Development of portable plantar pressure mat sensor and monitoring system

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Abstract

Plantar pressure distribution represents a variety of information including the functions of the foot and balancing ability. This study aimed to develop a low-cost, portable plantar pressure mat sensor with a monitoring application for both static and dynamic locomotion measurement. A pilot testing to examine the performance of the developed sensor was performed as a comparison with a commercial plantar pressure measurement system. This study developed a 35 x 50 sensor matrix based on Velostat film for plantar pressure distribution measurements and an application for real-time analysis of lower limb movements. For performance test of the developed sensor, footprint area and the trajectory of center of pressure (COP) were compared with that of MatScan. Pilot data of a male subject (bodyweight: 70 Kg, height: 181 cm, shoe size: 275 mm) were collected for 10 seconds of static standing on both feet and 5 steps of dynamic in-place gait. Comparison results of the developed sensor and MatScan showed an average error of 2.35(±1.86) cm^2 for footprint area, X-axis of COP had an average error of 0.24(±0.34) index, and Y-axis of COP had an average error of 0.92(±1.05) index. The preliminary findings of this development study may be the basis for further development of the sensor. Our future studies will focus on the sensor's feasibility for general use in daily living and expansion to clinical uses by including larger number of subjects in various environment setting.

***Keywords*:** Plantar Pressure, Center of Pressure Trajectory, Footprint Area, Portable, Mat Sensor

1. Introduction

Plantar pressure (PP) is the force that the sole of the foot presses against the ground and its distribution represents a variety of information including the functions of the foot, balancing ability, and risk of falling [1,2]. For easier and more practical measurement of plantar pressure distribution (PPD), many researchers have endeavoured to develop various forms and methods including shoe insoles and exercise mats [3]. One of the popular and research-verified mat-type pressure sensors is force plate, which is known to accurately measure and analyze the key parameters related to human body movements and locomotions, especially PPD and center of pressure (COP) trajectories. The demerits of force plate are its high cost and

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heavy weight, making it difficult to be carried around for outdoor use [4].

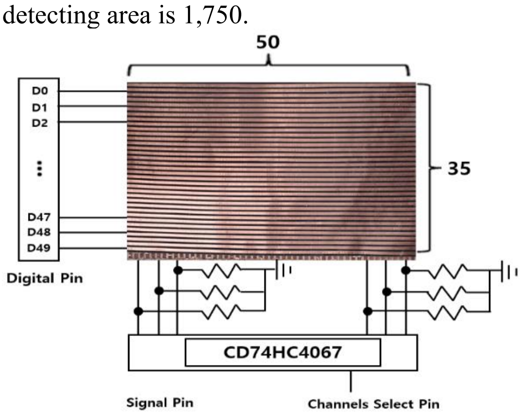
Velostat (Adafruit, USA), on the other hand, is a light-weight, flexible material made of polymeric foil (polyolefins) that is electrically conductive. Any pressure applied on Velostat changes resistance as the applying force causes conductive particles to touch, increasing the current through the sensors [1]. Due to its flexibility and low cost, Velostat has been used by many researchers for measurement and analysis of human body posture and foot pressure [1,5,6].

For more various forms of future locomotive researches, this study developed a low-cost portable plantar pressure measurement mat sensor using Velostat film and a real-time monitoring application.

2. Method

2.1 Plantar pressure mat sensor (PPMS)

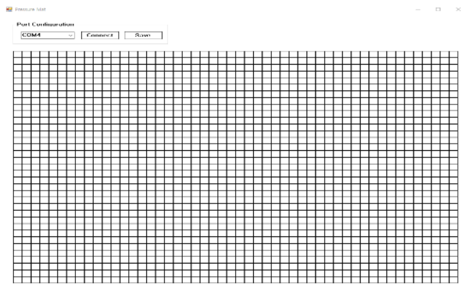
This study developed a portable plantar pressure mat sensor (PPMS) using Velostat in a 35 x 50 sensor matrix in the size of 0.5 cm^2. Each sensor was located 0.3 cm apart to prevent short circuit. To measure the resistance value of Velostat, copper tape was used for conductor plate. The upper and lower layers of the plate were arranged orthogonally and the point of intersection corresponded to the pressure sensing area. The pressure sensing region was based on the voltage distribution law and the offset resistance was set to 100 Ω. The structure of PPMS is as shown in Figure 1 and the total number of pressure detecting area is 1,750.



