Bioengineering Research

Developing an In-expensive Device for Measuring the Pressure of Children's Soles

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Abstract

Walking is one of the most necessary and important movements among humans, especially children. Walking problems can have serious consequences for children at an older age. In this paper, a system is developed that can show the pressure on the soles of children's feet. With this device, children's walking problems can be solved to a high extent. First, the weight sensor information is amplified with the help of an op-amp, and then it is read through an analog-to-digital converter, and with the help of this analog-to-digital converter, it is digitized. As it turns out, sensors have to translate information into machine language in order to transmit information, which can be done with the help of an analog-to-digital converter. After the micro converts this data to digital, the system is then calibrated and the calibrated data is sent to the computer via the UART protocol using a TTL to USB converter. This data is displayed on the computer for further review.

Keyword: Pressure of foot sole, Load cell, microcontroller, Hx711
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1. Introduction

Today, there are many wearable sensors [1-2] that can be used for monitoring body movements especially in rehabilitation [3-5], healthcare [6-7], medical [8-9] and so on. Additionally, image processing is not used only for detection of type of cancer [10] and it is utilized for analyzing image of foot sole [11]. Foot is a key organ in body and the wearable system can be mount on them for movement analyses. The foot is the only anatomical structure of the body that is in contact with the ground and as the last part of the lower limb chain resists the applied forces. Improper distribution of forces causes abnormal movement and increased stress and leads to damage to the tissues and muscles of the foot and therefore can cause a wide range of foot deformities. Accordingly, knowledge of the forces acting on the sole of the foot not only helps to understand the relationship between the structure and function of the foot, but also is important in assessing many pathological conditions such as diabetic foot and musculoskeletal disorders [12].

Measurement of plantar pressure in people with neuropathy diabetic shows a link between increased local pressure and ulceration under the soles of the feet. Numerous studies have reported the usefulness of pressure measurement methods for regular evaluation of these patients' feet and providing an appropriate treatment plan based on it. In order to assess the pathology of the foot, it seems logical to first have accurate information about the functional structure and normal movement of the foot, and then to introduce the major deviations as a pathological condition. According to standards, people need to study with it. Studies show that knowing how the load

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on the sole of the foot is distributed while standing and walking is a good criterion for examining the normal position of the foot. There are many ways to study foot loading. One of the most common and newest methods is measuring the pressure of the sole of the foot while standing and walking using a pressure measuring devices, which have been studied several times [13]. While most studies have examined the impact of structural factors such as age, body mass index, or methodology such as various pressure measurement methods as well as the use of different devices in measuring pressure such as sensor-equipped insole or pressure measuring plate, there is much information specifically available in this area. So far, the results of research done in this field show that there are controversial results in studies from the point of view of pressure distribution in standing position. One of the famous sensors used in this field is load cells. Load cells help a lot to measure force. They consist of four resistors that are in Watson bridge, two of which are fixed and the other two are variable. The output voltage changes with the change of power and it can be extracted with the help of analog to digital converter [14].

In a study in [15], the peak pressure of the foot sole and the time to reach it in walking at normal speed for people with a back knee problem and healthy individuals were compared [13]. Any change in the pressure pattern of the foot sole increases the risk of tissue damage and pain. In a study in [16], a weak and negative relationship between Q angle and the distribution of foot pressure in the middle area of the right foot of footballers was reported and it was related to the prevalence of brace knee deformity in footballers [17]. In another study, the obtained result showed that the pressure on the thumb and metatarsals increases in people with plantar fasciitis [17]. Also, the heel varus and valgus changes the distribution of plantar pressure and increases overtraining injuries by altering the foot dynamic [17]. In the study, it was found that flat feet can change the distribution of foot pressure when walking by changing the activity of lower limb muscles [18]. Also, people with flat feet show more mobility during walking than people with normal feet. In addition, previous studies have shown that people with flat feet are at risk for many hyperactive injuries include metatarsal fracture stress, iliotibial band syndrome, and Patellofemoral pain syndrome [19]. For example, Simkin et al. focused on the risk of fracture stress associated with foot structure and reported that people without flat feet are more prone to femoral fracture stress, while people with flat feet are more at risk in the fracture stress of the metatarsal bones of the foot [20].

