Motion Detection System based on Plantar Pressure Distribution

Yizhong Xin[1, a],Chuhong Liu[1,b]

[1]School of Information Science and Technology, Shenyang University of Technology, Shenyang,110870,China

[a]xyz@sut.edu.cn, [b]liuchuhong7@sina.com

Keywords: plantar pressure distribution, motion detection, wearable measurement system

Abstract. Measurement of foot pressure distribution is clinically useful for evaluation of gait pathologies and practically useful for the detection of motion. In order to improve portability of the detection device, this paper come up with a wearable system to detect plantar pressure thus to detect motion. Compared with traditional system, this system utilizes high-precision sensor toenhance portability of the system. In order to improve the compatibility of the system, Inter IC Bus communication protocol and blue-tooth are assembled. Results show that the combination of significant differences for pressure, peak values and correlation between areas could be used to judge common motions. The system is of good practicality and portability.

Introduction

Nowadays, wearable devices are gradually changing and improving peoples' lives. Measurement of plantar pressure is not only of clinical usage but also of practical usage in life because changes in motion can be predicted through pressure, especially with the help of mobile phones [1, 2, 3]. While measuring plantar pressure, the device widely being put into practical use is called "footscan", which can offer users' information including peak, mean pressure and contact area of foot etc. However, the information can only be given when users stand still on the device, thus situations of dynamic motion are excluded. Pervious literatures also studied related measurement system. For instance, [4, 5] studied the measurement system in-shoe and achieved expected effect. However, the pressure sensor used in the paper are piezoelectric film transducer and loop antenna sensors, which are different from the sensors used in this paper, and the literatures focused on how the circuit works instead the design of the whole system. [6] studied foot pressure distribution through analyzing frequency domain. The collection images of foot pressure distribution are not mentioned in the paper, and it focused on studying the images after Fourier transformation. And [7] described the differences between old and young adults with detail factors which may attribute to the differences. Different from the literatures mentioned above, the paper focus on how to build the measurement system with force sensing resistors and how blue-tooth technology is applied in the communication module.

Integrating previous literature, the paper designed a wearable measurement system of plantar pressure distributions with FSR (force sensing resistors).The delay of blue-tooth in communication module is within acceptable range, which meets the requirements of portability.

Analysis of Communication Protocol and Theory of FSR

IIC Bus

IIC (Inter IC Bus) communication principle is adopted in the systemas well as blue-tooth 4.0. As iswell known to allthat serial bus is dominated by making the size of hardware smaller and more reliable. In IIC communication, there are two bidirectional signal line, and one is data line SDA, the other one is clock line SCL. Every device connected to the IIC bus owns unique address.When SCL is high and SDA is changing from high to low,start signal begins to work; when SCL is high and SDA is changing from low to high, then termination signal begins to work. Start signal and termination signal are emitted by the host.Signals transferring on IIC bus contain address and data. It is difined in IIC protocol that 7 bytes are used for address. D7 – D1 compose slaves' address. And D0 means the data transfer direction. "0" indicates host is writing data on slave, and "1" indicates host is reading data from slave. When the host sends address, every slave would compare the 7 address code with its own address on the bus. If matched, then that is one the host is addressing, and according to R/W to decide whether the slave is the receiver or the transmitter.

Bluetooth

Taking portability into consideration, blue-tooth specification V4.0 BLE is adopted in this paper. Mobile phone supporting blue-tooth 4.0 or personal computer with a receiver following USB V2.0 protocol can both receive data within distance of 100 meters. Modulation of it is GFSK (Gaussian Frequency Shift Keying), and it could be modified by AT instructions. The shortest delay time is within 3ms, and all the data packet is of 24-bit parity. The transfer speed can hit 1Mbps, and adaptive frequency hopping is adopted to avoid much interference from other 2.4GHz ISM band.

FSR

FSR (force sensing resistor) is a resister with material of polymer which is a thick film. The theory of FSR is that the force on the surface increasesas the decrease ofresistance. FSR is used to optimize the sensitivity of the force of the electronic device controlled by touch. Despite a similar nature, FSR is not a load cell or strain gauge.FSR series consists of four types of resistors, which are FSR400, FSR402, FSR406 and FSR408.They are not the same at the size of the force area; the working principle is the same: the greater the pressures on its surface, the lower aretheir resistance. They can be applied to biped robot, spider robots, and other allowable pressure in 100g-10kg occasions.

