Plantar Pressure Measuring System: A Comprehensive Evaluation

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Abstract

Real-time foot pressure data collection provides important information for understanding the gait of a person. Measurements of plantar pressure can indicate a good or false posture as well as foot abnormalities such as deformation or ulceration. In this study, our team has developed a prototype of smart shoe insoles that can track and provide accurate plantar pressure data based on the acquired pressure measures and real-time data analysis. Components used for pressure acquisition were calibrated with relatively high accuracy along with an intuitive graphical display of pressures for easy visualization. Foot pressure data from fifteen healthy participants was collected to evaluate the accuracy of the procedure. The set of plantar pressure measures from this healthy population was used to generate a typical data set for normal gait recognition. Data from this study can be used as a useful tool for further analysis related to symmetry characteristics of the foot, as the asymmetry of foot pressure is attributable to various foot deformities, which may indicate a person's abnormal gait at an early stage.

Keywords: *insole, plantar pressure, heatmap, data acquisition*

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1. Introduction

Foot plantar pressure refers to the pressure distribution in the sole of the foot when a person is standing on any surface. It is an important feature related to the internal anatomy. For instance, patients with diabetes will likely have numbed feet as consequences of neurological complications, which causes alterations in the muscles and skin, as well as joints at high pressure points on the feet. As a result, the foot may be deformed and become vulnerable, which may lead to amputation in some serious situations (diabetic patients occupied 40 – 70 % of total lower limbs non-traumatic amputations in the late phase) (Moxey et al., 2011). To predict foot anomalies in a person, the foot pressure data must be collected accurately and sufficiently using a highly reliable foot-plantar pressure measuring system.

Nowadays, there are two main types of devices that are being studied and developed to assess foot plantar pressure, namely the flat pressure distribution and the sole system. This study developed a prototype based on the sole system, since it requires less pressure sensors but still provides data with high precision on normal using conditions (Tan, Fuss, Weizman, Woudstra, & Troynikov, 2015).

This paper describes our plantar pressure measuring system using a smart insole design, along with the process of analyzing acquired data from our device. Participants are thirty people from our university, with the shoe size of 40.

2. Objectives

This study consisted of an experiment with fifteen participants for measurement of pressure distribution at different positions on their soles, using a smart insole system with attached pressure sensors. The objectives of this study were to design an efficient plantar pressure measuring system with high precision, in order to evaluate and construct a data set of the distribution of foot pressure in people with normal gait. The main factors to be considered here are the sensor positions, as well as the pressure measured at each point.

3. Materials and Methods

3.1 General Hardware Design

The system is responsible for acquiring data from 16 pressure sensors in real time, then processing and displaying or storing data. The system consists of 16 Piezo Resistive Sensors, 16 Op Amps 10-bit ADCs with 16 channels (Arduino Mega2560), microcontrollers (ATmega 2560) and computers (Figure 1).

The microcontroller board used was Arduino Mega2560, with 16 analog inputs, sampling frequency up to 10 KHz. The data from the sensor would be transferred to the USB port of the computer via the UART interface.

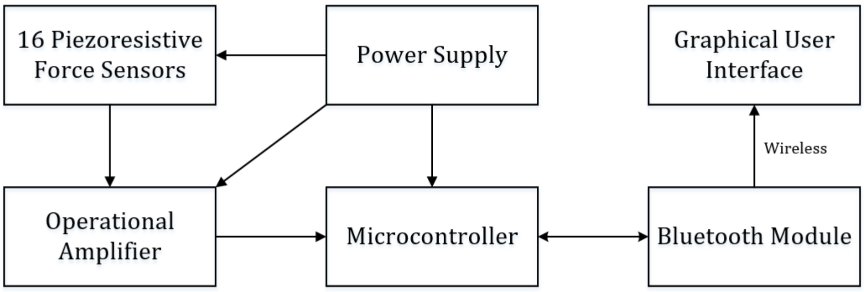

Figure 1 General structure of plantar pressure measuring system

3.2 System Implementation

We have completed the hardware prototype for the measuring system by designing an in-shoe pad that included eight pressure sensors attached to each insole at different positions (Figure 2) (Claverie, Ille, & Moretto, 2016; Razak, Zayegh, Begg, & Wahab, 2012). The type of sensor used was FlexiForce A301 of Tekscan, USA. These are light and flexible sensors which can be easily attached to the insole as its pressure range (0-1.2MPa) is suitable for our design (Wertsch, Webster, & Tompkins, 1992) (Figure 3). We made the insole with the size of 40, which is a popular shoe size of an adult in Vietnam, as well as in other South East Asian countries. Signal from the sensors will be transmitted to computers and other smart devices via Bluetooth. Our system appeared to provide accurate and visual plantar pressure data from multiple channels at a high sampling frequency in heat map and line chart formats without affecting normal gait of the user (Figure 4).

