中國機械工程學刊第四十二卷第二期第 141~149 頁(民國一百一十年)
Journal of the Chinese Society of Mechanical Engineers, Vol.42, No.2, pp 141~149(2021)

Development of a Portable Image-Based Plantar Pressure Measurement System

Thossaporn Kaewwichit*, Chien-Hsun Tseng**, Ke-Han Su*** and Chong-Ching Chang****

Keywords：Plantar pressure measurement, Sensor-based, Image-based, Portable pressure image box

ABSTRACT

Plantar pressure has been generally used to refer to the physical force exerted between the sole of the foot and ground contact during daily activities. Measuring plantar pressure provides data on foot in gait and posture, which is useful in footwear design, and other health-related applications for lower limb treatment and injury prevention. Therefore, to acquire accurate measurement of planta pressure is of paramount importance. To do so in a convenient and efficient fashion, this study developed a portable image-based plantar pressure measurement system. A portable pressure image box (PIB), which could be operated with any kind of portable photo-taking devices that are able to produce images with highly quantitative accuracy, was equipped to capture the needed plantar image. Based on the measurement data from 11 subjects, the performance indices of statistical metrics on mean square error (MSE) and normalized absolute error (NAE) of the 198 footprints show that the proposed PIB system could exhibit close agreement with the sensor-based Tactile pressure measurement system (TP) as a measurement reference. When compared with the high-cost image-based scanning machine (SM) system, the proposed PIB also showed better performance on plantar pressure measurement. The findings suggested the proposed PIB system could be another economical and viable option for plantar pressure measurement in assistive devices for footwear design or customized insole manufacturing.

Paper Received December, 2014. Revised March, 2015. Accepted March, 2015. Authors for Correspondence: Ke-Han Su

* *Department of Mechanical Engineering Technology, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand*

** *Department of Information Engineering, Kun Shan University, Tainan 71070, Taiwan*

*** *Department of Automatic Control Engineering, Feng Chia University, Taichung 40724, Taiwan.*
E-mail: kehsu@fcu.edu.tw

**** *Graduate Institute of Mechatronic System Engineering, National University of Tainan, Tainan 70005, Taiwan.*
E-mail: jeff0718@mail.nutn.edu.tw

INTRODUCTION

Each year millions of people have suffered foot pain without knowing the cause of the problem. The development of chronic pain is most often associated with gait pattern which accumulatively contributes to plantar fasciitis. Several studies have shown that gait pattern, to certain extents, has an effect on locomotor performance (Femery et al. 2002; Lin et al. 2003). Apart from clinical treatment and physical therapy, suitable customized insoles with fitted feet arch supports are usually used as the primary preventive method to provide stable alignment and improve the posture of the entire body, which subsequently may reduce or even relieve the conditions of shock and imbalance (Witana et al. 2009; Nakajima et al. 2009). In order to design customized insoles, proper measurement of plantar pressure in some contact areas is usually required and can be acquired via either a sensor-based or an image-based method.

The sensor-based plantar pressure measurement system (e.g. Tactile pressure measurement system utilizing a fully conforming array pressure sensor) has been widely used in commercial devices in quantifying and analyzing areas of high pressure in scientific and clinical settings. Several studies have investigated its efficiency in terms of accuracy, repeatability and characteristics of measurement (Chevalier, Hodgins, and Chockalingam, 2010; Putti et al. 2008). To obtain accurate plantar pressure measurement, the system requires reliable software and users' technical skills, thus being of high cost. Equipped with a scanning machine (SM), the image-based plantar pressure measurement system has been developed to generate 3D images that schematically show details of the foot function and evaluate the plantar pressure (Chang and Lee, 2003; Chang, Lee, and Wang, 2007; Huang, Lee, and Chang 2011). Hence, a simple and yet effective methodology for plantar pressure measurement can be applied to the Computer Numerical Control (CNC) machine tools or Rapid Prototyping (RP) manufacturing systems for customized insole manufacturing (Cheng and Liang, 2013). The SM measurement system determines the distributed average pressure for each region of the foot and creates a model of the sole for more ergonomic and comfortable insoles. However, in practice the SM measurement system is complex because it heavily involves stereo-photographic technology to capture a proper 3D images of the sole. In addition to the software complexity, operating the SM measurement system is time-consuming, especially for plantar pressure evaluation because mechanic scanning of the two scanners are processed sequentially. The generated output image is usually in low resolution, which may affect the measurement accuracy. The conventional footprint through a FRP (Flat Rubber Pad) system is most widely used for orthotic manufacturers to acquire foot functions for fitting insoles as it involves a simple and inexpensive equipment (Razeghi and Batt, 2002). More specially, the FRP can produce a permanent record with identified areas of higher pressure shown through darker patterns observable within the print (Urry and Wearing, 2001). Although the FRP system can yield qua**n**titative data on plantar pressure measurement, the operation is inconvenient and time consuming.