In the system designed in this paper, FSR combined with main chip monitor the pressure generated when foot contact on the FSR. As mentioned above, the working principle of FSR is that its own resistance value R varies with the force f applied on it, and there exists a nonlinear relationship according to its material. The main chip reads voltageVo across the resistance. In this way, f of every FSR could be calculated. Main chip returns a value between 0-N (N is concering with AD conversion bit of main chip, if AD conversion bit is n, then $N=2^n-1$), and the formula is:

$$\frac{V_O}{V_I} = \frac{R}{R-r} \quad (1)$$

Where r is dividing resistorin series with FSR, and V_I is peak maximum value of main chip. Thus voltage across FSR and its resistance is:

$$R = \frac{V_0}{2^n - V_O} \quad (2)$$

The resistance value of FSR is known from above formula, and the force could be known from the nonlinear relationship between f and R.

Design and Implementation of the measurement system

Literatures concerning skeleton and muscles structure offer much information in deciding the number and locations of force sensing resistors. [7] covered tiny pressure sensor on the insole, and find out that zone the sole into several representative areas can reduce the number of sensors and data redundancy. Nuances exist in how to divide the areas, for example, [4] suggested dividing sole into 8 areas, while [7] suggested 9 areas. Thus, place one pressure sensor on every representative area is reasonable based on previous literatures. Taking all these factors into consideration, this paper divides the sole into nine areas. How the areas are divided is shown in Fig. 1.

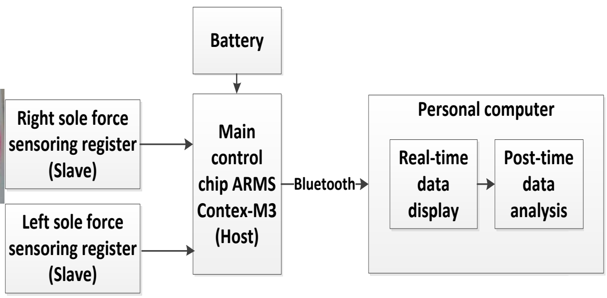


Fig.1 Force sensing resistors arrangement on insoleFig.2 System block diagram

Through collecting and storing data from different areas under sole, some simple motions can be judged fromplantar pressuredistributions. For instance, whether a subject is leaning forward or backward can be clearly seen from the data collected. Also, data can be plotted into graphs or histograms via MATLAB and tobe observed more clearly on the screen. Figure 2 shows block diagram of the measurement system. The whole system is tied to shoe.Two modes are available that one foot is a slave and the other one is a host, while the second mode is that two feet are both slaves and the control chip is the host. The system adopts the second mode because in this mode the two feet are tackled in the same way, and the data could not cover each other. If the data is not tackled well, data would cover each other for the delay and the transfer time is not in accordance with each other. A blue-tooth receiver is connected to a personal computer to communicate with main chip (Fig. 3).

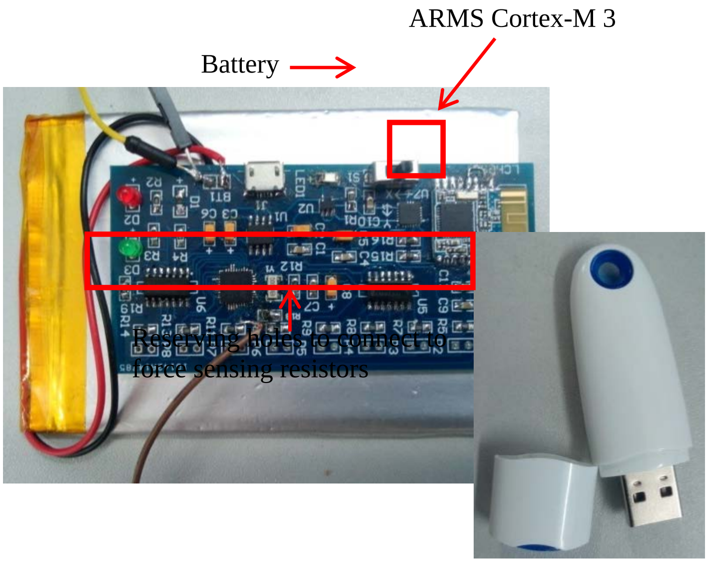


Fig. 3 Designed circuitboard (right) and bluetooth receiver (left)

