems and it can take a while to obtain a stable value. For example, if the resistor is bent on one side and the opposite end bends in the opposite direction, the output voltage value will increase. Also, if a slightly higher pressure is applied on the other side of the sensor when clamping at one point, the output voltage value will increase too. On the other hand, after bending the sensor and bringing it back to the flat position, the next value for the same bending position can vary considerably.

However, when the sensors are inside the glove the stability problems are significantly reduced. With the resistors inside a pocket in the glove, when bending them to a certain angle and returning to the flat position, the deformation of the sensor itself is not going to affect in the same way as in the previous conditions (sensor outside the glove).

Therefore, most of the stability problems when measuring the sensors outside the glove can be due to the measurement method. When holding the resistors at two points and bending them to a certain angle with the fingers, small movements will have a considerable influence in the voltage output and this can be the main source of instability.

5.2. FSR Model 400 Force sensing resistor

When we observe the results for the percentage change of FSR Model 400 Force sensing resistors, we realize that the obtained values are negative since the resistance values decrease when applying larger forces. In any case, if the square deviation is observed, only in one of the cases (400g) has a deviation of more than 5%. Therefore, these sensors offer good stability in terms of measurements when the forces are applied along the entire surface of the sensor.

Table 16. Average percentage change and Square deviation of FSR Model 400 Force sensing resistor

	200g	**400g**	**600g**	**800g**	**1000g**
Average percentage change	0%	-30%	-47%	-53%	-57%
Square deviation		0,09	0,05	0,03	0,04

According to the manufacturer's data sheet [10], the approximate voltage output values when using a second impedance Z2=10kΩ are:

Table 17. Manufacturer's Vout values for a standard FSR in a for a standard FSR in a voltage divider configuration with a resistor Z2=10kΩ

	200g	**400g**	**600g**	**800g**	**1000g**
Vout (V)	2,25	2,75	3,10	3,25	3,40

If the values provided by the manufacturer are compared with the voltage outputs obtained during the measurements (*Figure 19*), we can observe than the measured values curves are analogous to the manufacturer's curve. Therefore, the obtained results can be accepted.

