Foot Plantar Pressure Measurement System for Static and Dynamic Condition

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Abstract. The purpose of this paper is to measure human foot pressure at various important points and to provide the proper diagnosis for treating the post-operative orthopedic patients. Measurement of the human foot pressure distribution can provide vital information and is of great value for medical diagnostics. The distribution of human plantar pressure data depends on the conditions of the foot such as foot structure, function, the posture control of the entire body and gait. This device data will contribute greatly to the diagnosis, estimation of surgery and a better understanding of the pathogenesis of diseased foot with abnormal pressure distribution. The device will measure the foot pressure with the help of FSR, force sensitive resistor sensors which are placed on the upside of the sole of shoe. These sensors are connected to the Arduino Mega 2560. A custom-made software is created using LabVIEW. The patient's details can be fed in and are saved in this software and when executed, the pressure data values collected is converted into digital pattern and a pedobarography is generated. This pedobarography image is displayed and saved in a word document and thus, enables the doctors to examine the foot pressure based on the deduced results.

Keywords: Foot Plantar, Piezo crystals, Sensitive Resistor, Pedobarography

1. Introduction

Solutions for healthcare industry application have tremendously increased due to the growth and development of technology. Thus, a lot of attention and focus is given on these research areas, especially biomedical and sports related. Since birth, our first involuntarily movement is walking, which is any human’s daily activity and gait plays an important role in the human movement. The synchronization of both neural and musculoskeletal systems is essential to achieve stability and balance of the body during movement. Analysis of gait parameters plays an important role in the evaluation of different factors. The feet are the major source of support during gait and are corresponding to the rapid changes of the surrounding and thus, are exposed to large force.

The deduction of the human foot pressure distribution can provide the essential information and thus, greatly assist the medical diagnosis. This foot plantar uses the FSR, force sensitive resistor sensors to collect the necessary data which is then processed to give digital output. These values are fed in custom-made software to give a pedobarography image that depicts visually the different pressure distribution of the foot. The study of pressure fields acting between the plantar surface of the foot and a supporting surface is called pedobarography. This image will be saved in a document format with the help of the custom-made software and can be studied by doctors for proper diagnoses. Thus, this foot plantar pressure device will
provide better efficiency and improve functionality than the already existing devices in the measurement system [1-3]. Feet are in contact with the surrounding environment during motion and thus, interact with the ground. Many activities are solely possible due to the movement of feet such as walking, running. Thus, the importance of feet in daily activities is immense and so proper care should be taken to avoid injury. To analyze the condition and suitable standard of feet is with the help of foot plantar characteristics. Thus, an accurate and secure measurement system for foot plantar pressure is imperative [4-6].

Footwear has been one of the first factors for determining the foot plantar pressure. 1997 witnessed the influence of mean peak plantar pressure on shoes with and without viscoelastic insoles, thus, giving the optimized effective result. In time, many various studies were available for foot pressure measurement and designs of footwear for non-disabled people. It was deduced rocker bottom shoes would reduce pressure under the first and fifth ray (metatarsal head) and thus, they were also used to decrease the foot pressure beneath the forefoot. These metatarsal heads are frequently the position of ulceration in patients with imbalance muscle deformity. It was concluded that the future shoe pattern will be different according to gender to avoid the metatarsal head formation as the plantar pressure varies between the two genders, men and women [7-9].

Considering the applications that are connected to disease diagnosis, many scientists have determined that foot problems are mainly because of diabetes that causes extreme foot plantar pressures in specific sites under the foot. Diabetes is now considered as a widespread condition and, according to reports; the number of patients suffering from diabetes is ever increasing. Balance is considered as a top priority for various sports and other biomedical applications such as soccer balance training and forefoot loading during running. Pressure distribution is promptly seen in aged and other impaired personal due to the gait instability. Thus, it is essential to develop and create capable techniques to measure the foot plantar pressure precisely and with efficiency [10, 11].

The objective of this paper is to develop a compact, affordable and efficient device that aids the healthcare industry. Thus, understanding the internal surface pressure between the foot plantar surface and shoe sole is important to determine the analyses of foot plantar pressure distribution.

2. Design of foot plantar pressure measurement system

The most crucial aspects of the project are to identify the most ideal sensor for the application and ensuring the practicality of the entire system. The system should produce reliable outputs at any given instance and the data should have sufficient resolution so it can be examined and analysed correctly. To ensure these parameters were adhered to, the following considerations were made:

2.1 Selection of Sensors

Figure 1 Piezo crystals are being tested for output range and repeatability

Choosing the correct sensor was by far one of the most important aspects of the project. To ensure this, several sensors were analysed based on their hysteresis, repeatability and accuracy. Another consideration made was to ensure a relatively high output voltage for various pressures applied, in order to keep the circuitry less complex. Ultimately, piezo sensors and force resistive sensors were shortlisted. In order to understand the output values corresponding to the pressure applied, the F-V characteristics of sensors were plotted. For this different weight were
placed on a Piezo sensor. Voltmeters were connected across them to measure the voltages as illustrated in Figure 1. For each value of force applied on the force sensor, voltage reading is noted.