The symmetry between two legs for walking in the selected parameters from the pressure distribution of foot sole in elite male karatekas in [21]. The foot has a key effect on the transmission of forwarding forces by playing a lever role as well as bears the weight and absorbs the forces due to the impact with the ground in walking. Additionally, the foot has a decisive role in walking due to its anatomical structure and position in the lower limb. The sole of the foot is the common boundary of the force distribution between the lower limb and the ground; Therefore, it is very important to pay attention to the sole of the foot as a member that is constantly in direct contact with the outside environment [21]. Also, the effect of the orthosis with longitudinal arch support on the distribution of plantar pressure in people with flexible flat feet was investigated [22]. Complications of flexible plantar fasciitis are conditions in which the longitudinal arch of the sole of the foot decreases or disappears in bearing weight. The main function of the longitudinal arch of the foot is to absorb and distribute the applied forces to the sole of the foot. When the longitudinal arch reduces or eliminates, the distribution of plantar pressure is disrupted and forces are applied to deeper tissues and higher joints, leading to complications such as pain in the higher joints [22]. Moreover, the distribution of foot pressure in adults in walking and standing was examined. The foot is the only anatomical structure of the body that is in contact with the ground and resists the applied forces as the last part of the lower limb. Improper distribution of forces causes abnormal movement and increased stress and leads to damage to the tissues and muscles and therefore can cause a wide range of foot deformities. Accordingly, knowledge of the forces acting on the sole of the foot not only helps to accurately understand the relationship between foot structure and function but is also important in assessing many pathological conditions such as diabetic foot and musculoskeletal disorders [23].

In this paper, a system for measuring the pressure on the soles of children feet is developed. The main components of the developed system consist of a load cell, microcontroller, and a USB to TTL converter. First, the load cell output is amplified using an Op-Amp, and then it is digitized by an analog to digital converter. After that, the obtained data is saved on microcontroller and the processor sent the data to personal computer through a serial port using TTL to USB converter. The obtained data in the PC can be displayed and saved for further investigation. Additionally, the system is low-cost and can be used in laboratories of movement analyses.

2. Material & Methods

In this paper, a system was developed to measure the pressure on the soles of children's feet. For this purpose, first, the proposed hardware and then the presented algorithm in software is described.

2.1. Hardware

The proposed hardware consists of a load cell sensor, a processor (microcontroller) and a TTL to USB converter that are introduced as follows.

The signal output of the load cell has very little change in voltage when the force was applied to it. Considering amplification is required to read the signal, and without amplification, the output cannot be converted into a digital signal, it is necessary using an Op-Amp. After amplification of the signal, an analog to a microcontroller digital converter is used for digitizing. This process can cause problems for the circuit and make the circuit very sensitive to environmental noise. Because using an analog-to-digital converter in the processor requires very precise isolation and filtering of noise. For this purpose, a module (Hx711) is used that performs the work of amplifying and digitizing the signal itself and the digital number is sent to the micro. This procedure increases the accuracy of the system and reduces the error rate to a minimum. The HX711 is a module for load cell sensors and converting their analog output to digital, so it is one of the most widely used sensors in the applications of weight detection and load cell setup (Figure 2, left-side). Since setting up a load cell has always been a difficult and sensitive task due to very small changes in output voltage and high noise, it can be used this module without the need for any adjustments and hassle for analog circuits, load cell output is converted to 24-bit accuracy. If this module is used, which has better accuracy than its previous version and also has better filters, noise from other circuits is minimized and it can be adjusted and calibrated the device with very high accuracy.