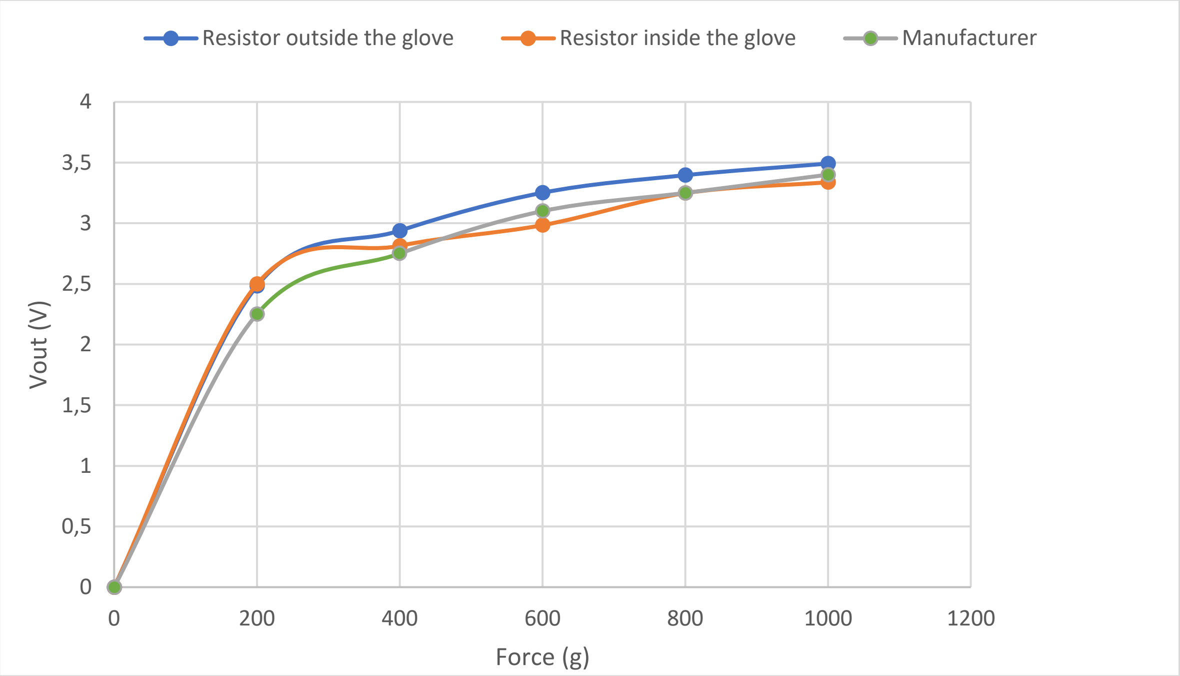


Figure 19. Voltage values (V) obtained for the FSR Model 400 force sensing resistor. The graph compares the results of the measurements of sensors outside and inside the glove when different forces are applied with the values provided by the manufacturer

Regarding to the resistance values, as the manufacturer establishes, they descend with an increasing applied force (*Figure 20*).

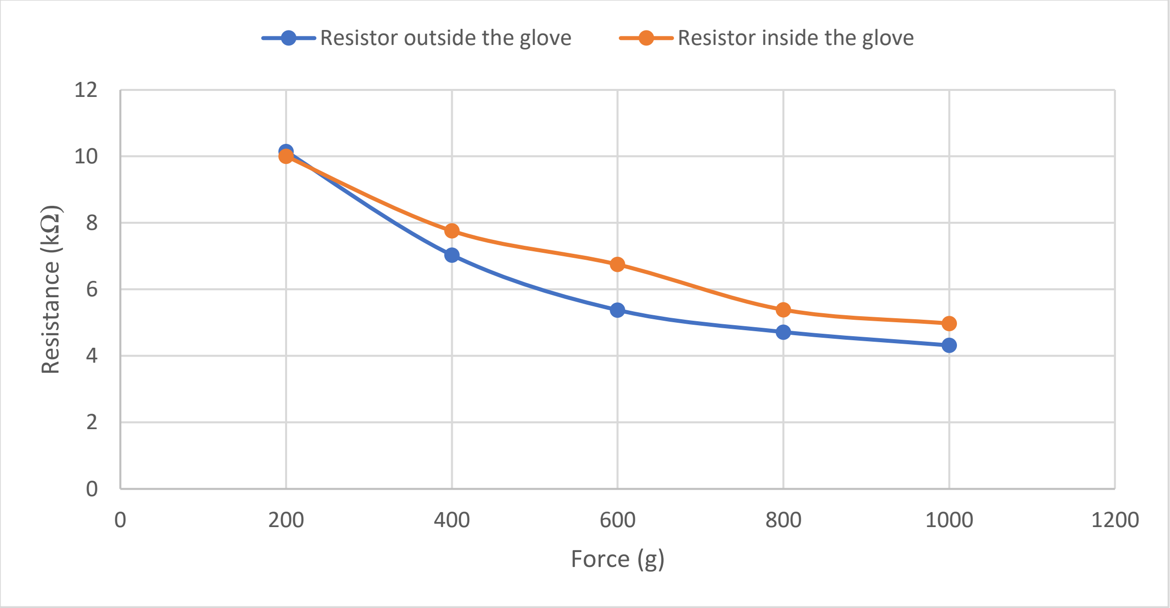


Figure 20.Voltage values (V) obtained for the FSR Model 400 force sensing resistor. The graph shows the results of the measurements of sensors outside and inside the glove when different forces are applied

In the case of pressure sensors, the opposite to what occurs with flexible sensors is true. When taking the measurements of the sensors outside the glove, it is very easy to apply the force in exactly the same point and along the entire surface of the sensor. However, when measurements of the sensor are taken inside the glove, small movements of the thumb when applying the force will directly affect the voltage output. The cause of this instability is that the sensor can move inside the glove due to its small surface area.

A solution to avoid the movements of the sensor inside the glove could be to sew it to the fabric. To implement this solution, it would be necessary to drill holes in the sensors, but it has not been studied how the sensitivity range would be affected in this case.