After testing piezo sensors, it was concluded that they are not suitable for the application as the repeatability and reliability are not satisfactory. Now that piezo sensors were ruled out, FSR sensors were tested.

2.2 Force Sensitive Resistor

FSR sensors have simple structure and are reliable in nature. Each sensor is built from two membranes separated by a small layer. When a force is applied, a carbon film on the top layer is pressed onto the active area of the bottom layer, resulting in a change of resistance which depends on the force being applied. With an appropriate electronic circuit, this change in adhesive resistance can be measured and the corresponding pressure can be calculated. The FSR sensors are obtained commercially in three different sizes as shown in the figure 2.

![Figure 2](image)

Figure 2 The three different size variants in FSR sensor

As it has low impedance, FSR is easily compatible with most microcontrollers. After testing the conclusion drawn was that FSR sensors are most suitable for the application due to their high repeatability, accuracy and reliability.

2.3 Controller selection

Numerous controllers are readily available in the market, Thus, choosing the most ideal controller was an important task. The system required a controller with thirteen analog pins. Therefore, it was decided that Arduino Mega 2560 was the most suitable microcontroller for the initial prototyping. The Arduino mega provided a sufficient number of analog pins and can be easily programmed through the Arduino IDE. Moreover, the Arduino platform has ample support in the form of forums and discussion platforms in case of the need for troubleshooting. Each sensor in the sole of the shoe is to be connected to controller. The connections were made carefully because FSR pins are delicate and have to be soldered very carefully.

2.4 Calibration of FSR

At the first stage of the process, standard weights were placed over the sensor in order to obtain a relation between the applied force and the output voltage of the circuit. The weights and the increment between each reading were chosen according to the value of RM (repetition maximum) such that the limits of the sensor are not exceeded.

An algorithm was implemented in a Software platform to acquire signals from the circuit and plot a Voltage Vs Time Graph, while storing the acquired data in a text file for post-processing. The curves formed with this data were discrete and discontinuous in time. An arithmetic mean value of voltage was calculated for each weight in order to obtain a Force vs. Voltage plot and its respective regression. The dispersion graph approximates to that of a logarithmic function.

Nevertheless, these tests showed the existence of an undesired behavior of the sensor, creep, as a consequence of the FSR’s electric resistance decrease in time. In order to overcome the creep, the algorithm was modified by obtaining the derivative in time of the acquired voltage signal. Hence, the derivative value becomes a criterion at determining if an increase of
the signal corresponds whether to an increase of the applied load, or creep behavior under static load conditions.

A range of allowable values for the derivative of the voltage must be defined when the applied load changes, in order to make this criterion useful. Thus, by using an automatic system, a 0.2 Kg weight was placed and removed from the sensor with variable velocity. The velocity range was kept between 5mm/s and 30mm/s.

The derivative value increases when the load and unload velocity is increased; with its smallest registered value around 3.6V/s. Furthermore, the typical values of the derivate, when the sensor is statically loaded, are below 0.2V/s. Therefore, it can be determined that derivative values below 0.2V/s correspond to creep signals which should not be taken, instead keep the previous voltage value to determine the applied force.

3. Software/application development

An application in .exe format was developed using LabVIEW[10], so that it can be installed in Any Windows PC. The function of the application is to show real-time data from the system. The software requires the user to enter the patient details (Name, Age, Height, Weight and Gender). Then, the user is asked to select the com ports of left and right foot shoe respectively. After that, the user is given two options to select the mode to be monitored, one is static and other is dynamic. When a mode is selected gives pedobarography report. The pedobarography image is shown on a foot shaped 3D model. The 3D model was designed using Solidworks and it is imported to LabVIEW. Finally, the pedobarography report is saved in a MS Word document. In the static condition document, patients details, a pedobarography image and The sensor values are printed in a table along with nominal values. The nominal values are printed if the persons' weight is between 59 Kg and 71 Kg. In the dynamic condition document, patient details and pedobarography image are printed. The each image has time gap of 2 seconds.