To enhance the quality of plantar image as well as simplify the operation of measurement hardware to be more economical and portable, this paper examined the usability of a Pressure Image Box (PIB) of plantar pressure measurement. The proposed PIB measurement was developed to be compatible with any portable photo-taking devices with high quantitative accuracy. Its size is that of a suitcase (45 cm x 36 cm x 10 cm) for the portability purpose. In this paper, to assess the effectiveness of the proposed PIB system, the data acquired from the PIB and the existing image-based system (i.e. SM) were gathered to compare with those of the reference sensor-based Tactile pressure measurement (TP) system. To further analyze the performance of measurement systems, the statistical metrics of the mean square error (MSE) and normalized absolute error (NAE) were calculated. The experimental results on the disparities between the reference TP system and image-based systems show better performance of the proposed PIB system than that of the SM system. The proposed PIB measurement system is nearly costless as compared with the high-cost commercial sensor-based TP system and image-based SM system.

The rest of the paper is organized as follows: Section 2 consists of the design of a portable image-based plantar pressure measurement system. Image acquisition of plantar pressure, a mathematical model of plantar pressure distribution calculation, and how the plantar pressure measurement system works will be presented. In Section 3, the experimental setup and results are discussed. Finally, the conclusions are summarized in Section 4.

PORTABLE IMAGE-BASED PLANTAR PRESSURE MEASUREMENT SYSTEM

This section describes the design methodology of the proposed PIB with the integrated plantar pressure measurement system which includes the plantar image acquisition, the mathematical model of plantar pressure distribution calculation, and the plantar pressure measurement system.

Image Acquisition of Plantar

Figure 1 shows the PIB with a cubic dimension of 450x360x450 mm^3, where a sheet of 10-mm thick reinforced acrylic on the top of the station. The plantar images are generated by the developed portable PIB as seen in Fig.1. To avoid the light reflection, black matt papers were attached inside as indicated in Fig. 1(a). The developed portable PIB could acquire the plantar image easily by using any kinds of photo-taking equipment, e.g. a digital camera or a smartphone. In this paper, the smartphone iPhone 5 produced by Apple Inc. was used as the photo-taking equipment.

(a) (b) (b)

Fig. 1 The design of proposed portable PIB: (a) The PIB structure, (b) Plantar image taken by camera/smartphone and (c) Portable and foldable.

Table 1 The comparison of features between different systems

System	TP[1]	PIB[2]	SM[2]
Type	Sensor	Camera	Scanner
Output	Raw pressure data	Image	Image
Price	High	Low	Medium
Operation time	Real time	<5 min.	<10 min.
Data transfer	Wire	Wire*/Wi-fi**	Wire
Resolution	32 × 32*	1488 x 1984*	1168 x 1670*

[1]Sensor-based measurement system
[2]Image-based measurement system
[*]The resolution performed in this study.
[**]The optional photo-taking devices.

The PIB was designed to be foldable in the size of a suitcase for its portability purpose. Table 1 is a summary of different plantar pressure measurement systems, that is, TP, SM, and PIB. As shown in Table 1, the proposed PIB consumed less operation time with high resolution of output image, which is dependent on photo-taking devices used when compared with other systems.

Mathematical Model of Plantar Pressure Distribution Calculation

The calculation approaches of plantar pressure distribution exploited in this paper were developed by (Chang and Lee, 2003; Chang, Lee, and Wang, 2007; Huang, Lee, and Chang 2011) and can be summarized as shown below.

When both feet were placed on a surface with a body physically supported, the downward parallel forces extruded the blood out of the soles' capillaries causing pale skin on the sole of the foot. While differences of local contact pressures were generated in regions where the soles made the surface in contact, the level of the paled skin on the sole would be directly proportional to the amount of load built up on the sole. This relationship can be represented by the following model involving the digital imaging system as:

$$G_k = f\frac{W_k}{W}G\,, \tag{1}$$

where f is denoted as an adjustment factor based on conditions such as the insole material, the person's health, and specific physical activity. G_k, $k \in [1, N]$ is the gray level within the k-th region of the plantar surface A_k. W denotes the total body weight consisting of a set of parallel discrete forces purely represented by the uniformly or non-uniformly distributed body weight W_k across A_k, which is defined by:

$$W = \sum_{k=1}^{N} W_k\,. \tag{2}$$

G is the sum of the gray level values in all regions, which is defined as:

$$G = \sum_{k=1}^{N} G_k\,. \tag{3}$$

In addition, the gray level can be determined by the source of the image as:

$$G_k = \sum_{i=1}^{m}\sum_{j=1}^{n}(g_{i,j}), \tag{4}$$

where $g_{i,j}$ represents the values of gray image pixel at any image coordinates $i \in [1, m]$, $j \in [1, n]$.