6. Discussion

Throughout this project, it has been possible to study how different conditions affect the behaviour of the sensors. With respect to flexible sensors FSL-0095-103-ST, the stability provided by the glove in terms of fastening, stabilize the sensor measurements. Besides, changes in the surface bent will result in small voltage output fluctuations -in volts-, which will not have a bigger impact in the value of the resistors -values in the range of kΩ-. But it should be noted that some of the resistors have nominal values in their flat position outside the range offered by the manufacturer. Although it is out of scope for the current project, it is necessary to study how big differences in the nominal value of the resistors will affect the measurements.

The FSR Model 400 pressure sensors have a less stable behaviour inside the glove than outside the glove. Because of its small active surface, the sensors can move, and the applied force will not be measured exactly.

Therefore, the objectives of characterization and study of behaviour have been accomplished but other problems have been identified and will have to be studied in the future.

One of the features to improve is that the glove must be more comfortable. The actual glove is tightening the hand and forearm a lot, and this can cause reluctance to wear it. If this device is meant to be used by people during their work day, it must not obstruct any movement or suppose any inconvenience.

Another aspect that can be improved is the fastening of the sensors. To avoid the resistors movements, they could be integrated directly in the fabric or they could be stitched.

Although the sensors already provide information that can be analysed, this data does not arrive directly to the user. For this reason, some feedback to the user could be implemented.

Moreover, wearing gloves can also increase the grip effort to compensate for a loss in adherence [2]. For this reason, it would be interesting to study the long-term effects of wearing the glove depending on the tasks carried out.

Wearable devices like the one studied in this project could substantially improve quality of life for workers. There is ample evidence that above some levels, exposure increases the risk of suffering a musculoskeletal disorder. This does not necessarily mean that there is no risk below those levels [3]. Consequently, it is difficult to determine safe exposure “thresholds” only with experimental observations. Although the sensors incorporated in the glove do not allow for the analysis of accurate wrist movements, they provide enough data to evaluate the movements of the workers and can improve the established safe exposure “thresholds”. The use of these technologies in companies will imply higher initial costs and investments. However, the positive effect on workers in long-term can be much more positive, improving their work conditions and quality of life. By utilizing these technologies to analyse work habits and establish safety standards the costs for the companies due to WMSDs of their workers can be substantially

7. References

[1] "CDC - NIOSH Program Portfolio : Musculoskeletal Disorders : Program Description." [Online]. Available: https://www.cdc.gov/niosh/programs/msd/. [Accessed: 21-May-2018].

[2] S. Simoneau, M. St-Vincent, and D. Chicoine, "Work-Related Musculoskeletal Disorders (WMSDs): A Better Understanding for More Effective Prevention," *Ergon. Improv. Work Concr. cases*, pp. 1–54, 1996.

[3] L. Punnett and D. H. Wegman, "Work-related musculoskeletal disorders: The epidemiologic evidence and the debate," *J. Electromyogr. Kinesiol.*, vol. 14, no. 1, pp. 13–23, 2004.

[4] Health and Safety Executive, "Work-related Musculoskeletal Disorders (WRMSDs) Statistics in Great Britain 2017," *Work. Musculoskelet. Disord. Stat. Gt. Britain 2017*, vol. 1, no. 1, p. 22, 2017.

[5] "Quelles sont les causes possibles de la contracture du biceps." [Online]. Available: http://www.manifeste-euroafricain.org/plateforme-de-jeux/quelles-sont-les-causes-possibles-de-la-contracture-du-biceps-.html. [Accessed: 07-May-2018].

[6] A. Sawant, "Measurement of Joint Motion: A Guide to Goniometry, Third Edition," *Physiother. Canada*, vol. 56, no. 04, p. 250, 2004.

[7] Atlanta Equine Clinic, "AEC Client Education - LDE Tenosynovitis." [Online]. Available: http://www.atlantaequine.com/pages/client_lib_LDEtenosynovitis.html. [Accessed: 07-May-2018].

[8] Osteohealth, "Carpal Tunnel Syndrome." [Online]. Available: https://osteohealth.net.au/carpal-tunnel-syndrome/. [Accessed: 07-May-2018].