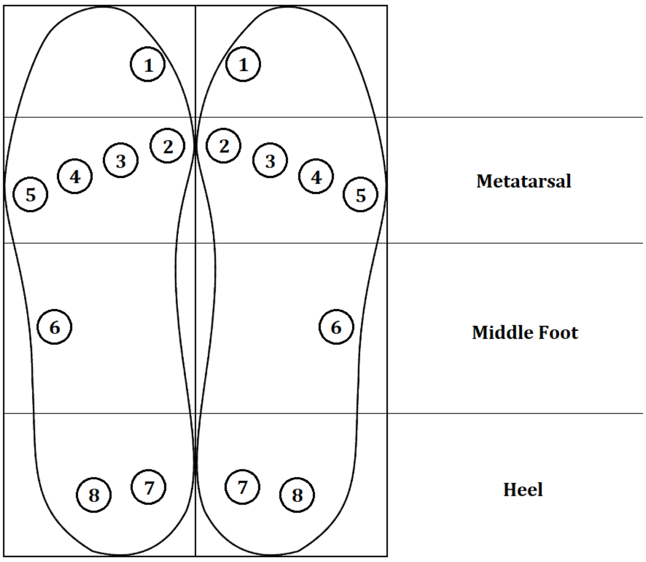

Figure 2 Sensor positions

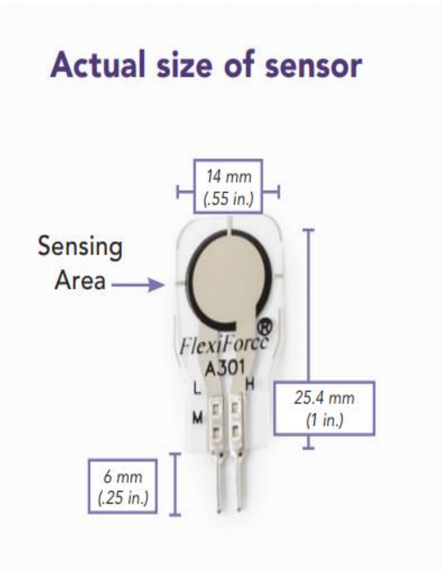

Figure 3 Flexi force A301 FSR sensor

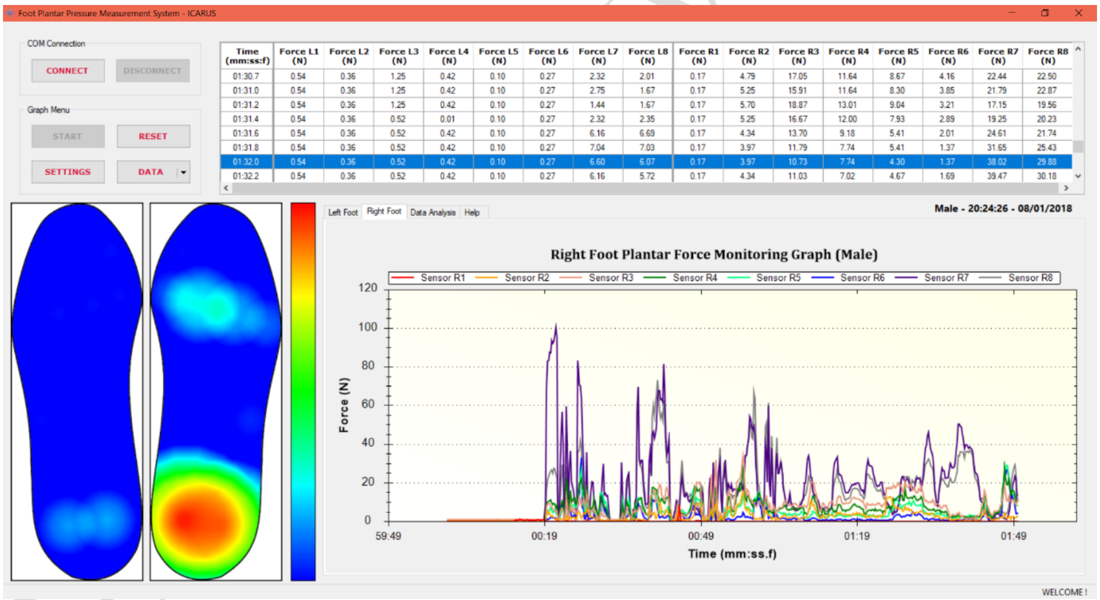

Figure 4 Data displaying on the computer

3.3 Experimental Procedure

To acquire precise data about plantar pressure distribution, we set up two separate tests. Firstly, we calibrated the pressure data of our system by using different weights to put on the center of sensing area on each sensor. In the second test, we invited 15 participants in our university to participate in the procedure. Each person was asked to stand still on a pair of shoes with our insoles added for thirty seconds. Data were recorded on the sensors every 0.1s to ensure the pressure data was recorded sufficiently in the process. The procedure was repeated 5 times before the average value for each point on the insole was calculated to establish an overall statistics of foot plantar pressure.

4. Results and Discussion

Table 1 System calibrating results

Samples (kg)	Mean (N)	Standard Deviation (N)	Error Percentage (%)
3.85	37.58	0.59	1.57
6.95	68.66	0.52	0.75
10.75	105.70	0.59	0.55

Table 2 Pressure measuring results of 15 participants

No.	Pressure at each position (kPa)															
	Pos. 1		Pos. 2		Pos. 3		Pos. 4		Pos. 5		Pos. 6		Pos. 7		Pos. 8	
	L1	R1	L2	R2	L3	R3	L4	R4	L5	R5	L6	R6	L7	R7	L8	R8
1	41	47	42	45	93	106	68	84	58	65	45	48	298	273	341	326
2	48	40	45	34	83	100	60	46	58	64	46	58	494	546	375	313
3	43	47	58	55	65	59	75	85	99	92	60	50	194	232	320	305
4	36	32	31	35	74	92	46	57	86	72	58	44	403	454	342	298
5	82	38	35	49	65	53	205	134	245	177	66	94	180	372	302	403
6	57	48	44	61	67	57	78	83	96	78	65	50	218	260	279	346
7	26	88	75	62	96	117	120	229	176	259	50	59	201	288	274	204
8	51	62	50	59	81	59	231	173	273	233	75	90	257	296	354	316
9	89	62	91	78	103	124	215	149	189	235	50	66	190	249	266	290
10	65	68	104	112	102	97	132	123	165	154	62	67	332	365	362	403
11	131	140	213	237	167	158	190	202	107	103	76	83	182	198	167	149
12	41	47	98	87	92	107	75	85	56	63	54	48	485	511	468	452
13	101	94	42	48	59	55	205	196	189	173	66	94	279	291	358	378
