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Microprocessor system for measuring pressure between orthosis and foot

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When using orthotic devices to correct foot or limb deformities, the pressure sensor often used to estimate the value and position of the corrective force. The Interventional Pressure (IP) between the orthosis and the foot in this study was measured by using a manufactured pressure sensor (MPS) device the components of the (MPS) are: force sensor mat (43.5 x 43.5 mm), LCD display, connecting wires and Arduino. The (MPS) is described as being lightweight, easy to move, and inexpensive compared to other force sensor devices. The (MPS) device was manufactured and programmed to measure the pressure applied between the orthosis and the foot-sole in three regions, and compared to an F-Socket sensor (FSS). An experimental test was carried out on a patient who suffered from instability of the right leg in the ankle joint. In the regions (calcaneus center L1, little toe-base L2 and big toe-base L3), the intervention pressure was calculated in two ways between the foot-sole and the orthosis. The first method results by using the (MPS) device are (110,173 and 147 KPa), while the second method result by using the (FSS) device is (118, 166 and 141 KPa) respectively, the test results showed that the pressure readings obtained from the (MPS) device are close to the readings obtained by using the (FSS) device. This shows the accuracy of the readings of the pressure sensor device in this study despite the fact that it has a simple design.

Keywords: orthosis, Arduino, foot-sole, interventional pressure (IP), MPS, FSS.

Микропроцессорная система для измерения давления между ортезом и стопой

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При использовании ортопедических аппаратов для коррекции деформации конечности или стопы датчик давления часто используют для оценки величины и положения корректирующей силы. Значение давления (IP) между стопой и ортезом в этой работе измерялось с помощью изготовленного аппарата с датчиком давления (MPS). Компонентами аппарата (MPS) являются: пленка датчика силы (43,5 x 43,5 мм), соединительные провода, ЖК-дисплей и Arduino. Аппарат (MPS) описывается как легкое приспособление, удобное в перемещении и недорогое по сравнению с другими устройствами для измерения силы. Аппарат (MPS) был изготовлен и запрограммирован для того чтобы измерить давление, прикладываемое между ортезом и подошвой стопы в трех частях, и сравнения с датчиком F-гнезда (FSS). Экспериментальное испытание было проведено на пациенте, страдающем от нестабильности правой ноги. В областях (центр пяточной кости L1, основание мизинца L2 и основание большого пальца L3) давление вмешательства рассчитывалось двумя способами между подошвой стопы и ортезом. Результаты первого метода с использованием устройства (MPS) составляют 110,173 и 147 кПа, а результаты второго метода с использованием устройства (FSS) составляют 118; 166 и 141 кПа соответственно. Это дает нам точность показаний устройства датчика давления в данном исследовании. Несмотря на простую конструкцию, аппарат может предоставить персоналу больницы ценную информацию о состоянии пациента в реабилитационный период.

Ключевые слова: ортез; Arduino; подошва стопы; интервенционное давление (IP); MPS; FSS.

Introduction

The invention of an in-shoe device to measure plantar pressure distribution for gait analysis is presented in this paper [1]. This research describes a methodology and tools for improving the lower limb prosthesis design by measuring pressure at the residual limb-socket contact [2]. The early efforts to construct adjustable inserts were presented in this paper [3], which consisted of the sensorized inflatable pressure actuators tiny arrays, that could expand in response to volume changes. This work [4] describes a prosthetic silicone liner with a (FBG) that provides cushioning for the residual limb and can easily detect interface pressures inside socket of the lower-limb prosthetic in a simple and practical way. The design guidelines for a high - sensitivity piezo-resistive pressure sensor with a high enough output to be detected by simple and affordable circuits has been established to assure wear-ability in this study [5]. The data gathering system was designed and development to capture the influence of footwear on the human foot and gait cycle is described in this article [6]. In this study the FSR sensor unit of the QA system is used to measure the force between an immobilization device and a patient's skin [7-10]. They describe a pair of pressure-sensitive insoles based on optoelectronic sensors for real-time assessment of temporal gait metrics in this paper [11]. In this study the most recent breakthroughs in research are analyzed addressing two common devices used for health monitoring and foot motion analysis: the in-shoe system and smart socks [12].