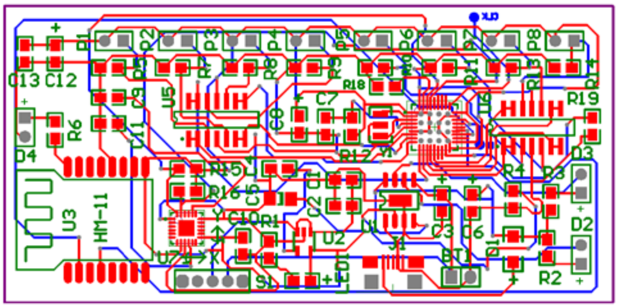


Fig.4 PCB of the circuit diagram

Pressure information transfers from force sensing resistors to main chip via DMA method. Smaller-sized battery can be used and the PCB board can be designed to a smaller and compact size, thus the system can be bound in shoe. Main chip solve the data and begin to communicate with personal computer. Personal computer plot data and store data for further analysis via MATLAB. Distribution of pressure of each area maps into different motion.

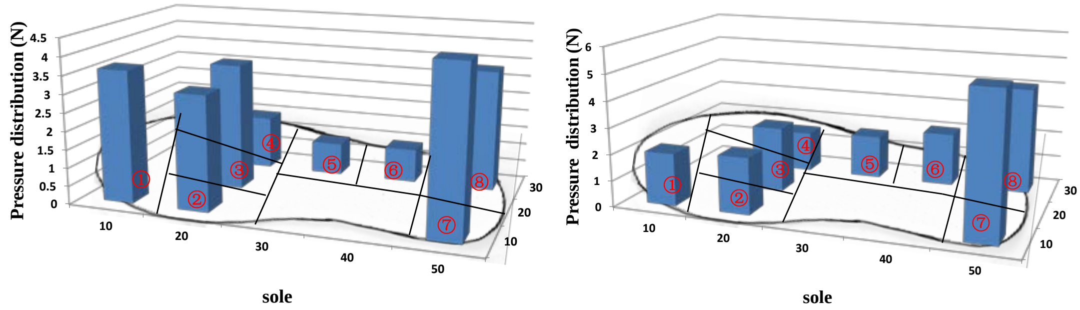
Experimental Study

Subjects and System Environment

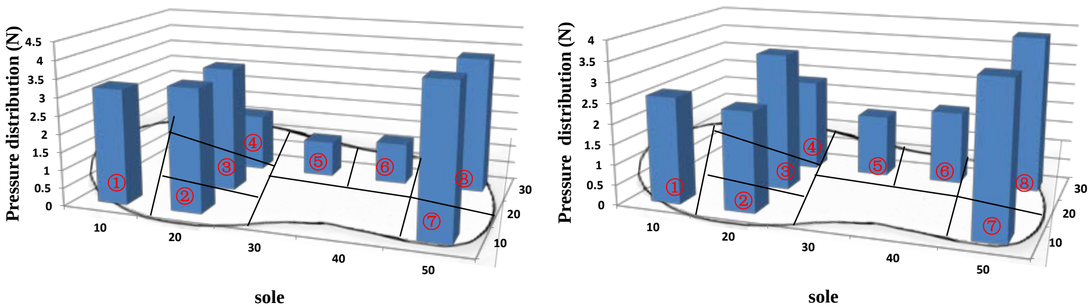
21 subjects (14 males and 7 females), aged from 16 to 34 participated in the experiment. Although there exists tiny difference takingfemale's and male's height and weight into consideration, plantar pressure distribution are almost the same between female and male in previous literatures. The pressure sensor used in this paper is force sensing register, and the master chip is ARMS Cortex-M3.The advantage of ARMS Cortex-M3 is DMA, which is short from direct memory access. DMA does not rely on interrupts and load in CPU. Baud Rate set in the system is 57600Hz. RT 9157 instead of ASM 117 is used in the system along with 4056, and they are voltage stabilizer. The transfer range of ASM 117 is smaller than that of RT 9157. And the principle of mobile power bank is the same with the combination of RT 9157 and 4056.The diameter of FSR sensing area is 1.27cm.

Experimental Results

Data collected from RS232 or blue-tooth can be stored on computer in format of txt or csv through serial debugging tools, and be plotted into histogram. Bluetooth is preferred in this system because wired communication is not conducive to portability. The ordinate of the three-dimensional diagram is the pressure value, and the abscissa and ordinate of the bottom plane record only the coordinate information of each representative area of the sole. The pressures are in Newton, which represent every FSR output value. Combined with the contact area of FSR, $1N/m^2$ can be transferred into Pascal. All the figures contain right sole information with different motions: Fig.5 (a) is under normal walking mode, Fig.5 (b) is when subjects are leaning right, Fig.5 (c) is when subjects are leaning backward, and Fig.5 (d) is when subjects squat.