14	37	44	104	103	86	91	147	125	177	167	69	75	308	313	327	322
15	60	75	86	97	38	59	117	99	83	125	112	134	207	246	250	344

The results showed that our device was calibrated with high accuracy, as the error percentage in measurements reduced when we used weights with higher value. Experimental results also suggest that the collected pressure data was reliable, which is firmly correlated to the main pressure bearing points on the foot. In particular, most weight of the body is pressed on two areas: calcaneus and metatarsal bones of the foot (Kapandji et al., 1988). Among all people who participated in our tests, pressure data showed the balance characteristics of the gait, based on the different pressure at the same position on each foot. These outcomes highlighted the significance of recognizing abnormalities in the distribution of foot pressure, as well as the non-standard posture is often difficult to be seen by the naked eye.

5. Conclusion

The shoe sole system was calibrated with high accuracy, along with a compact, convenient design, which would be suitable for users who are looking for an efficient product. The graphic user interface on the computer visually shows pressure value of each sensor point in real time. Data collected from the experiment provided an overall view about the characteristics of foot pressure distribution of people with high accuracy and reliability. From these promising results, we will continue to experiment on a larger population to improve the representativeness of foot pressure data of normal people. Besides, we will try to find out the important factors related to the distribution of foot pressure in people with abnormal gaits to have a better understanding of the effects of diseases to the foot pressure. In particular, symmetry angle parameter (SA) will be used to assess effectively the difference in the structure of each lower limb of a person, which is related to the plantar pressure data collected from our device (Zifchock, Davis, Higginson, & Royer, 2008).

6. References

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