The aim of this work is to study aforementioned researches and methods of manufacturing sensors (systems of the pressure mapping), the high cost of these devices was noticed with the need for laboratory preparations, as these requirements face many obstacles, especially in the uses of the clinical settings. For this reason, this study dealt with the manufacture of a pressure sensor device that works to simplify the measurement and installation process so that it is easy to carry and install and does not require laboratory preparations, taking into account the accuracy of measurement and the low cost to enable workers in physical rehabilitation centers in hospitals to use it easily.

Materials and method

Force Sensitive Resistor (FSR)

The FSR is an inexpensive and easy-to-use sensor that detects physical weight, pressure, and heat. As shown in (Fig. 1), the sensor area is (43.5 x 43.5 mm, and thickness 1.25 mm). The FSR consists of resistors that change their resistance value depending on how much they are compressed. These devices are relatively inexpensive and easy to operate. [10].

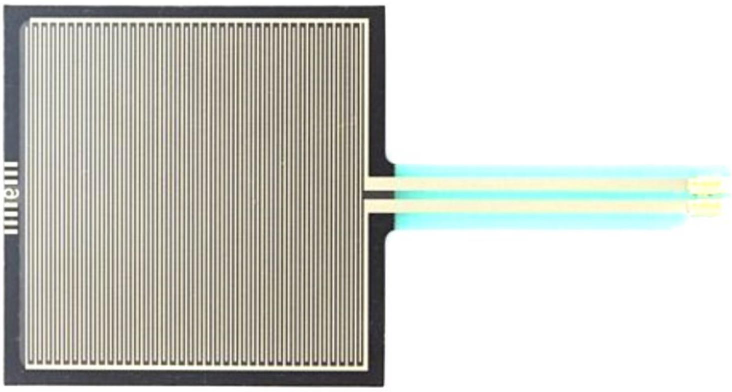


Fig.1. FSR

The FSR detects or senses any compression and is used to calculate the force value or pressure applied, which the sensor then converts into voltage. The calibration chart is using to calculate the pressure value by understanding the each voltage value, the force sensor used in this work consists of 2 main layers. The conductive polymer is the first layer and the film sensor is the second layer as shown in (Fig. 2). Submicrometer-size particles that form a sensitive layer are electrical structures (non-conductive and conductive). The resistance of a conductive polymer is changed by applying pressure to the surface of the polymer, one (FSR) terminal is connected to Vcc and the second to ground through a pull-down resistor, the RPDR is the constant resistance and the R_{FSR} is the variable resistance for the FSR.