[9] Spectra Symbol, "Flex Sensor FS Data Sheet," vol. 1. Salt Lake City, UT, pp. 1–2, 2014.

[10] Interlink Electronics, "FSR 400 Series Data Sheet." Westlake Village, CA, pp. 1–10, 2014.

Appendix: All measured data

The following table contains the data form the voltage measurements of the nine FSL-0095-103-ST flexible sensor outside the glove.

Table I. Voltage values in volts (V) obtained after the measurement of the flexible sensors FSL-0095-103-ST outside the glove

			0º	**15º**	**30º**	**45º**	**60º**
0118-18	**L 1/3**	$Vout_1$	1,55	1,36	1,15	1,03	0,94
		$Vout_2$	1,54	1,36	1,17	1,06	0,90
		$Vout_3$	1,52	1,38	1,16	1,02	0,91
		$Vout_4$	1,56	1,40	1,18	1,03	0,90
		$Vout_5$	1,56	1,41	1,16	1,08	0,95
		Vout (average)	**1,55**	**1,38**	**1,16**	**1,04**	**0,92**
	L 2/3	$Vout_1$		1,29	1,21	1,15	1,12
		$Vout_2$		1,32	1,20	1,17	1,13
		$Vout_3$		1,30	1,28	1,16	1,06
		$Vout_4$		1,33	1,30	1,21	1,09
		$Vout_5$		1,34	1,19	1,22	1,11
		Vout (average)	**1,55**	**1,32**	**1,24**	**1,18**	**1,10**
0118-5	**L 1/3**	$Vout_1$	1,4	1,25	1,1	0,89	0,81
		$Vout_2$	1,34	1,18	1,11	0,9	0,81
		$Vout_3$	1,42	1,27	1,07	0,91	0,83
		$Vout_4$	1,43	1,26	1,03	0,92	0,82
		$Vout_5$	1,44	1,29	1,04	0,93	0,79
		Vout (average)	**1,41**	**1,25**	**1,07**	**0,91**	**0,81**
	L 2/3	$Vout_1$		1,30	1,16	1,08	0,98
		$Vout_2$		1,31	1,24	1,09	1,02
		$Vout_3$		1,32	1,18	1,06	1,03
		$Vout_4$		1,34	1,12	1,04	0,95
		$Vout_5$		1,36	1,09	1,07	0,96
		Vout (average)	**1,41**	**1,33**	**1,16**	**1,07**	**0,99**
0417-17	**L 1/3**	$Vout_1$	2,38	2,20	1,97	1,90	1,84
		$Vout_2$	2,36	2,18	2,02	1,92	1,85
		$Vout_3$	2,35	2,17	2,01	1,88	1,84
		$Vout_4$	2,38	2,15	2,02	1,87	1,85
		$Vout_5$	2,35	2,16	2,06	1,85	2,04
		Vout (average)	**2,36**	**2,17**	**2,02**	**1,88**	**1,88**
	L 2/3	$Vout_1$		2,21	2,14	1,99	1,97
		$Vout_2$		2,18	2,16	2,00	1,98
		$Vout_3$		2,19	2,12	2,02	1,91
		$Vout_4$		2,2	2,13	2,01	1,93
		$Vout_5$		2,2	2,16	2,06	1,89
		Vout (average)	**2,36**	**2,20**	**2,14**	**2,02**	**1,94**
0817-11	**L 1/3**	$Vout_1$	1,17	1,09	1,01	0,95	0,95
		$Vout_2$	1,17	1,08	1,03	0,95	0,94
		$Vout_3$	1,14	1,08	1,01	0,96	0,96
		$Vout_4$	1,17	1,09	1,00	0,94	1,02
		$Vout_5$	1,16	1,08	1,01	0,95	1,00
		Vout (average)	**1,16**	**1,08**	**1,01**	**0,95**	**0,97**