(a) normal walking (b) leaning backward



(c) squat (d) leaning right

Fig.5 Pressure distributions in different motions

In normal walking mode, subjects are required to walk without any restrictions or instructions. 30 steps are required, and the first and last 5 steps data were deleted to ensure the data free from interference of noise. Thus, the left 20 steps are calculated the average in the eight areas. In other motions, subjects are required to repeat the still motions for 20 times.

Some data are alike, but we still can tell the differences between them. The most obvious examples are Fig.5 (d) and Fig.5 (b) when subjects are leaning right and backward. Repeated measures analysisof variance (RM-ANOVA) showed a significant main effect on pressure values for different motions($F_{3, 60} = 3.89$, $p < .001$). Whether there shows significant difference on pressure values for the eight areas are decided by the motion. For instance, when subjects are leaning right, there shows significant difference on pressure for area 7 and 8; however, there shows no significant difference for area 7 and 8 when subjects are leaning backward. Thus, not only the peak value of each area of pressure can help to judge motion, the significant difference and the correlation between every area can get help to judge. However, for the reason that some motions are similar, factors above combine to determine the motion. It can be roughly estimated that when there shows no significant difference and the mean values of area 7 and 8 are both higher than that of area 1, subjects are leaning backward.

Table.1 Pressure values in the four common motions

Motion (right foot)	Mean(N)	Maximum peak(N) and its area	Minimum peak(N) and its area
Leaning right	2.70	3.67/⑧	1.55/⑤
Leaning backward	2.66	5.36/⑦	1.56/④
Squat	2.72	4.10/⑦	1.01/⑤
Normal walking	2.67	4.47/⑦	0.89/⑤

From Table 1, it could be inferred that when the motion is concerned with vertical axis of foot, area 7 and 8 are different from each other; and when the motion is concerning with the horizontal axis, area 7 and 8 are almost the same.

Conclusions

Results show that the system measuring plantar pressure is wearable, and through distributions of plantar pressure, some simple motions can be judged. The system designed in this paper is of portability and the delay of communication between the slaves and host is within the acceptable range. Real-time data transfer from the collector chip with personal computer via blue-tooth V4.0. Collected data can be stored in the computer, and through analysis from SPSS and MATLAB, changes of plantar pressure distributions can be clearly observed after being tackled. The combination of significant difference, peak values and the correlation on pressure for different areas to judge common motions is feasible.

Acknowledgements

This study has been partially supported by National Natural Science Foundation of China (No. 61100091), Program for Liaoning Excellent Talents in University (LJQ2012007), SRF for ROCS, SEM, Shenyang University of Technology Young Key Academic Teacher Foundation, and Shenyang University of Technology Research Start-up Foundation for Doctors.

References

[1] F. Ahmed, K. Sheikh, I.Ahamed and R. Love: Smartphone Based Multimodal Activity Detection System Using Plantar Pressure Sensors,edited by SAC'14,Gyeongju, Korea(2014), p.468-469.

[2] A.Bränzel, C.Holz, D. Hoffmann, D. Schmidt, M.Knaust,P.Lühne, R.Meusel, S. Richter and P.Baudisch:GravitySpace: Tracking Users and Their Poses in a Smart Room Using a Pressure-Sensing Floor, edited by CHI 2013, Paris, France, p.725-734.

[3] H.Noshadi, F.Dabiri, S.Meguerdichian, M.Potkonak, and M.Sarrafzadehin: Behavior-Oriented Data Resource Management in Medical SensingSystems edited by ACM Transactions on Sensor Networks, Vol. 9, No. 2, Article 12, 2013.

[4] A.J. Nevill, M.G. Pepper, M. Whiting, in: In-shoe foot pressure measurement system utilizing piezoelectric film transducers, edited by Medical&Biological Engineering&Computing, (1994).

[5] I. Mohammad and H. Huang: Plantar Pressure Sensing Using Loop Antenna Sensors, submitted to Heraklion, Crete, Greece, ACM (2012).

[6] C. T. Lim, J. C.H. Goh (Eds.)P.G. Clem: Bhavesh Parmar. Assessment of Foot Drop Surgery in Leprosy Subjects Using Frequency Domain Analysis of Foot Pressure Distribution Images, edited by ICBME 2008, Proceedings 23, pp. 1107–1111.

[7] M. J.Hessert, M.Vyas, J. Leach, K. Hu, L. A.Lipsitz and V. Novak: Foot pressure distribution during walking in young and old adults, edited by BMC Geriatrics.