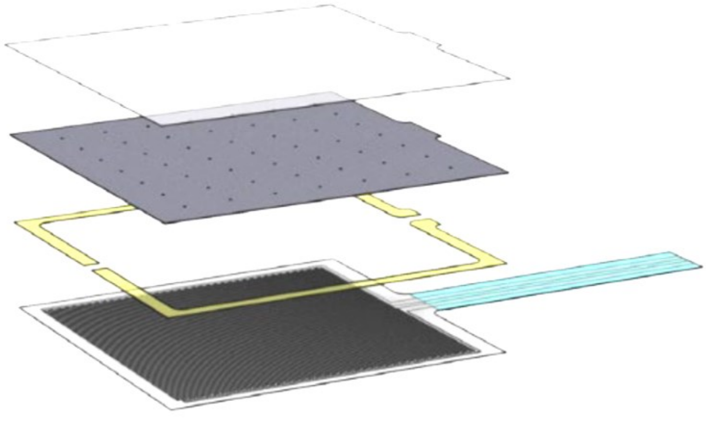


Fig. 2. FSR layers

When combined the resistance R_{FSR} and R_{PDR} provide an analog output voltage as Vo, which is then used at the point of the analog output as Vcc. The STL, SDA, VCC and GND pins on the I2C LCD were connected to the Arduino by same pins cod order. The data will be displayed on the Liquid Crystal Display as shown in (Fig. 3). The current conductivity is determined by the resistance between the film sensor and conductive polymer. The elements of active points are added to the conductive polymer as pressure is applied to the FSR surface, giving a high protected area for current conduction, that means the high pressure applied created the high contact channels, reducing the FSR resistance. The voltage of the analog output can be calculated by using the following equation.

$$Vo = \frac{R_{PDR}}{R_{PDR} + R_{ASPS}} Vcc$$

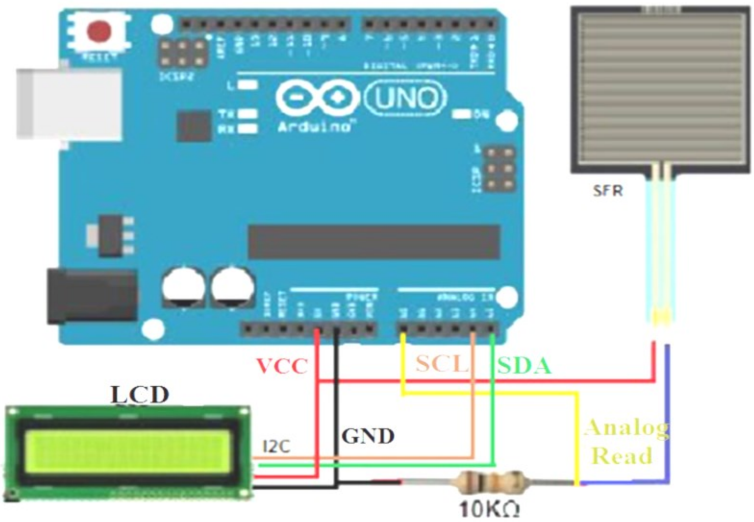


Fig. 3. Pressure measuring system components

Force Sensor Calibration

The force sensor calibration procedure must be performed to ensure the correct operation of the (MPS) in this study. The calibration procedure was tested by applying many known masses on the force sensor and reading the resulting voltages for each mass. The voltage for each mass will be displayed directly by LCD. To transform the calibration chart from a relationship between voltage and mass (v & m) to a relationship between voltage and force (v & f), each mass is multiplied by the ground gravity value (g). Then, dividing each force value on the sensor area. Now the relationship between the (v & f) is converted to the pressure and voltage relationship (v & p) as shown in (Fig. 4). To prepare for a pressure measurement operation, all these calibration data were entered in the Arduino settings.

