ICIC Express Letters
Part B: Applications
Volume **9**, Number **6**, June **2018**

ICIC International ©2018 ISSN 2185-2766
pp. 493–499

A PORTABLE PLANTAR PRESSURE SENSING SYSTEM

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Received December 2017; accepted March 2018

Abstract. *A portable plantar pressure sensing system is proposed in this paper. The walking situation observations of users are easier, through a smartphone application. The real-time plantar pressure values are shown in the App. The force sensing resistor (FSR) is used to catch the pressure information, due to small size and thin thickness. The both advantages are suitable to install in soles to measure the plantar pressure. The popular bluetooth low energy (BLE) device is low power consumption, and it is adopted to transmit the plantar pressure to the smart phone. The App will convert the plantar pressure value into different colors, which help users to observe easily the plantar pressure changes. The combination of sensors and smartphone App not only reduces the cost but also is more convenient for users.*
Keywords: Plantar pressure, FSR, BLE, App

1. **Introduction.** Human body movements are very complex and include a lot of physiological information; moreover, we could find the pathogenesis by observing specific parts, [1] analyzing the physiological signals of gait to find the cause of disease. Plantar pressure sensing is used to study the pressure change of movements or diseases. However, most of the sensing equipment is not portable due to its weight and sizes, and it usually is used in the hospital or rehabilitation center. In [2-5], the major premise is portable. The device is combined with personal digital assistants (PDAs) to record physical information in [2]. A computer is used to display in [3-5]. [4] proposed Bluetooth commutation, and the information is transmitted to the computer for data analysis. [5] used an ARM-based microcontroller to convert the plantar pressure and transmit data by means of a 2.4GHz radio frequency (RF) module. [6] proposed a battery-free pressure monitoring system, and the system is powered by RF energy harvested from the smartphone-hosted radio frequency identification (RFID) reader. [4-6] converted the plantar pressure by a microcontroller and the converted data is transmitted by another RF module.

Considering the cost, device size and convenience, this paper proposed a portable plantar pressure sensing system which is designed for portability and instant observation. The system uses a BLE system-on-chip (SoC) to convert and transmit the plantar pressure data to smartphone, allowing users to instantly know the plantar pressure through the phone App.

2. **System Architecture.** The system architecture is shown in Figure 1. It includes four blocks: power supply, force detection, wireless communication, and user interface blocks, respectively. The hardware circuit is powered by button cell battery. The FSR is installed to measure the plantar pressure; next, the conversion circuit and BLE control IC (TI CC2541) are used to convert the pressure information to digital information; finally, the information is transmitted to the smartphone with BLE, and presented in a graphical manner.

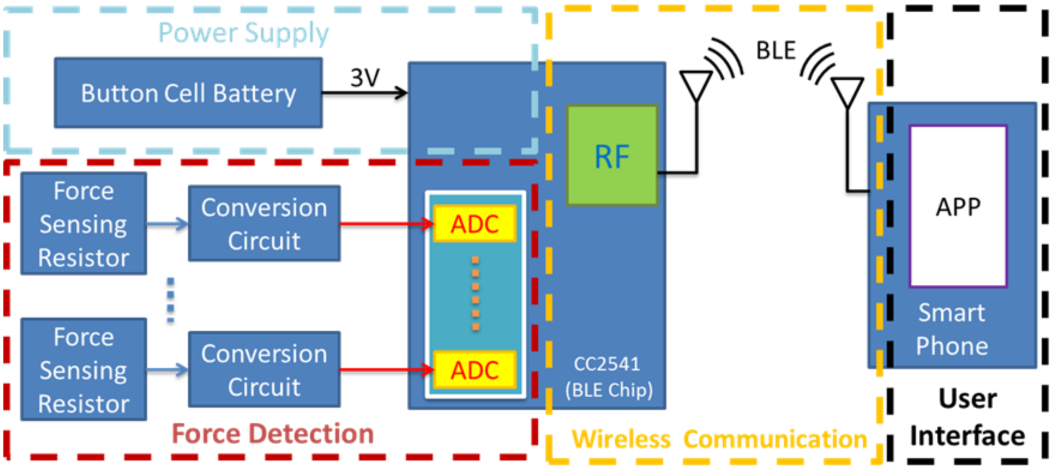

FIGURE 1. System architecture diagram

2.1. **Force detection block.** TI's CC2541 is the microcontroller of the system, and BLE transmission and 12-bit eight-channel ADC are built in this controller. The system can capture the plantar pressure signals without extra ADC chips. [8] shows the capture frequency should be more than 20Hz in order to fully represent the walking status. Considering the battery life, the system signal capture frequency is set to 20Hz. When the signal capture completes, the data will be transferred by BLE and the phone will display results.