Generally, the pressure can be defined as the force over the unit area. By using this concept, the plantar pressure at k-th contact region A_k of the foot image is given as P_k. In this paper, the plantar pressure is regarded as the body weight W_k over the contact region A_k, which is expressed as:

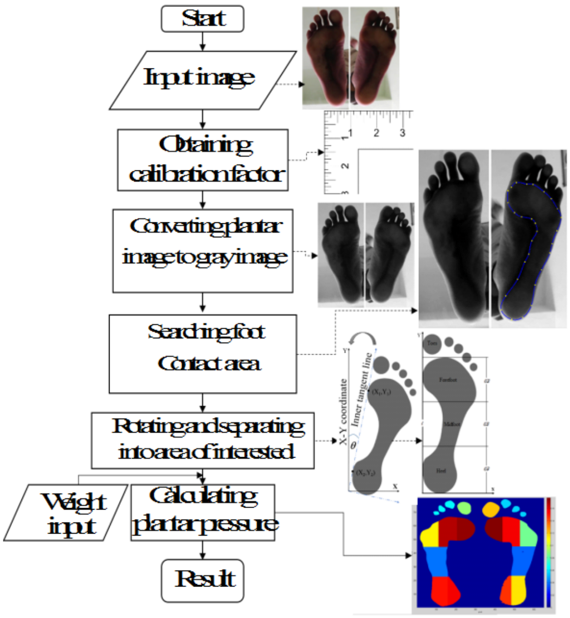


Fig. 2 Flow chart of the portable plantar pressure measurement system.

$$P_k \equiv \frac{W_k}{A_k}\,. \tag{5}$$

By submitting Eq. (1) into Eq. (5), Eq. (5) can be rewritten as:

$$P_k \equiv \frac{1}{f}\frac{G_k}{A_k G}W\,. \tag{6}$$

Having the image of the sole transformed to the gray binary code, the local plantar pressure P_k can then be calculated in the manner of effectiveness and efficiency by adopting Eq. (6). About the adjustment factor f in Eq. (6), it can indicate, as a prediction of further activity, insole materials or even the difference in activity on specific foot regions. For example, an approximation of body weight during locomotion should be given as three to six times (Hills, 2001) or the pressure during one foot landing should be one and half times that of one foot standing on the heel region (Kellis, 2001). In this paper, which has a focus on the research topic of plantar pressure calculation, the adjustment factor was set to 1.

Plantar Pressure Measurement System

This subsection describes the developed portable plantar pressure measurement system. The flow chart of the developed PIB system is illustrated in Fig. 2, and the operation steps are summarized as follows:

(I) Obtain the calibration factor from known actual scale and image resolution following by acquiring the sole image with the PIB system. The calibration factor ρ can be obtained as below:

$$\rho = \frac{L_a}{L_p}, \tag{7}$$

where L_a is the actual length of known actual scale and L_p is the length of pixel.

(II) Convert the acquired plantar image into 8-bit gray scale image.

(III) Search plantar contact regions.

(IV) Rotate plantar images: Rotate the plantar images by using the inner tangent line (as shown in Fig. 3(a)) into the X-Y coordinates as depicted in Fig. 3(b) for further plantar pressure calculation. The rotation angle (θ) can be found as follows:

$$\theta = \tan^{-1}\frac{X_1 - X_2}{Y_1 - Y_2}, \tag{8}$$

where (X_1,Y_1) and (X_2, Y_2) are the two points laid on the inner tangent line in Fig. 3(a).

(V) Separate the plantar images (i.e. contact area of the sole) into regions of interest as shown in Fig. 3(b). In this paper, the plantar image was divided into 4 regions with 15 areas: heel region (areas 1–3), mid-foot region (areas 4–5), metatarsal region (areas 6–10), and toe region (areas 11–15), as shown in Fig. 3(c), based on the suggestions made in the study by Shu et al. (2010). Generally, the above areas can physically support most of the body weight and are constantly adjusted by the body's balance. The above three main regions in forefoot, mid-foot, and heel are used for the purposes of plantar pressure calculation and comparison. In general, the area of acquired plantar image can be divided into several parts of region such as 5, 7, and 9 regions for different requirements.