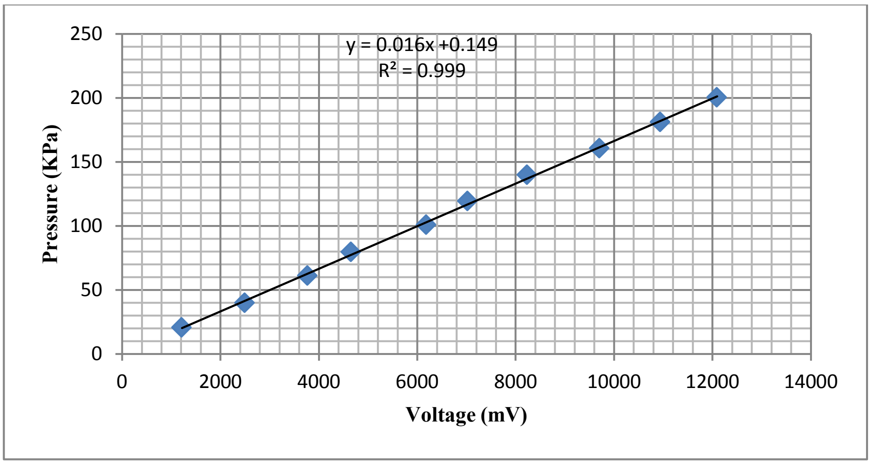
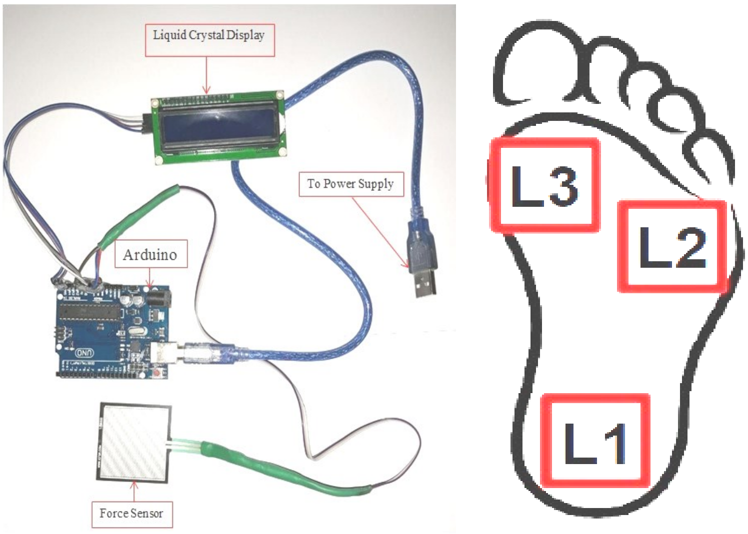


Fig. 4. Calibration curve

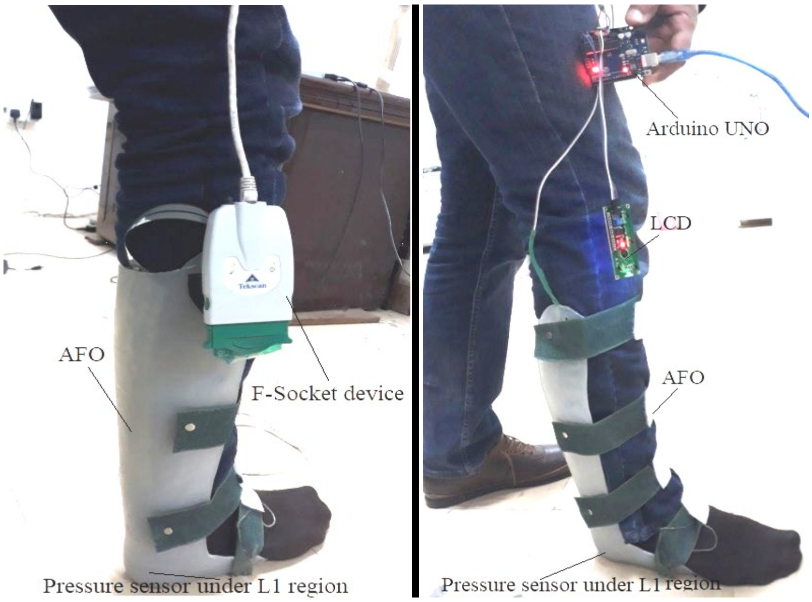
Experimental work

As shown in (Fig. 5a) the (MPS) device consists of FSR, Arduino, power supply and LCD. The resistance is converted to voltage by modified voltage divider using a switching circuit. The data of acquisition module receive the serial data from Arduino, which it displays as pressure in (KPa) on the LCD. The test was done by a pathological person suffering from instability in the left ankle joint the subject wore the orthosis (AFO) to treat his deformation case. Two measuring methods are used in this work to measure the pressure between the patient foot-sole and (AFO), in three areas (calcaneus center L1, little toe-base L2 and big toe-base L3) as shown in (Fig 5b). The first method by using the (MPS) device and second method by using the (FSS) device as shown in (Fig. 6), and the devices results method were compared to ensure that the measurement sensor was manufactured in this study is working properly.