2.2. **Sensor placement.** When standing, the first metatarsal head, fifth metatarsal head and heel, around the arch, support the entire body. The arch structure slows down the effect of shock, absorbs the impact and decentralizes weight. It is helpful for the standing, walking, running and other actions. So, the sensor positions are under the first metatarsal, medial longitudinal arch, lateral longitudinal arch and heel, as dots shown in Figure 2. By the measurement information of these sensing points, the doctors could observe the movement situations, and calculate the strides and step counts.

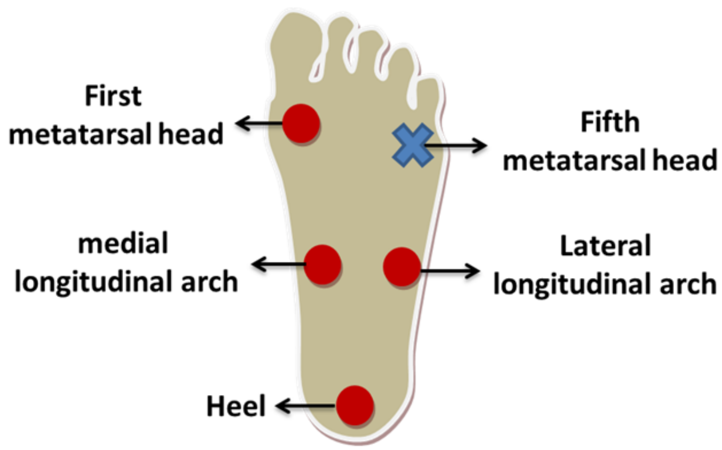

FIGURE 2. Sensor placement

2.3. **Force conversion circuit.** The resistance of the FSR sensor is variable when pressure changes, as shown in Figures 3 and 4. The Vout is the output of the voltage follower, and the voltage is division across the FSR and resister RM. The FSR resistance value is shown in the resistance-force conversion table provided by the provider, as shown in Figure 4.

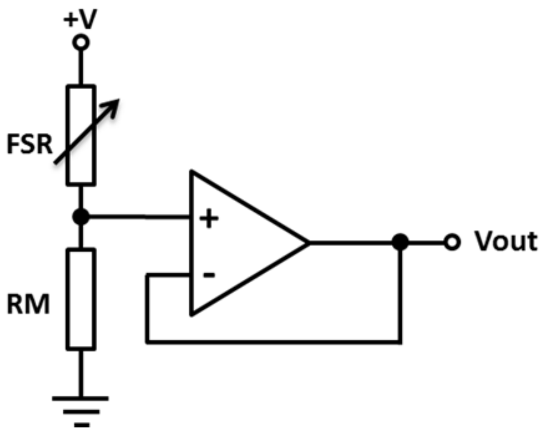

FIGURE 3. Voltage divider circuit

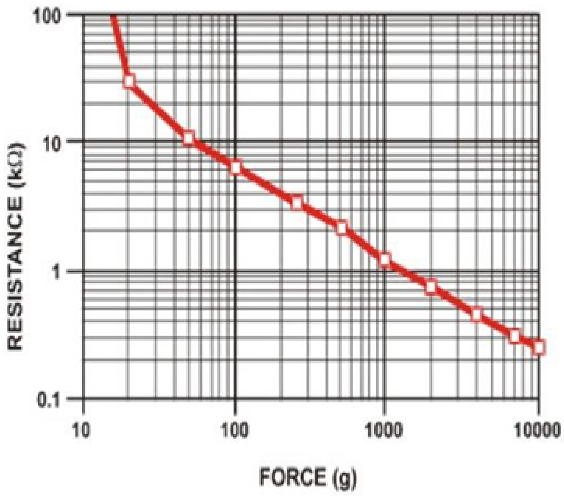

FIGURE 4. Resistance and force conversion [7]

3. **Software Architecture.** The software includes the firmware of force detection block and the data processing App. The former is the drivers of ADC and BLE on CC2541, and the latter is a smartphone App, which is designed for the plantar pressure display and the step calculation.