In this paper, an Atmega 8, which is an AVR model processor, is used in order to read out the load cell data through microcontroller's pins, and then the data is sent to a personal computer through serial protocol by the processor. After that, using a USB to TTL converter, a system can be easily equipped with a USB interface and consequently allows serial communication with a computer via the USB port. In fact, by connecting this converter to a computer and installing a driver program, a virtual serial port is added to the computer ports. This converter can work with operating systems of Windows, MAC, Android, Linux.

After introducing the important components and also modules, this circuit was simulated along with other electronic elements in Proteus software. The circuit schematic drawn in Proteus software is shown on the left side of Figure 1.

With the help of the schematic in Figure 1, the connections in Altium Designer software is made (Figure 1, right-side). As Figure 1 of the right-side shows, there are some blue and red tracks. The blue tracks are at the bottom of the circuit, while the red tracks are at the top of the circuit. To make holes to attach the parts on the board, holes whose size can be changed are used. Figure 1 right-side shows the print circuit board (PCB) of the developed system. Also, a ground margin has been created around the circuit to reduce noise. After design in Altium Designer, the PCB was given to a PCB company to make the design on the copper fiber. After that, it is time to attach the components on the board that the developed system is as Figure 2 after this operation. The components include consist of microcontroller, load cell, Hx711 module, TTL to USB converter, crystals, resistor, and MKT capacitors that are shown in Figure 2.

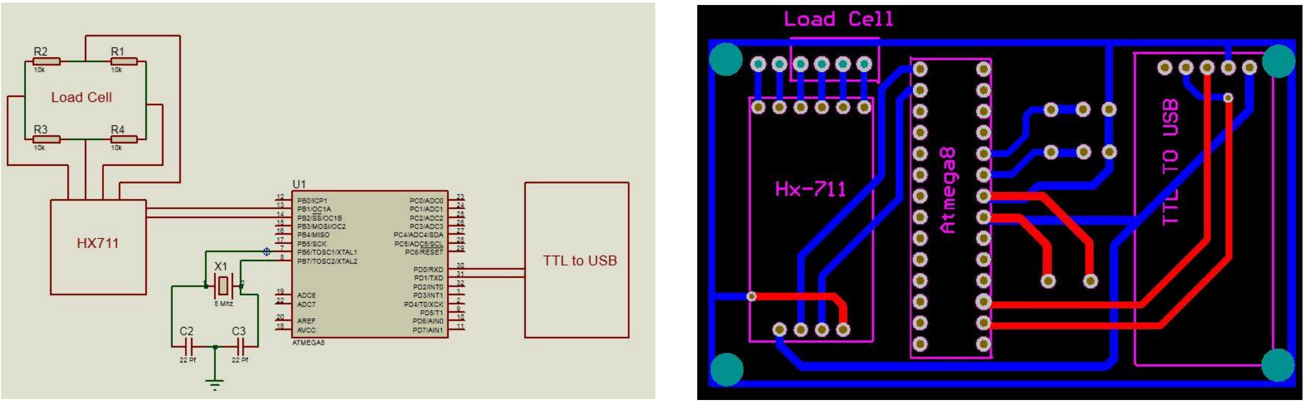

Figure 1: The schematic and the printed circuit board (PCB) of the developed system are the left side and the right side, respectively.