(*a*) (*b*)

Fig. 5. (*a*) Manufactured force sensor device and (*b*) Patient foot areas



(*a*) (*b*)

Fig. 6. (*a*) F-Socket device (FSS) method and (*b*) Manufactured pressure sensor (MPS) method

Results and discussion

Now the experimental part is completed, we found that the calculating results of the applied pressure between the patient foot-sole and the orthosis (AFO) in the (calcaneus center L1, little toe-base L2 and big toe-base L3 region), respectively the results for both pressure sensors devices (MPS & FSS) are very close together in same regions, the experimental results value showed that when using the (MPS) device were (110, 173 and 147 KPa) while the results value of the F-Socket sensor (FSS) device were (113, 164 and 139 KPa) as shown in the (figs 7-12) and Table 1. Through the values of the results obtained from both pressure sensors, we note the reliability of the manufactured pressure sensor (MPS) and calibration method was effective in achieving good results despite the simplicity of the factory device and its low material cost.

Table. 1. Interface pressure value in three regions by using (FSS & MPS)

Method	Test Region	Pressure Value (KPa)
FSS	L1	118
	L2	166
	L3	141
MPS	L1	110
	L2	173
	L3	147

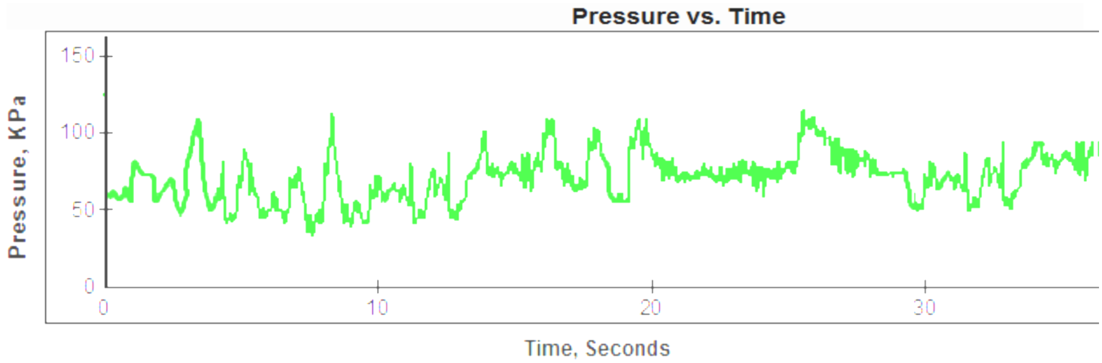


Fig. 7. Interface Pressure L1 region, by using (FSS)

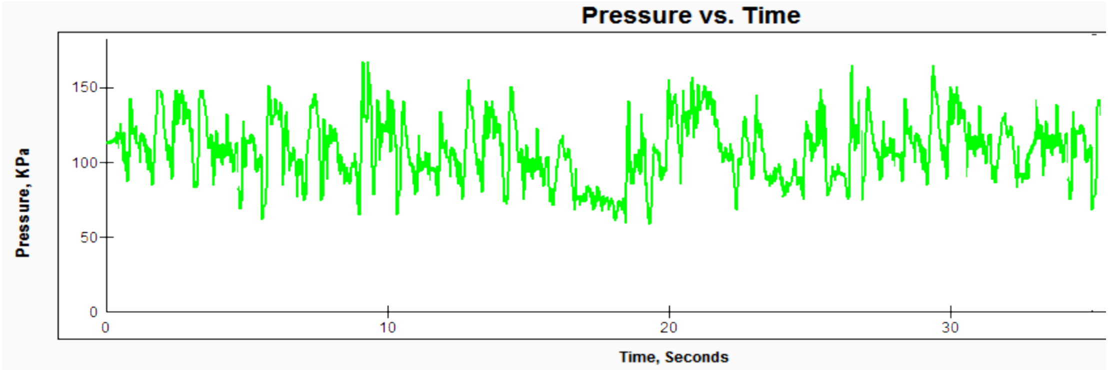


Fig. 8. Interface Pressure L2 region, by using (FSS)