The functions of the App are real-time plantar pressures display, the step count and pressure abnormal warning. The App screen is shown in Figure 5. Graphical user interface is implemented to show the plantar pressure which is divided into seven value intervals in different colors. The colors are red, orange, yellow, green, blue, indigo and purple, and these colors indicate the plantar pressure values from large to small as shown in

FIGURE 5. (color online) Smart phone App user interface

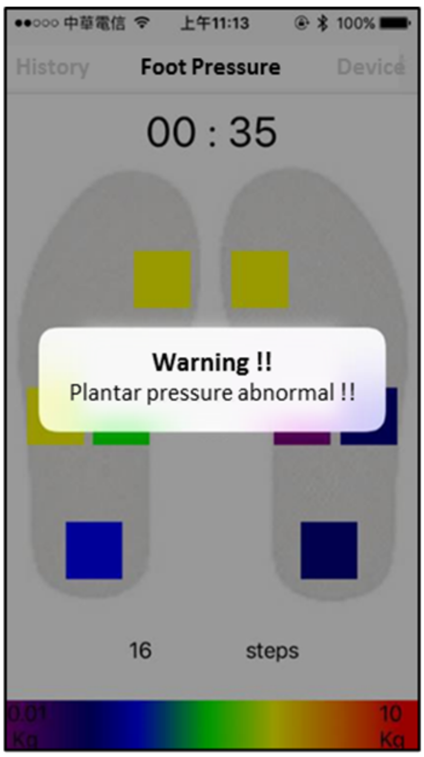

FIGURE 6. (color online) Plantar pressure abnormal warning message

the bottom of the screen. In the App screen, the color of sensing blocks changes when the plantar pressure is different. The changes in plantar pressure are more easily to be observed by the difference of color. When the color is red, the pressure of the measured point is heavy. On the counter, purple means the measured point is slight.

The plantar pressure status changes in one walking step. First, the pressure of heel is maximum value. Second, the plantar pressure is distributed evenly. Third, the pressure of forefoot is maximum value. Last, the pressure of foot is slight. The software will identify the user's one step, and calculate the step count. In addition, by comparing the previous data, the system will warn the user to pay attention to the users' walking status as shown in Figure 6, if any abnormal.

4. **Experimental Results.**

4.1. **Sensing device.** As shown in Figure 7, four pressure sensors are placed in one insole, the sensor signal wiring to circuit board and CC2541.

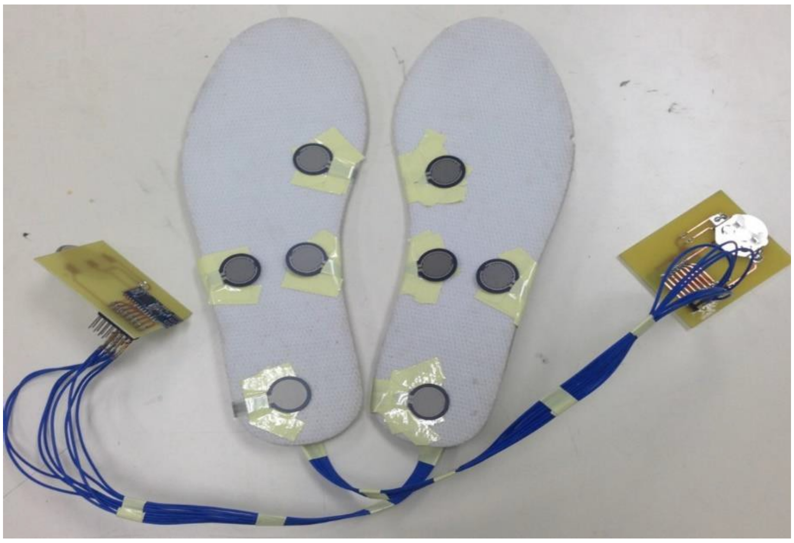

FIGURE 7. Sensing device

4.2. **Application program function.**

4.2.1. *Main page.* The main page as shown in Figure 8, presses the "Start" to carry out the plantar pressure sensing. The real-time plantar pressure measurement and step count will show at the same time. Press the "Pause" to pause sensing and "Continue" to continue sensing. "Device" on the upper right corner is the setting connection procedure. "History" on the upper left corner shows the measurement records.