	L 2/3	$Vout_1$		1,07	1,09	1,04	0,96
		$Vout_2$		1,08	1,11	1,05	0,98
		$Vout_3$		1,08	1,10	1,06	0,95
		$Vout_4$		1,09	1,09	1,03	0,97
		$Vout_5$		1,10	1,08	1,04	0,97
		Vout (average)	**1,16**	**1,08**	**1,09**	**1,04**	**0,97**
0817-13	**L 1/3**	$Vout_1$	2,35	2,20	2,12	1,79	1,73
		$Vout_2$	2,38	2,22	2,10	1,81	1,75
		$Vout_3$	2,34	2,21	2,09	1,80	1,75
		$Vout_4$	2,31	2,22	2,06	1,83	1,77
		$Vout_5$	2,39	2,21	2,07	1,89	1,76
		Vout (average)	**2,35**	**2,21**	**2,09**	**1,82**	**1,75**
	L 2/3	$Vout_1$		2,25	2,18	1,90	1,76
		$Vout_2$		2,25	2,19	1,92	1,79
		$Vout_3$		2,23	2,15	1,91	1,77
		$Vout_4$		2,25	2,10	1,94	1,77
		$Vout_5$		2,24	2,11	1,93	1,76
		Vout (average)	**2,35**	**2,24**	**2,15**	**1,92**	**1,77**
0817-2	**L 1/3**	$Vout_1$	2,07	1,95	1,89	1,50	1,38
		$Vout_2$	2,08	2,00	1,83	1,50	1,37
		$Vout_3$	2,05	1,96	1,84	1,46	1,40
		$Vout_4$	2,06	1,97	1,87	1,48	1,39
		$Vout_5$	2,08	1,95	1,91	1,51	1,40
		Vout (average)	**2,07**	**1,97**	**1,87**	**1,49**	**1,39**
	L 2/3	$Vout_1$		1,96	1,81	1,63	1,45
		$Vout_2$		1,97	1,78	1,64	1,43
		$Vout_3$		1,84	1,77	1,59	1,44
		$Vout_4$		1,87	1,75	1,65	1,41
		$Vout_5$		1,89	1,78	1,63	1,42
		Vout (average)	**2,07**	**1,91**	**1,78**	**1,63**	**1,43**
0817-7	**L 1/3**	$Vout_1$	2,57	2,45	2,34	2,25	2,09
		$Vout_2$	2,60	2,43	2,37	2,32	2,13
		$Vout_3$	2,55	2,47	2,36	2,26	2,06
		$Vout_4$	2,54	2,44	2,41	2,30	2,07
		$Vout_5$	2,56	2,45	2,39	2,32	2,11
		Vout (average)	**2,56**	**2,45**	**2,37**	**2,29**	**2,09**
	L 2/3	$Vout_1$		2,53	2,4	2,25	1,97
		$Vout_2$		2,42	2,41	2,27	1,95
		$Vout_3$		2,44	2,43	2,28	2,04
		$Vout_4$		2,43	2,47	2,23	1,99
		$Vout_5$		2,43	2,45	2,24	2,01
		Vout (average)	**2,564**	**2,45**	**2,432**	**2,254**	**1,992**
0817-15	**L 1/3**	$Vout_1$	2,49	2,37	2,26	2,17	2,10
		$Vout_2$	2,48	2,39	2,31	2,21	2,08
		$Vout_3$	2,5	2,36	2,28	2,20	2,06
		$Vout_4$	2,49	2,37	2,34	2,10	2,07
		$Vout_5$	2,47	2,4	2,36	2,14	2,13
		Vout (average)	**2,49**	**2,38**	**2,31**	**2,16**	**2,09**
	L 2/3	$Vout_1$		2,33	2,24	2,19	2,02
		$Vout_2$		2,34	2,25	2,15	2,01
		$Vout_3$		2,37	2,32	2,15	2,01
		$Vout_4$		2,36	2,26	2,24	2,00