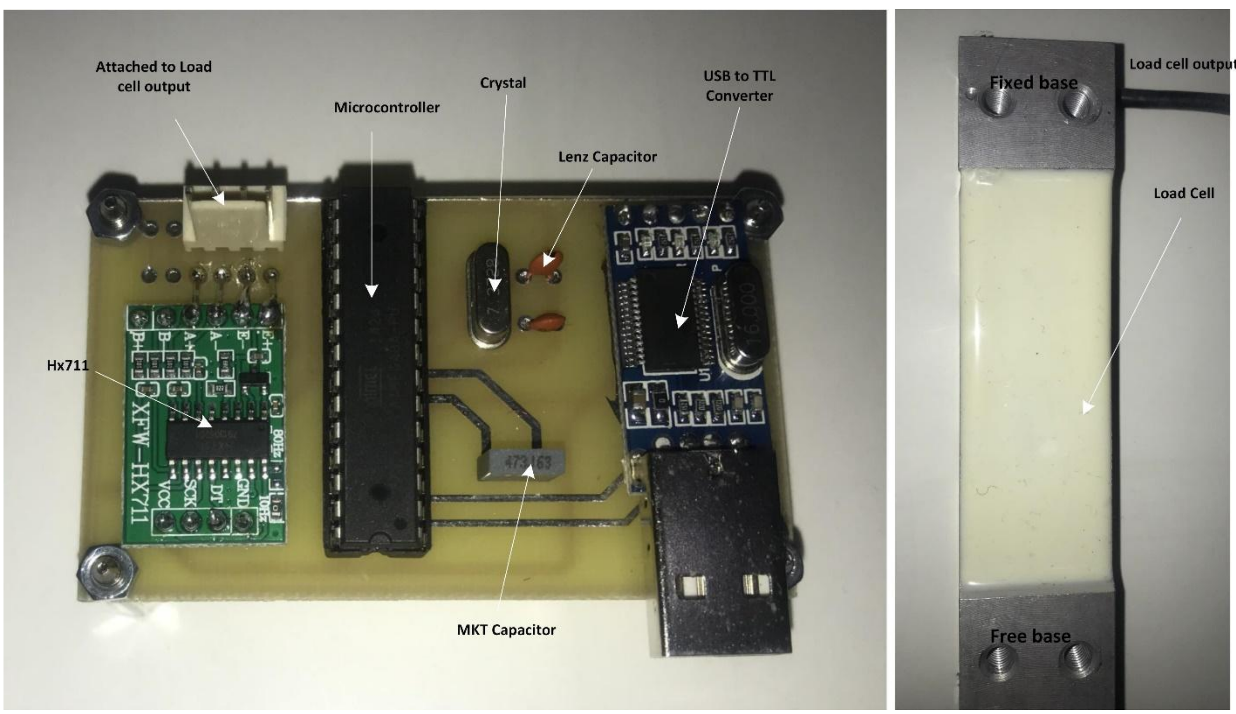

Figure 2: The prototype of the developed system and load cell sensor used are left-side and right-side, in turn.

The crystal is used for regulating the external frequency of the microcontroller, which is 8 MHz, and is connected to two lens capacitors with a capacity of 22 pf to remove noise. The MKT capacitor is used to eliminate high-frequency noise.

Briefly, the operation of the developed device is explained that the data of the load cell sensor is amplified with the help of Hx711 and converted to digital as well. This data is then read by two pins of the microcontroller and then stored in the flash memory of the microcontroller. The data is sent to the computer via a TTL to USB converter. In the computer, data storage and display operations are performed with the help of MATLAB software. To measure the pressure on the sole of the foot, first, the developed device is connected to the laptop via USB port. Then, a side of the load cell is fixed at a point by bolts, and force is entered in a free point, as shown in Figure 2 the right-hand.

2.2. The proposed algorithm for receive the data

Here, a proposed algorithm is presented in Matlab software in order to record the obtained data. The algorithm is shown in Figure 3. As it turns out, the serial port settings are performed and the baud rate of this transmission is 9600 and the port used is port 9 to read the data. Then the port is opened and in an iteration loop, the data is read from the port. Since data is a string, it is mandatory converting it to a number. Then, the values are gotten and stored in a variable called w1. After this, port 9 is closed. In order to calibrate the raw data in the sensor, the raw data is subtracted from first or second data. It should be noted that there is no force on the load cell for 0-5 seconds first. A FOR iteration is defined for the calibration. Then the obtained data is illustrated. The mentioned algorithm for sending the data is as figure 3.