4.2.2. *Device settings page.* As shown in Figure 10, the device setting page displays the connected device and the discovered BLE devices. Click on the device name to connect or disconnect the device, if set the device automatically connected; click the blue symbol to enter the automatic connection page, refer to Figure 11. When automatic connection is turned on, the device will automatically be connected, next time.

4.2.3. *History data page.* In Figure 12 the history data page shows the measurement records. Press the "Start" to watch the plantar pressure changes, the screen will replay the progress and the time of the record will show at the same time, as Figure 13. The top of the page shows the date of the measurement record.

Clicking on the "Export", the plantar pressure-related data can be read on the computer by iTunes. As shown in Figure 14, the form titles are Time, R-FMH (Right foot-First

Figure 8. (color online) Main page

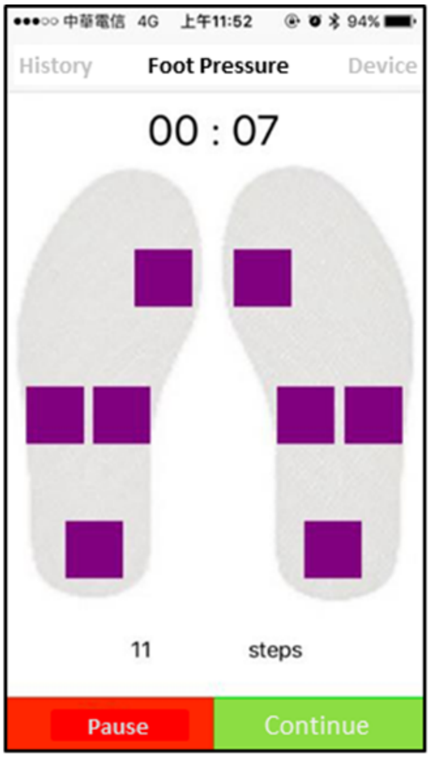

Figure 9. (color online) System pauses

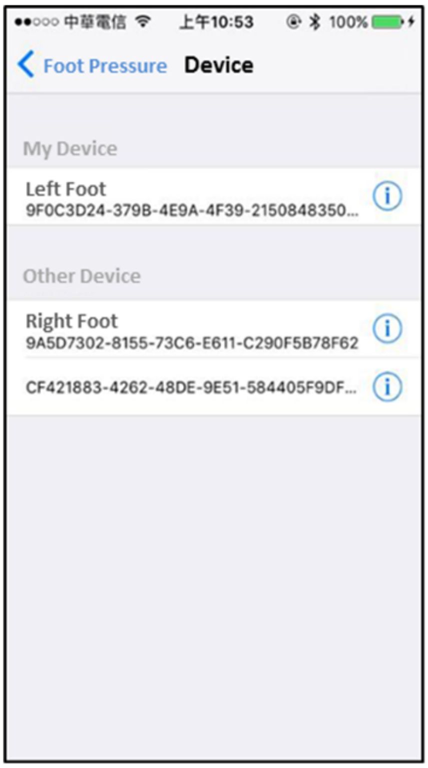

Figure 10. Device settings page

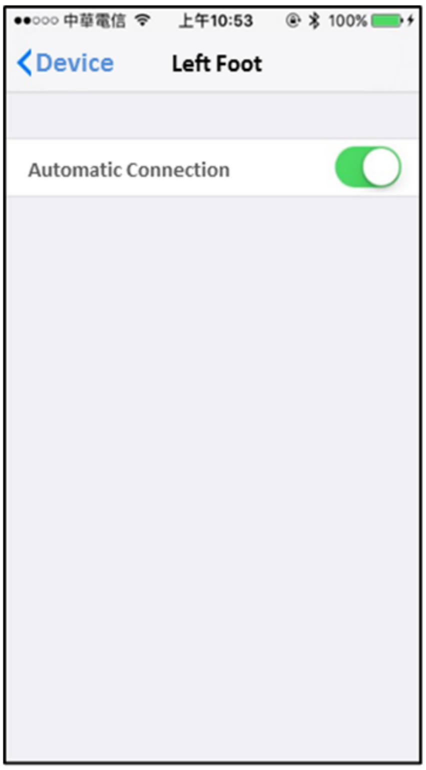

Figure 11. Automatic connection settings

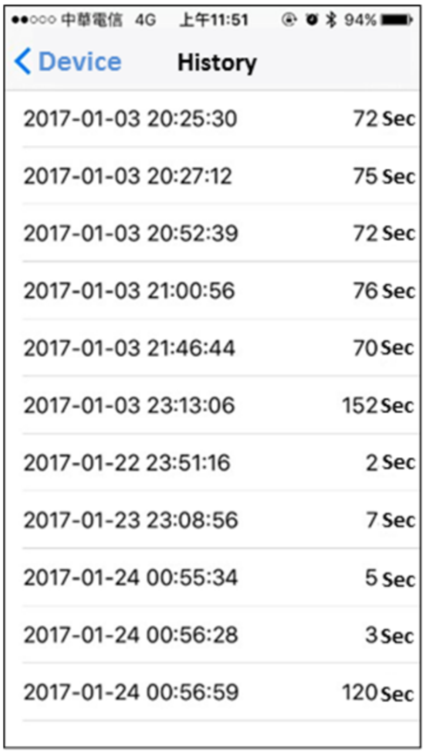

Figure 12. History page

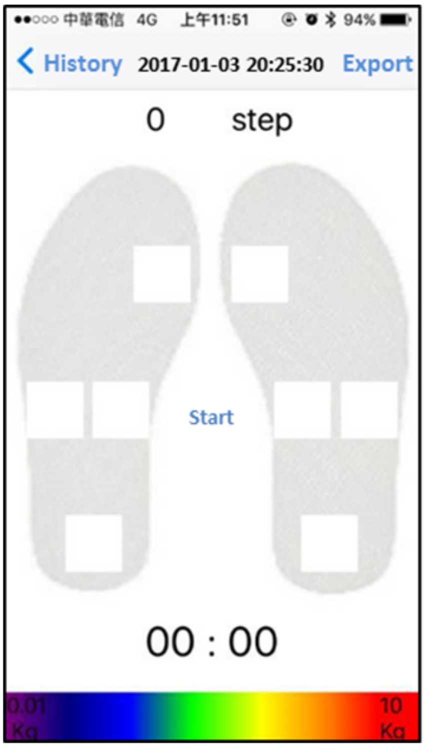

Figure 13. (color online) History record page

Time(Sec)	R-FMH(ADC)	R-MLA(ADC)	R-Heel(ADC)	R-LLA(ADC)	L-FMH(ADC)	L-MLA(ADC)	L-Heel(ADC)	L-LLA(ADC)	Step
0	0	0	0	0	0	0	2395	905	0
0	0	0	2808	435	0	0	0	0	0
0	0	0	0	0	0	0	2291	1517	0
0	120	0	3095	868	0	0	0	0	1
0	0	0	0	0	175	0	2250	1914	1
0	658	0	3235	1220	0	0	0	0	1
0	0	0	0	0	555	0	2422	2349	1