		$Vout_5$		2,33	2,23	2,12	2,01
		Vout (average)	**2,49**	**2,35**	**2,26**	**2,17**	**2,01**
0817-23	**L 1/3**	$Vout_1$	2,29	2,16	2,13	1,90	1,65
		$Vout_2$	2,29	2,14	2,06	1,93	1,66
		$Vout_3$	2,28	2,16	2,14	1,91	1,67
		$Vout_4$	2,27	2,17	2,09	1,88	1,7
		$Vout_5$	2,32	2,16	2,07	1,93	1,68
		Vout (average)	**2,29**	**2,16**	**2,10**	**1,91**	**1,67**
	L 2/3	$Vout_1$		2,19	2,16	1,99	1,75
		$Vout_2$		2,21	2,18	1,95	1,71
		$Vout_3$		2,22	2,20	2,02	1,70
		$Vout_4$		2,19	2,16	1,96	1,72
		$Vout_5$		2,23	2,19	2,02	1,71
		Vout (average)	**2,29**	**2,21**	**2,18**	**1,99**	**1,72**

Table II. Voltage values in volts (V) obtained after the measurement of the flexible sensors FSL-0095-103-ST incorporated in the glove

		0º	***15º***	***30º***	***45º***	***60º***
Rflex$_1$ 0817-7	$Vout_1$	2,53	2,34	2,25	2,14	2,05
	$Vout_2$	2,56	2,36	2,31	2,17	2,04
	$Vout_3$	2,50	2,34	2,23	2,17	2,10
	$Vout_4$	2,52	2,36	2,28	2,16	1,96
	$Vout_5$	2,55	2,38	2,27	2,20	2,03
	Vout(average)	**2,53**	**2,36**	**2,27**	**2,17**	**2,04**
Rflex$_2$ 0817-15	$Vout_1$	2,43	2,34	2,17	2,05	2,02
	$Vout_2$	2,46	2,33	2,16	2,06	2,03
	$Vout_3$	2,45	2,30	2,16	2,06	2,00
	$Vout_4$	2,44	2,32	2,15	2,04	2,01
	$Vout_5$	2,43	2,30	2,20	2,05	2,00
	Vout(average)	**2,44**	**2,32**	**2,17**	**2,05**	**2,01**
Rflex$_1$ 0417-17	$Vout_1$	2,27	2,10	2,02	1,88	1,81
	$Vout_2$	2,24	2,11	2,01	1,89	1,83
	$Vout_3$	2,27	2,11	2,05	1,90	1,83
	$Vout_4$	2,25	2,12	2,04	1,93	1,86
	$Vout_5$	2,26	2,09	2,05	1,95	1,84
	Vout(average)	**2,26**	**2,11**	**2,03**	**1,91**	**1,83**
Rflex$_2$ 0817-13	$Vout_1$	2,31	2,18	2,05	1,98	1,83
	$Vout_2$	2,31	2,17	2,06	1,97	1,81
	$Vout_3$	2,30	2,20	2,08	1,98	1,82
	$Vout_4$	2,34	2,19	2,06	1,98	1,83
	$Vout_5$	2,33	2,21	2,08	1,98	1,79
	Vout(average)	**2,32**	**2,19**	**2,07**	**1,98**	**1,82**

Table III. Voltage values in volts (V) obtained after the measurement of FSR Model 400 force sensing resistors outside the glove

