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A Study on the Cost-Effective Personalized Plantar Pressure Measurement System

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Abstract

Plantar pressure data can be used not only for walking patterns in daily life, but also for eating, health care, and disease prevention. For this reason, the importance of plantar pressure measurement has recently increased. However, most systems that can measure both static and dynamic plantar pressure at the same time are expensive, not portable, and not universal. In this study, we propose a system that effectively reduces the number of sensors in plantar pressure system. Through this, we want to increase the economics and practicality by reducing the size and weight of the system, as well as the power consumption. First, for static plantar pressure and dynamic plantar pressure, the values measured by existing precision instruments are analyzed to determine how many measurement parts the insole is divided into. Next, for the divided measuring parts, the position of the sensor is determined by calculating the Center of Pressure (COP) for each part with the values of all dynamic and static plantar pressure sensors. Finally, in order to construct a personalized plantar pressure measurement system, we propose a weighting method for the static plantar pressure COP and the dynamic plantar pressure COP for each part.

Keywords: *Plantar Pressure, Insole, COP, Force Sensitive Resistor (FSR)*

1. INTRODUCTION

A plantar pressure is a pressure field that acts between the feet and the supporting surface during daily exercise activities. Information obtained from these pressure measurements is considered importantly in the diagnosis of lower limb disorders, shoe design, sports biomechanics, walk and posture studies for injury prevention and other applications [1]. While the human body is subjected to a force applied to the ground during its movement, it is subjected to a ground reaction force of the same size through the ground, which acts as a kind of impact on the human body. According to Nigg, there are two vertices in the ground reaction graph, the first peak is related to the impact force and the second peak is related to the propulsion. Since the greatest force among the impact forces is shown at the contact phase where the feet and the ground are in contact with, it tends to study the impact forces at the supporting section and the timing of the onset [2].

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Therefore, in this paper, the aim is to reduce power consumption through miniaturization and lightening by reducing the number of sensors in the plantar pressure system, and thus to consider economic efficiency. Based on this, I would propose a measure of an economical personalised plantar pressure measurement system in which pressure sensors can be placed on the basis of COP and the COP can be weighted according to individual application and measured at the same time.

2. COST-EFFECTIVE PLANTAR PRESSURE

2.1 Plantar Pressure

The plantar pressure is one of the most interesting measurements in the clinical and research fields of kinematics. By measuring the plantar pressure, the pressure applied to the specific part of the plantar during various daily life motions and functional activities can be observed [3]. Since the mid-1990s, the shoe-insertion-type measurement methods have been used for a variety of purposes, providing time and quantitative data on pressure for each part of the foot [4]. Prior studies on plantar pressure are Development of Smart Healthcare Scheduling Monitoring System for Elderly Health Care [5], Comparison of Triceps Surae EMG in Plantar Flexion Test of MMT at Different Knee Angles [6], Comparison of Distribution of Foot Plantar Pressure between Normal and Diplegic Children [7], An analysis on the Comparison of the Center of Pressure, Gait Angle, and Gait Time between Female College Students and Elderly Women [8].

2.2 Pressure Sensor for Measuring Plantar Pressure

Various pressure sensors are currently being commercialized on the market. Among them, the most common pressure sensors are capacitive sensors, resistors sensors, and piezoelectric sensors. The capacitive sensor is separated into a dielectric elastic layer and consists of two electrically charged plates. Once pressure is applied, the dielectric elastic layer bend, and the distance is shortened between the two plates. This results in a voltage change in proportion by the pressure applied. The resistance sensor measures the resistance of the conductive foam between the two electrodes when pressure is applied to the sensor. Current through a resistive sensor increases as the conductive layer changes by pressure. A typical example of a resistance sensor is Force Sensitive Resistor (FSR), which is made of conductive polymers that vary resistance by force, and when applied forces conductive particles through the sensor, increasing the current. The piezoelectric sensor produces a voltage in response to pressure and has a high impedance [1]. There are F-scan, Parotec system and Pedar x system in commercial plantar pressure measurement system.

2.3 Data Extraction

In this experiment, we propose an economical and personalised insole system for the determination of plantar pressure in dynamic environments. Accordingly, a small number of pressure sensors will be proposed as long as they can replace a number of precision sensors attached on them. The verification plantar pressure measurement system used in the experiment is Pedar x system. As an alternative sensor, FSR is used. It is a sensor whose resistance changes with pressure. It has the advantages of simple circuit configuration and low cost. The data obtained by the FSR is the same as the measured value of the commercial force plate, and since the reproducibility of the FSR is as good as the force plate, it was considered that the measurement of the plantar pressure by the FSR was feasible [9].