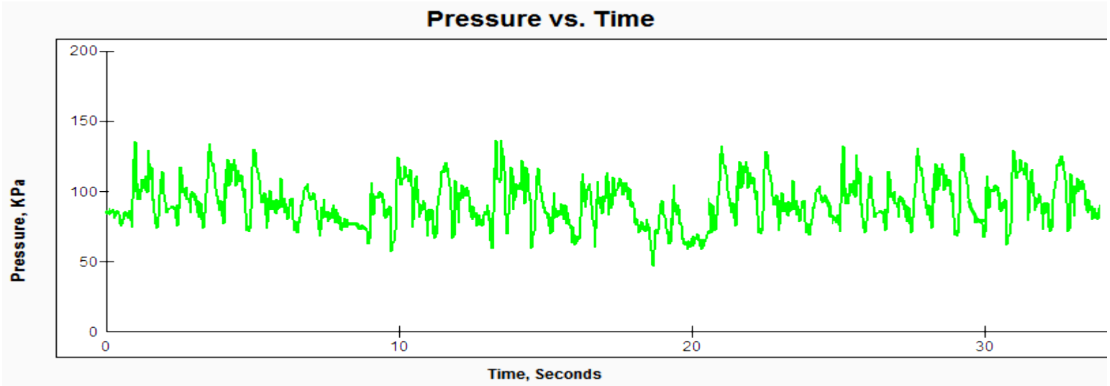


Fig. 9. Interface Pressure L3 region, by using (FSS)

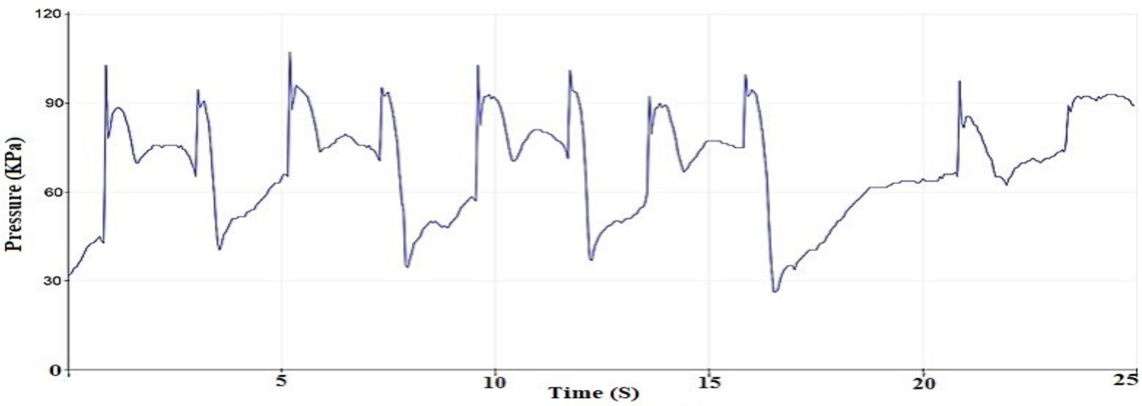


Fig. 10. Interface Pressure L1 region, by using (MPS)