Sensor identification number		**200g**	**400g**	**600g**	**800g**	**1000g**
1	$Vout_1$	2,50	2,87	3,28	3,38	3,40
	$Vout_2$	2,53	3,01	3,21	3,39	3,44
	$Vout_3$	2,51	2,94	3,19	3,42	3,48
	$Vout_4$	2,47	2,96	3,17	3,43	3,50
	$Vout_5$	2,54	2,97	3,17	3,41	3,52
	Vout(average)	**2,51**	**2,95**	**3,20**	**3,41**	**3,47**
2	$Vout_1$	2,48	3,02	3,13	3,39	3,44
	$Vout_2$	2,49	2,08	3,30	3,38	3,41
	$Vout_3$	2,56	3,12	3,33	3,39	3,54
	$Vout_4$	2,64	3,12	3,30	3,35	3,47
	$Vout_5$	2,56	3,15	3,37	3,39	3,41
	Vout(average)	**2,55**	**2,90**	**3,29**	**3,38**	**3,45**
3	$Vout_1$	2,38	3,06	3,35	3,38	3,49
	$Vout_2$	2,39	3,06	3,40	3,40	3,51
	$Vout_3$	2,48	3,10	3,37	3,37	3,50
	$Vout_4$	2,49	3,11	3,39	3,30	3,56
	$Vout_5$	2,48	3,09	3,31	3,35	3,53
	Vout(average)	**2,44**	**3,08**	**3,36**	**3,36**	**3,52**
4	$Vout_1$	2,47	3,00	3,30	3,46	3,62
	$Vout_2$	2,43	3,05	3,24	3,42	3,61
	$Vout_3$	2,44	3,04	3,21	3,45	3,59
	$Vout_4$	2,51	3,01	3,21	3,41	3,59
	$Vout_5$	2,54	3,02	3,32	3,43	3,63
	Vout(average)	**2,48**	**3,02**	**3,26**	**3,43**	**3,61**
5	$Vout_1$	2,29	3,11	3,24	3,39	3,47
	$Vout_2$	2,27	3,01	3,15	3,40	3,45
	$Vout_3$	2,31	3,07	3,17	3,41	3,46
	$Vout_4$	2,35	3,05	3,37	3,39	3,51
	$Vout_5$	2,38	3,12	3,22	3,40	3,52
	Vout(average)	**2,32**	**3,07**	**3,23**	**3,40**	**3,48**
6	$Vout_1$	2,58	3,12	3,36	3,38	3,47
	$Vout_2$	2,67	3,01	3,41	3,35	3,48
	$Vout_3$	2,54	3,06	3,36	3,35	3,47
	$Vout_4$	2,46	3,00	3,39	3,42	3,49
	$Vout_5$	2,47	3,13	3,40	3,33	3,49
	Vout(average)	**2,54**	**3,06**	**3,38**	**3,37**	**3,48**
7	$Vout_1$	2,38	2,75	3,17	3,41	3,51
	$Vout_2$	2,35	2,72	3,18	3,42	3,50
	$Vout_3$	2,41	2,71	3,36	3,42	3,53

	$Vout_4$	2,48	2,69	3,06	3,38	3,50
	$Vout_5$	2,51	2,87	3,10	3,37	3,49
	Vout(average)	**2,43**	**2,75**	**3,17**	**3,40**	**3,51**
8	$Vout_1$	2,62	2,92	3,14	3,43	3,46
	$Vout_2$	2,63	2,91	3,17	3,42	3,42
	$Vout_3$	2,66	2,76	3,20	3,44	3,47
	$Vout_4$	2,63	2,82	3,13	3,40	3,51
	$Vout_5$	2,61	2,91	3,21	3,41	3,55
	Vout(average)	**2,63**	**2,86**	**3,17**	**3,42**	**3,48**
9	$Vout_1$	2,47	2,82	3,16	3,43	3,51
	$Vout_2$	2,52	2,84	3,31	3,41	3,49
	$Vout_3$	2,49	2,81	3,27	3,37	3,50
	$Vout_4$	2,50	2,89	3,26	3,39	3,53
	$Vout_5$	2,44	2,74	3,13	3,42	3,54
	Vout(average)	**2,48**	**2,82**	**3,23**	**3,40**	**3,51**
10	$Vout_1$	2,44	2,81	3,22	3,39	3,42
	$Vout_2$	2,42	2,84	3,21	3,37	3,39
	$Vout_3$	2,44	2,93	3,23	3,41	3,42
	$Vout_4$	2,46	2,88	3,22	3,38	3,40
	$Vout_5$	2,46	2,84	3,22	3,41	3,40
	Vout(average)	**2,44**	**2,86**	**3,22**	**3,39**	**3,41**

Table IV. Voltage values in volts (V) obtained after the measurement of FSR Model 400 force sensing resistor inserted in the glove

	0g	***200g***	***400g***	***600g***	***800g***	***1000g***
$Vout_1$	0,00	2,48	2,87	2,99	3,19	3,33
$Vout_2$	0,00	2,54	2,87	2,97	3,26	3,32
$Vout_3$	0,00	2,38	2,80	3,03	3,22	3,33
$Vout_4$	0,00	2,58	2,81	3,00	3,32	3,33
$Vout_5$	0,00	2,51	2,72	2,93	3,25	3,38
Vout(average)	**0,00**	**2,50**	**2,81**	**2,98**	**3,25**	**3,34**