Pedar x system insoles with 99 sensors on each side were placed in slippers. The transmitter and battery were laid flat on the floor with wires connected. The plantar pressure of the standing state was measured with the front staring for about 1 minute, and the plantar pressure data of the right foot was collected using FSR. The collected data were analyzed as insole-type data using a processing tool [10]. Pressure value classification is expressed in the following order in the same way as Pedar x system : White (0-14), black (15-39), blue (40-59), mint (60-99), light green (100-149), yellow (150-219), red (220-299), purple (300+). In order to more clearly represent the data with less fluctuations in the standing state, the data was processed to three times the measured pressure value, and the result obtained using the Processing is shown in Figure 1.

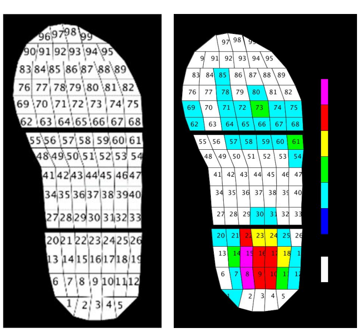
2.4 Data Analysis

2.4.1 Plantar Pressure

The plantar pressure is measured to quantify the static and dynamic pressure of the sole during walking. By measuring the plantar pressure, one can observe the pressure applied to a specific part of the foot during various daily and functional activities [3]. Accordingly, the data analysis criteria were determined as static and dynamic plantar pressure.

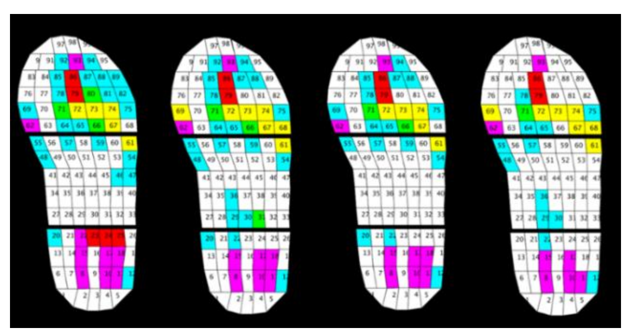
2.4.1.1 Determination of an effective parts

A number of precision sensors are intended to be replaced by a small number of practical sensors in order to reduce the size and weight of existing systems and to increase the economical efficiency. To determine the number of effective parts, 99 precision sensors were divided into 8 parts, 6 parts, 4 parts, and 3 parts.



(a) sensor No. (b) data

Figure 1. Data of Plantar Pressure



(a) 8 parts (b) 6 parts (c) 4 parts (d) 3 parts

Figure 2. Maximum Pressure in 8, 6, 4 and 3 parts

The maximum value of each part was obtained at every sampling time. Figure 2 shows the results for each part of the total time. In Figure 2, it can be seen that the plantar pressure distribution of the maximum pressure is not significantly different in all four cases.

2.4.1.2 Static Plantar Pressure

Static plantar pressure is a constant pressure given to the sole in the absence of movement, such as standing up. The value in the static state is equivalent to extracting the value of plantar pressure, and can simply be represented by an average value over the entire value.

$$S_i = \frac{1}{n}\sum_{t=0}^{n} p_{t,i} \qquad (i = 1\sim99) \tag{1}$$

According to equation (1), the average value of plantar pressure is shown in Figure 3-(a).

2.4.1.3 Dynamic Plantar Pressure

Dynamic plantar pressure is expressed in terms of impact and thrust. Impact force is the strength of the contact force between an object when it is hit or collided, Propulsion means the force that pushes an object forward. This means the amount of change in pressure, which can be expressed simply as the sum of the squares of the change of the present value and the previous value of each sensor. Accordingly, dynamic plantar pressure can be expressed in the following manner.

$$V_i = \sum_{t=0}^{n-1} (p_{t+1,i} - p_{t,i})^2 \tag{2}$$

Figure 3-(b) shows the total sum of the rate of change.

2.4.2 COP (Center of Pressure)

COP means the average weight of all pressure points in contact with the ground as a point of vertical rebound force vector at the foot. COP is where the force of the moment due to the vertical force is zero, the same as the position of the point of application [11].

The center of mass is the center point of mass across an object, acting on the external system as if the entire mass is at the center of mass. It can also be distributed inside an object and outside. What is certain is that there can be a center of mass anywhere on a two-dimensional plane. This allows each mass of the partitioned particles in a two-dimensional model to be represented in the following manner.

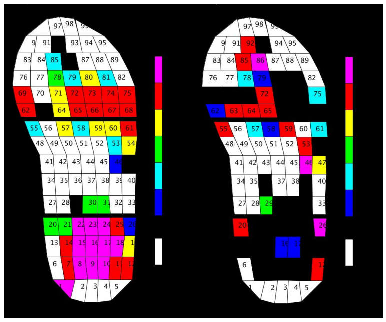
$$\sum_i p_i = P \tag{3}$$

Accordingly, the center of mass can be expressed in the following manner.