3. Results and Discussions

3.1. Stability

One of the most important tests is a stability test that helps to know a system that gives valid data for a long time. In the stability test, the sensor at a point is fixed for a long time without applying force to it. The obtained result can be seen in Figure 4. In stability tests, if the sensor does not deviate during this time without any force applying on it, it indicates that the system is stable. However, if the sensor output shows different numbers during this period, it indicates that the system is not very stable. The outcome results show sensor output is constant for 10000 samples for 228 seconds. Accordingly, the system is stable. As Figure 4 shows, the accuracy of the circuit is very high, and in there is no single data out of the value 0. It should be noted that during this period, no force has been entered the sensor. This indicates a very low error and proves that this system has good stability.

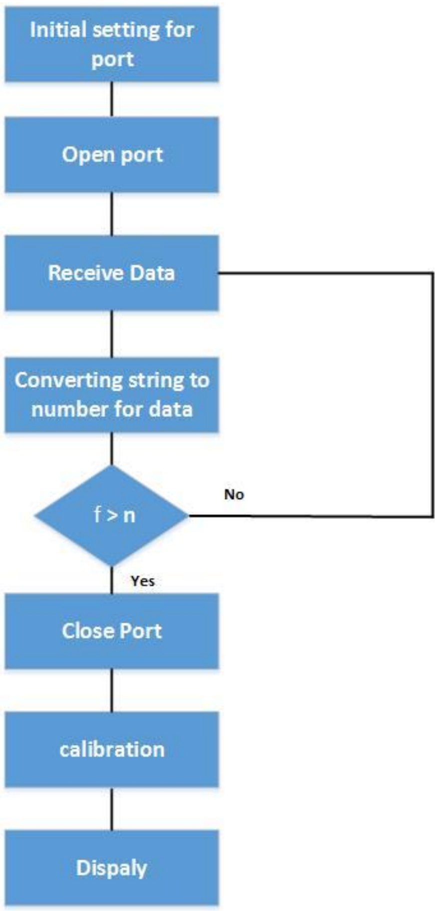

Figure 3: The proposed algorithm for collecting the data of the developed sensor.

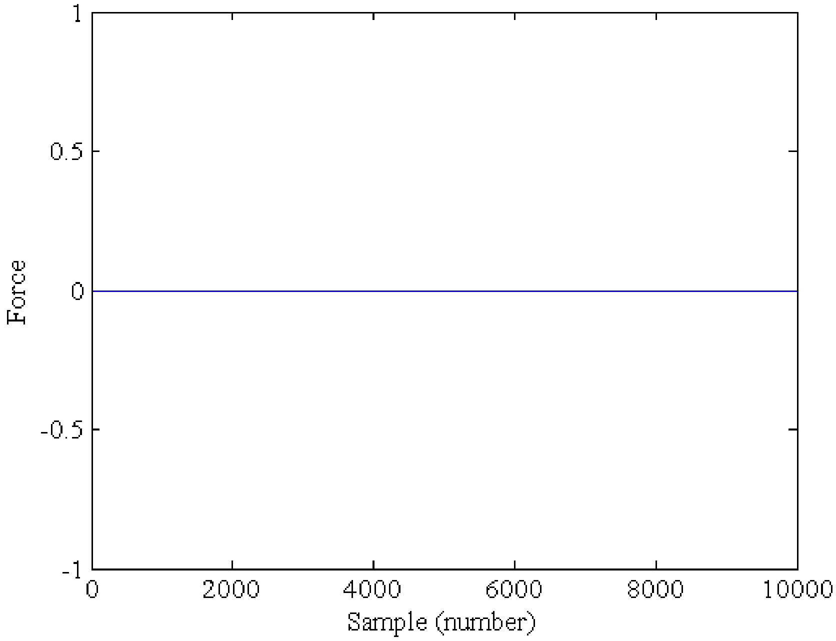

Figure 4: Stability test for the system which has a constant value in the output. This data is collected in 228 seconds.