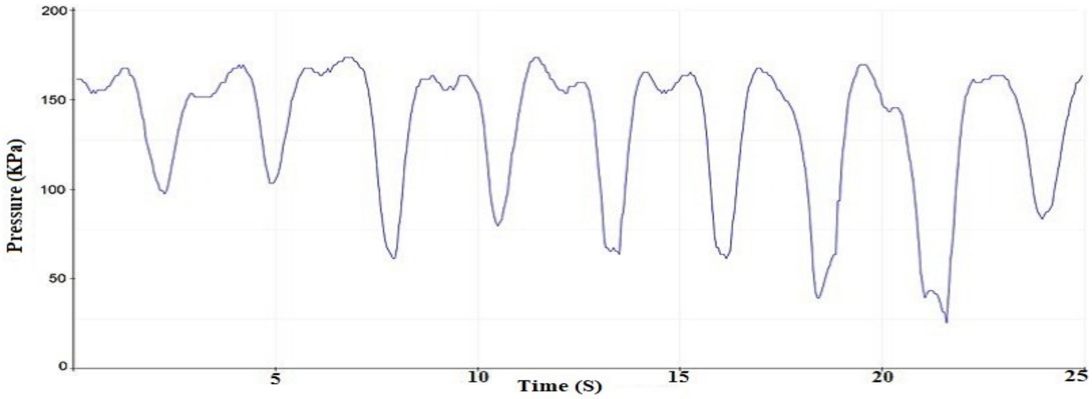


Fig. 11. Interface Pressure L2 region, by using (MPS)

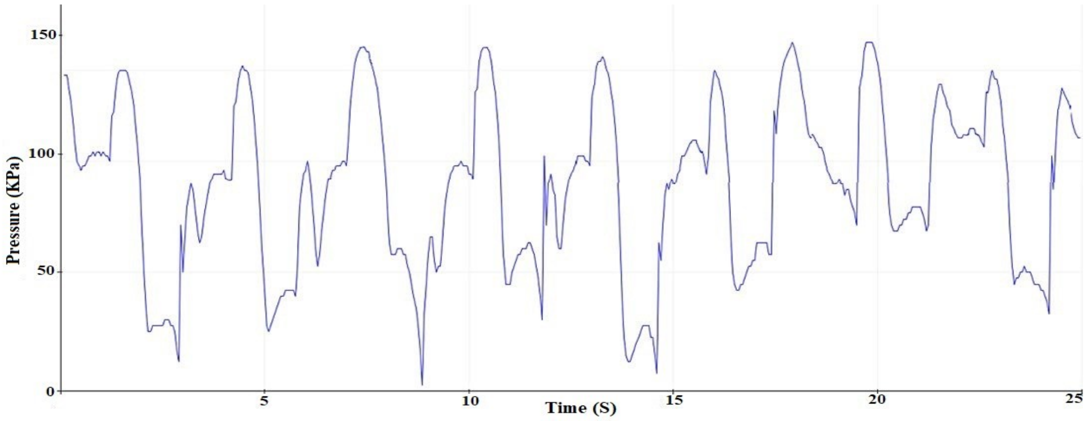


Fig. 12. Interface Pressure L3 region, by using (MPS)

Conclusion

1. The experimental results showed that the measure results for the (FSS) device of (118, 166 and 141 KPa) and the (MPS) device of (110, 173 and 147 KPa) are in same regions respectively.

2. As the results showed, the pressure readings of the (MPS) device are very close to the pressure readings obtained by the (FSS) device. This means that the manufactured pressure sensor (MPS) device, despite the low cost and simplicity of components, has good performance compared with the (FSS).