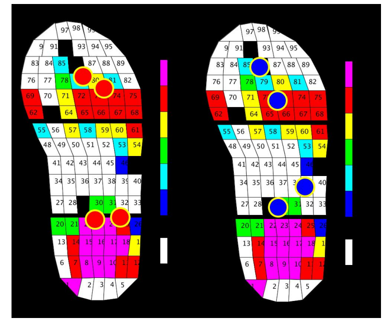
$$X_{cop} = \frac{1}{P}\sum_i p_i x_i \tag{4-1}$$

$$Y_{cop} = \frac{1}{P}\sum_i p_i y_i \tag{4-2}$$

When dividing into four parts, Figure 4-(a) shows the partial COP of the values obtained by the average (eq (1)), and Figure 4-(b) shows the partial COP of the values obtained by the variation (eq (2)).



(a) average by eq-(1) (b) variation by eq-(2)
Figure 3. Average and Variation



(a) static COP (b) dynamic COP
Figure 4. COP

3. RESULT

According to S.J Park [11], by determining the partial COP for the static and dynamic plantar pressures for the four parts, the location of the FSR (4 points) could be determined. We can now determine the location of the FSR taking into account both static plantar pressure and dynamic plantar pressure, which can be given by the following equation considering COP.

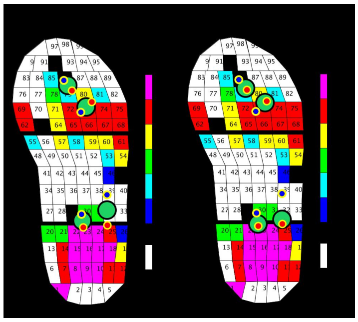
$$C_n = \frac{S_{C_n} X_{C_n} + V_{C_n} X_{v_n}}{S_{C_n} + V_{C_n}} \qquad (where \quad n = 1,2,3,4) \tag{5}$$

Furthermore, the location of the FSR can be determined by considering the weight, α of the static plantar pressure and the dynamic plantar pressure according to the characteristics of the individual.

$$C_n = \frac{(1+\alpha) S_{C_n} X_{C_n} + (1-\alpha) V_{C_n} X_{v_n}}{(1+\alpha) S_{C_n} + (1-\alpha) V_{C_n}} \qquad (where \quad n = 1,2,3,4 \ and \ -1 < \alpha < 1) \tag{6}$$

Figure 5-(a) shows the 4 points position of FSR, In the figure, it can be seen that 3 points of static plantar pressure and 3 points of dynamic plantar pressure are located in the same place, but the other points are different in position. In such a case, the system can be able to position FSR by weighting static or dynamic plantar pressure depending on the user's purpose of using the system by eq (6). Figure 5-(b) shows the position of COPs when $\alpha = 0.7$.

After obtaining the FSR position through the above-described process, the experimental apparatus manufactured for actual implementation is shown in Figure 6. Arduino Pro Mini is used as a small MCU, and it transmits data of FSR acquired through Bluetooth communication.



(a) $\alpha = 0$ (b) $\alpha = 0.7$

Figure 5. Position of FSR by COP

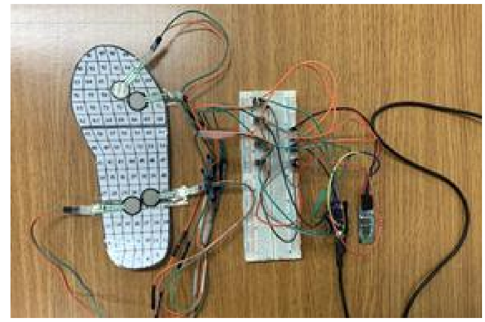


Figure 6. Plantar Pressure Measuring System using FSR

4. CONCLUSION

This study researched whether a small number of pressure sensors could replace a number of specialized systems in order to propose an economical personalized plantar pressure measurement system that is easily accessible in everyday life. The purpose of this study was to propose a system to measure static and dynamic plantar pressure simultaneously, to miniaturize and lighten the system, and to collect data with emphasis on the number and placement of sensors to consider economic efficiency. Accordingly, many sensors were tested in four different cases to replace the sensor with a small number of sensors, and the person-to-person zones were divided into 8,6,4, and 3 parts to see whether common areas were found in the distribution of plantar pressure in four cases.

As a result, the effective area of the pressure sensor was set to four parts by verifying that the distribution of the plantar pressure in each case is similar. Accordingly, the position of the FSR is selected based on the COP for static and dynamic pressure of each plantar pressure. As a result, COP values in some sections have a common range, whereas COP in some sections does not have a common range. In such cases, the system was intended to specify the position of the pressure sensor according to the purpose of use of the system and the individual's needs by weighting it according to static or dynamic plantar pressure. In addition, an economical personalised plantar pressure measurement system was proposed using FSR at the location of the specified pressure sensor. This study was meaningful in proposing an economical customized plantar pressure measurement system in various environments in daily life, and aims to conduct a study on the verification system and whether the results of this system's plantar pressure show the same results, and furthermore, it is expected to be utilized for postural calibration, health care, and seniority safety.

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