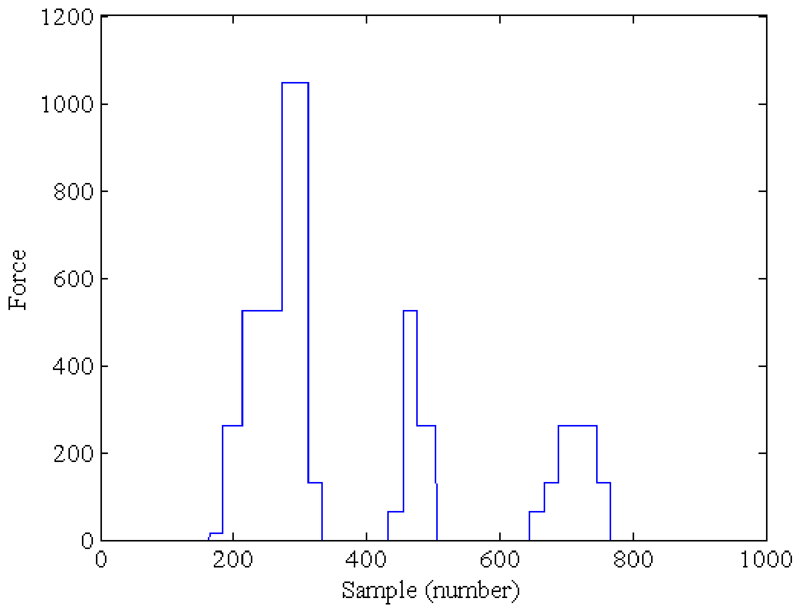

Figure 5: System output for different forces

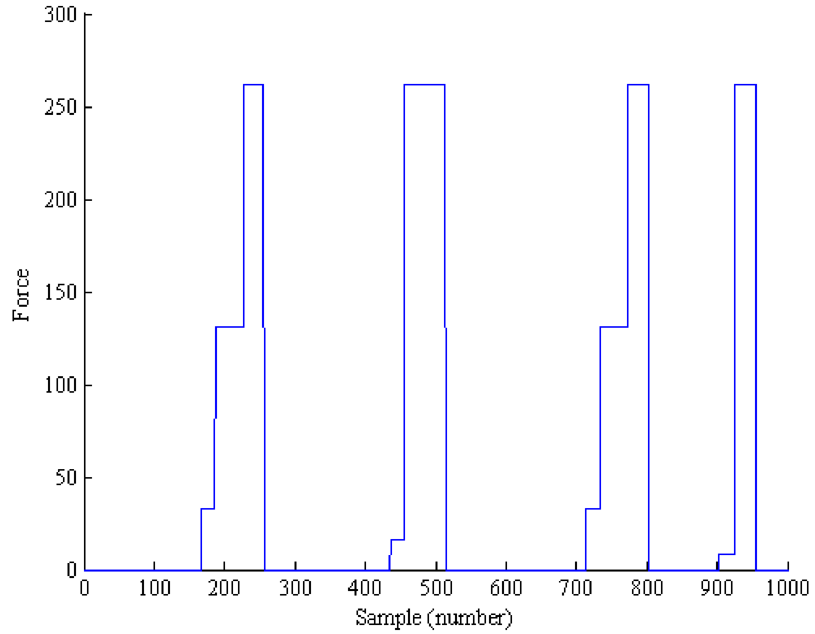

Figure 6: System output for equal forces

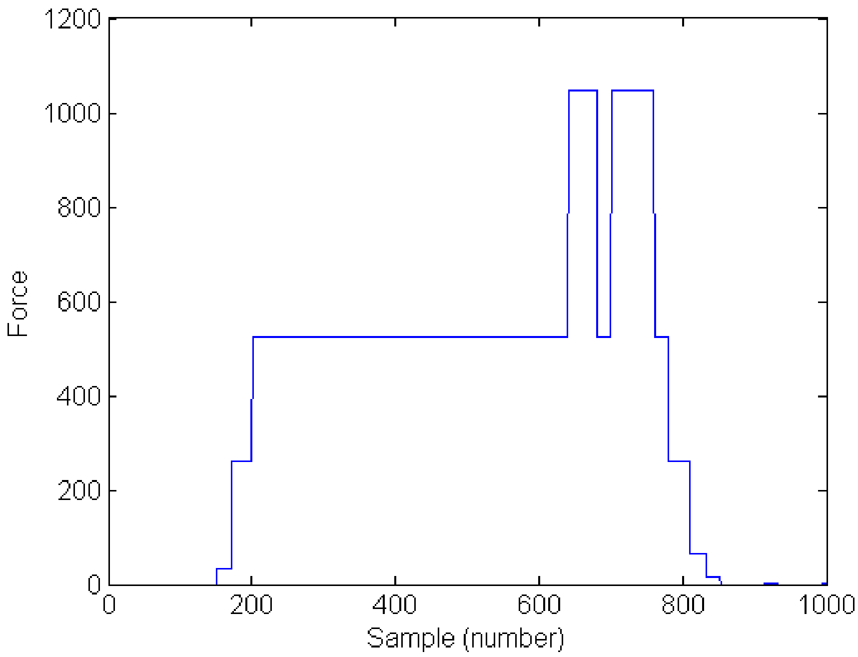

Figure 7: Sensor output for foot movement on the sensor.

3.2. Other tests

To perform further tests, the sensor is fixed at a point. If there are no bolts for fixing the load cell, it can be held by hand for tests. Nonetheless, it should be considered that many forces are put in fixpoint and can hurt to hand. After that, one volunteer is asked to put his foot on the load cell. As Figure 5 shows, these forces start from maximum and decrease to low, respectively. In the first peak in Figure 5, a lot of force is applied to the sensor. After that, the amount of force is reduced and Finally, this amount of force reaches the minimum value. Of course, this is not the minimum value that the sensor can measure, and the minimum value that the sensor can measure is much less than this value. The total time was 21.8 seconds (Figure 5) to perform this test.

In the next test, approximately equal forces are applied four times in 21.8 seconds for 1000 samples that the obtained results are shown in Figure 6. As can be seen, some forces are performed over a longer period of time and therefore have more space under the curve.

In the next test, Volunteers are asked to put their foot on the sensor completely and then remove the heel and apply the force to the load cell with their paw. Figure 7 shows that the foot is initially completely on the load cell. The amount of output increases when the heel is removed and the toe applies a lot of force to the load cell sensor. When the foot is completely removed from the sensor, the value 0 is displayed at the sensor output.