References

1. Krausz, N.E., Hargrove, L.J. A survey of teleceptive sensing for wearable assistive robotic devices. Sensors, 2019, vol. 19, no. 23. P. 5238.
2. Henrikson K.M., Weathersby E.J., Larsen B.G. et al. An inductive sensing system to measure in-socket residual limb displacements for people using lower-limb prostheses. Sensors, 2018, vol. 18, no. 11. P. 3840.
3. Dong D., Ma C., Wang M., et al. A low-cost framework for the recognition of human motion gait phases and patterns based on multi-source perception fusion. Engineering Applications of Artificial Intelligence, 2023, vol. 120. P. 105886.
4. Swanson E.C., McLean J.B., Allyn K.J., et al. Instrumented socket inserts for sensing interaction at the limb-socket interface. Medical engineering & physics, 2018, vol. 51. P. 111-118.
5. Armitage L., Turner S. and Sreenivasa M. Human-device interface pressure measurement in prosthetic, orthotic and exoskeleton applications: A systematic review. Medical Engineering & Physics, 2021, vol. 97. P. 56-69.
6. Vu H.T.T., Gomez F., Cherelle P., et al. ED-FNN: A new deep learning algorithm to detect percentage of the gait cycle for powered prostheses. Sensors, 2018, vol. 18, no.7. P. 2389.
7. Gabert L., Lenzi T. Instrumented pyramid adapter for amputee gait analysis and powered prosthesis control. IEEE Sensors Journal, 2019, vol. 19, no. 18. P. 8272-8282.
8. Hinrichs P., Cagle J.C. and Sanders J.E. A portable bioimpedance instrument for monitoring residual limb fluid volume in people with transtibial limb loss: a technical note. Medical engineering & physics, 2019, vol. 68. P. 101-107.
9. Ko S.T., Asplund F. and Zeybek B. A scoping review of pressure measurements in prosthetic sockets of transfemoral amputees during ambulation: Key considerations for sensor design. Sensors, 2021, vol. 21, no. 15. P. 5016.
10. Hussejn, T.S. Izyumov, A.I. Pressure measurement and analysis of ankle orthosis for a person with an ankle fracture // Engineering journal of Don. E-journal. 2022, vol. 88, no.4. P. 590-601. (in Russian)
11. Renganathan G., Kurita Y., et al. Foot biomechanics with emphasis on the plantar pressure sensing. Advances in Product Design and Design Methods for Healthcare, 2022. P. 115-141.
12. Faux-Nightingale A., Kelemen M. Ankle-foot orthosis adherence in children and adolescents with cerebral palsy. Prosthetics and Orthotics International, 2022, vol. 46, no. 4. P. 351-356.
13. Hussejn, T.S. and Izyumov, A.I. Design and analysis of plastic and metal-plastic ankle orthosis // Engineering journal of Don. E-journal. 2022, vol. 89, no. 5, P. 794-805. (in Russian).

14. Thalman C.M., Hsu J. Design of a soft ankle-foot orthosis exosuit for foot drop assistance. International Conference on Robotics and Automation ICRA, 2019. P. 8436-8442.
15. Schaller M., Sorkhabadi S.M.R. An ankle assistive device for gait plantar flexion assistance, American Society of Mechanical Engineers, 2020, Vol. 83549, V001T03A003 p.
16. Thalman C.M., Hertzell T. Lee, H. Toward a soft robotic ankle-foot orthosis (sr-afo) exosuit for human locomotion. International Conference on Soft Robotics, 2020. P. 801-807.
17. Sheffler L.R., Bailey S.N. and Chae J. Spatiotemporal and kinematic effect of peroneal nerve stimulation versus an ankle-foot orthosis in patients with multiple sclerosis: a case series. Pm&r, 2009, vol. 7, no.1. P. 604-611.
18. Taiar R., Adel C., Belassian G., at al. Can a new ergonomical ankle-foot orthosis (AFO) device improve patients' A preliminary study. Theoretical issues in ergonomics science, 2019. Vol. 20, no. 6. P. 763-772.
19. Schaller M., Sorkhabadi S.M.R. and Zhang An ankle assistive device for gait plantar flexion assistance. American Society of Mechanical Engineers. 2020, Vol. 83549, V001T03A003 p.
20. Moulzolf S.C., Behanan R., Lad R.J. Langasite SAW pressure sensor for harsh environments. IEEE International Ultrasonics Symposium, 2012. P. 1224-1227.