<Figure 1> Structure of PPMS

2.2 Real-time plantar pressure monitoring application

For real-time monitoring and measurement of 1,750 plantar pressure data collected by PPMS, a C# based application was developed. As shown in the upper left corner of Figure 2, the application has a scroll-down window for the users to select the type of ports, connections between PPMS and UART, and data saving functions. Underneath the port configuration window, the grid area in Figure 2 presents the plantar pressure data for real-time monitoring in gray scale.



<Figure 2> Real-time monitoring application

2.3 Protocol

For performance comparison analysis of the developed PPMS, a commercial plantar sensor (MatScan) was used. Pressure data from the two sensors were collected simultaneously; PPMS was placed over MatScan. Sampling rates for PPMS and MatScan were both set at 70 Hz. The subject for this study was a 27-year-old male with the bodyweight of 70 Kg, height of 181 cm, and shoe size of 275 mm. For the performance testing of PPMS, the subject was to stand still for 10 seconds and then to take 5 consecutive steps, respectively for static and dynamic movement analysis based on plantar pressure distribution. This experiment was performed to detect and calculate Center of Pressure (COP) Trajectory and Footprint Area, where the bodyweight was acting as pressure against the sensor. The subject was instructed to step on PPMS and MatScan on his third step among the 5 steps for the stability of the data [7].

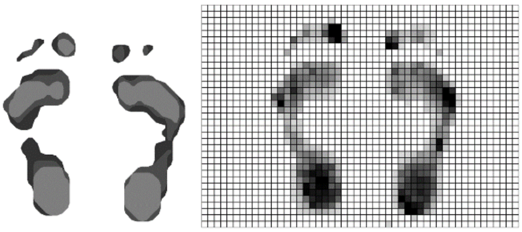
2.4 Data processing and analysis

Data collected in the static standing position were used to calculate the footprint area to which plantar pressure (bodyweight) was applied. For accurate data analysis, the first and last 3 seconds of the collected data were deleted and only the mid 4 seconds of data were used. The data collected from consecutive 5 steps were used for COP calculation by using Equation 1 [8].

$$CoP_x = \frac{\sum_{i=1}^{n} X_i \times P_i}{\sum_{i=1}^{n} P_i} \quad CoP_y = \frac{\sum_{i=1}^{n} Y_i \times P_i}{\sum_{i=1}^{n} P_i} \quad (1)$$

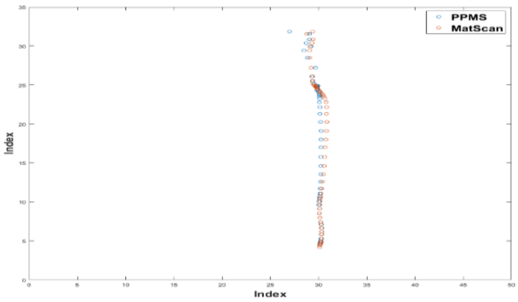
3. Results

Footprint area comparison between PPMS and MatScan showed an average error of 2.35(±1.86) cm2. Figure 3 shows the PPD comparison result of PPMS and MatScan.



<Figure 3> PPD comparison result of PPMS and MatScan

COP comparison results of PPMS and MatScan showed an average error of 0.24(±0.34) index on the X-axis of COP and an average error of 0.92(±1.05) index on the Y-axis.
For COP trajectory comparison, the number of channels was used as the index. The X-axis had 1 to 50 indices, and the Y-axis had 1 to 35 indices. Figure 4 shows the COP trajectory comparison result of the PPMS and MatScan.



<Figure 4> COP Trajectory comparison result of PPMS and MatScan

4. Conclusions

This study developed a low-cost, portable plantar pressure mat sensor based on Velostat together with a real-time monitoring application for both static and dynamic human locomotion measurement. The preliminary findings of this study may be the basis for further development and use of the sensor.

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