0	1035	0	3389	1456	0	0	0	0	1
0	0	0	0	0	702	0	2987	2546	1
0	1492	0	3683	1758	0	0	0	0	1
0	0	0	0	0	1241	0	3264	2830	1
0	1875	0	4177	1928	0	0	0	0	1
1	0	0	0	0	1990	0	3435	2904	1
1	2550	0	4446	1836	0	0	0	0	1
1	0	0	0	0	2414	0	3254	2683	1
1	3090	0	4334	1338	0	0	0	0	1

Figure 14. Export data

Metatarsal Head), R-MLA (Right foot-Medial Longitudinal Arch), R-Heel (Right foot-Heel), R-LLA (Right foot-Lateral Longitudinal Arch), L-FMH (Left foot-First Metatarsal Head), L-MLA (Left foot-Medial Longitudinal Arch), L-Heel (Left foot-Heel), L-LLA (Left foot-Lateral Longitudinal Arch), step respectively. The data shows the state of walking.

5. Conclusion.

A portable plantar pressure sensing system is proposed in this paper. The FSR and BLE are used to sense and transmit the plantar pressure information. The proposed App can immediately show the real-time pressure situation, and it also provides the record replay function. The size and weight are suitable to be installed in the insoles;

moreover, the low power consumption of BLE is proper to be adopted in a portable system. The experimental results show the system works well and the App could display and replay the plantar pressure information and analyze the stepping situations. By the proposed portable and record functions, this proposed system could be used in long time observation and to provide a convenient analysis tool in the rehabilitation treatment, in the future.

Acknowledgment. This work is partially supported by the Ministry of Science and Technology, Taiwan, under contract No. NSC 105-2815-C-224-008-E and 105-2218-E-150-004.

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