In the end, as the obtained results show, the system can be used for a laboratory for the investigation of the behavior of foot movement not only for children but also for adults. However, there is a larger load cell with higher price for adults. The system can be put in a lab set up in universities and students can use it for the aim of the research.

Due to the fact that the load cell sensor needs to be fixed on one side for testing, it must be fixed at one point with the help of bolts and the other side must be connected to a metal plate. The metal plate helps to take easy and fast tests. Nonetheless, it will have a cost a lot for the proposed device, although it greatly contributes to the accuracy of the sensor operation. Additionally, there are other load cell sensors that do not need to be fixed on one side to work with them. The total cost for the developed system is 50 dollars with the load cell used in figure 2 and without a metal plate. In the future, it can be changed the load cell to the canister load cell with higher accuracy. Also, the metal plate will add to the canister load cell to increase the accuracy of the system that can expand the cost to 100 dollars for improving the developed system.

4. Conclusions

In this paper, a system for measuring the pressure on the soles of children's feet was developed. For this purpose, first, the circuit was simulated with the help of Proteus software and then, the simulation was drawn in Altium Designer software in order to own a PCB. The mentioned components were attached to the PCB and after testing the circuit, the stability and system function was investigated. The obtained results showed that this system can store force variations, which can help a lot for future tasks and walking interpretations. This system is low-cost and can be used in lab set up for the purpose of walking interpretation.

Conflict of interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

Acknowledgments

No applicable.

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