3.1 Fabrication of in-sole

The product is built using in-shoe technology. The shoe size used was between UK 8- UK 9. A high ankle boot was used for the prototype. The material of the sole used was cardboard and rubber. The top surface of sole has 14 FSR’s (Force sensitive resistors) in a specific arrangement affixed by strong glue as shown in Figure 3. There are two sizes of FSR’s affixed i.e. square and circle of dimension 44.96 mm ± 0.25 and 13mm diameter respectively. The FSR sensors are being connected to Arduino Mega 2560. Each shoe has one Arduino mega 2560 to which sensors are connected shows in Figure 4.

Figure 3 The arrangement of the FSR sensors in the sole of the shoe has been depicted above
4. Results and Discussion

The prototype thus developed, successfully displayed the expected output via the windows application. The system provides the user a pedobarography result plotted on a 2D model of a foot and also displays the outputs of all the 14 FSR sensors used in the sole.

Figure 4 The construction of the system can be understood from the above image

Figure 5 (a), (b) & (c) Output of Pedobarography of static condition in the GUI
The pedobarography image shows a variety of colour distribution depending on the different foot plantar pressure in that area. The red colour site indicates high amount of pressure applied on that specific region whereas the purple and blue coloured area have low applied pressure. Thus, it becomes easier to differentiate maximum and minimum pressure. The above figure 5 (a), (b) & (c) shows red sites at the heel and the upper inside portion of the feet indicating that the pressure in these areas is excessive. The two conditions in which data can be gathered are static and dynamic. Dynamic condition provides data which is necessary to understand the gait of a person.

Figure 6

![Figure 6 Static condition graphical representation of left foot](image)

Figure 7

![Figure 7 Static condition graphical representation of right foot](image)

Figure 6 & 7 Shows the graphical data is interpreted as a report in the word document stating the various pressure values compared to the normal pressure value at that specific site as shown in figure6. The output of each FSR sensor is observed and noted. The document above, displays the values of the arranged sensors, for example; finger 1 sensor gives a value of 149.210 in the left foot and the normal for this foot is 153.50, as the difference is negligible, thus, it can be interpreted that the left foot has uniform pressure distribution at the finger 1 position. The comparison of the left foot values and the normal left foot values can be understood better by the graphical representation shown in graph1. Whereas the right foot at the same position shows 124.720 against the normal of 137.1 and thus, it is depicted that the right foot exerts less pressure at that specific area.
Similarly, considering the mid portion of the foot, values were received based on the data from the sensors. The mid foot sensor in the left foot shows 162.345 against the normal of 166.97 values and in the right foot the data is 146.18, given the normal to be 147.71 values. Thus, it’s interpreted that the mid portion sensor matched the standard values and so the feet are normally balanced and don’t exert high or low pressure in this area. The comparison of the right foot values and the normal right foot values can be understood better by the graphical representation shown in Figure 7. Thus, using the data collected, the doctors can specifically identify the portion of the foot that is defected and the pressure distribution of the entire foot. The pedobarography images in the GUI document representing the different value of pressure specific to the region where the sensor is placed.

![Figure 8 Output of Pedobarography of dynamic condition in the GUI](image)

![Figure 9 Pedobarography of dynamic condition report as a Word Document](image)

Figure 8 & 9 shows the output of pedobarography of dynamic condition, the data obtained as output shows the final report generated for the seven stances given dynamic condition. Using this data, doctor can analyze how the pressure is being varied for each different stance. So, this helps to treat the patients who do not have proper gait posture.

5. Conclusion

Thus, a device that measures foot plantar pressure for static and dynamic condition has been made. This device gives exact pressure values and the analysis of the foot for the doctor to examine to deduce correct diagnosis. However, there were many hurdles while carrying out the research. Selection of sensors was a hard decision and after conducting many tests the decision of using FSR sensors was made. The transfer of parallel data from the arduino to the software platform also had its own complications and after regressive work the problem was solved. The foot varies from person to person, some are flat footed while others have curved foot which plays a vital part in the pressure distribution and also in arranging the sensors as the sensors have to be arranged specific to the size of the foot to provide the pressure value in that specific region. The device made is only restricted to UK 8- UK9 size, Thus, the sensors are placed according to this size making this product difficult to be used universally.
For further validation of the data obtained, a survey was performed and the system was tested on 16 male individuals of two different age groups and repeatability of the system was analysed and found to be satisfactory. Future improvements can be made in the controller by developing a custom PCB. Thus, ensuring a better form factor. The communication between the shoe and the PC can be made wireless via Bluetooth or wifi. The data obtained can be used in various fields like footwear research and design, rehabilitation assessment, sport biomechanics and biofeedback systems.

Acknowledgement

This research was partially supported by SRM Institute of Science and Technology. We would like to thank the Institution for supporting this project by providing a manufacturing facility and the necessary funds for the completion of the project.

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