(VI) After obtaining the full body weight, the plantar pressure can be immediately measured by adopting Eq. (6).

EXPERIMENTAL SETUPS AND RESULTS

In this section, how the PIB plantar pressure measurement system was conducted to test its performance in terms of measurement accuracy is presented. A comparison with the aforementioned measurement systems listed in Table 1 was made.

Data acquisition and statistical analysis

11 healthy males voluntarily participated in this experiment. They have an average age of 24.2 years, average weights of 67 kg, and average heights of 171.5 cm, respectively. Without loss of generality, these selected subjects were those who had not experienced a lower-limb injury. During the acquisition of sole images using systems of the TP, SM, and PIB

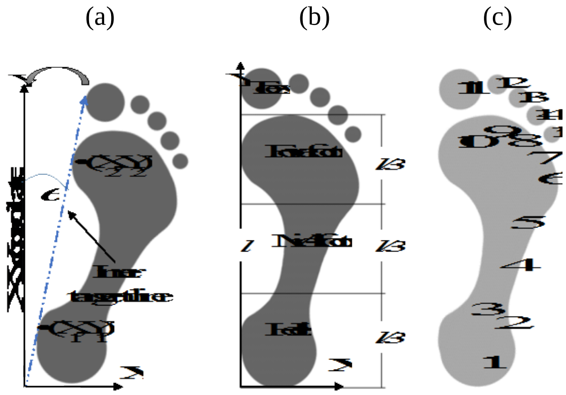


Fig. 3 The plantar contact area of interest: (a) The inner tangent line. (a) The inner tangent line after rotation to X-Y coordinates. (c) Foot anatomical areas (Shu et al. 2010).

consecutively, the subjects were asked to stand firmly on the surface of the platform, while looking straight ahead at the eye level above a specific point. Three prints were acquired from each subject out of the three systems. There were a total of 198 trials recorded for the plantar pressure analysis. The three main contact areas of the sole where the foot physically supports most of the body weight (and hence encountering most of the pressure from the body) were the metatarsal/forefoot region, mid-foot region, and heel region as described in Fig. 3. These acquired data of these three contact areas were used for effectiveness and accuracy comparison on plantar pressure measurement. Statistical metrics with strong mathematical tractability were applied to determine the performances of the systems. More specifically, with the prediction f_i and the true value (or the reference value) y_i,, the mean square error (MSE) and normalized absolute error (NAE) defined below were presented for measurement accuracy:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(f_i - y_i\right)^2, \tag{9}$$

$$NAE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{f_i - y_i}{y_i}\right|. \tag{10}$$

Furthermore, disparity estimation between the methods are calculated by the mean value of each group in the form of percentage disparity value. By taking the percentage (or the mean) of the estimated values of the TP (reference group) on each contact area and subtracting the percentage (or the mean) of the image-based groups. The same calculation procedure was applied for that of the SM and PIB groups. The percentage disparity value is defined as follows: positive values indicate that the plantar pressure is overestimated by the target method while the negative value means that the plantar pressure is underestimated by the target method.

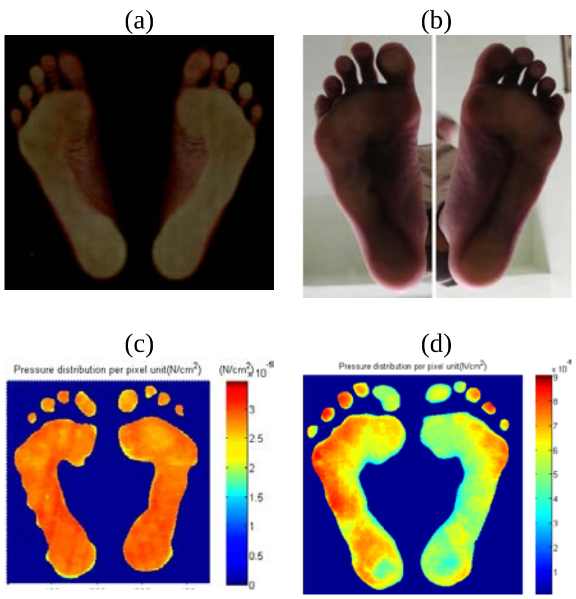


Fig. 4 The raw footprint images from each system and their transformed plantar pressure images: (a) SM raw footprint image. (b) PIB raw footprint image. (c) Plantar pressure images transformed from the SM. (d) Plantar pressure images transformed from the PIB system.

Experimental results

Figure 4 shows the raw images acquired from the different image-based plantar pressure measurement systems (SM and PIB in Fig. 4(a) and 4(b), respectively) and their transformed pressure distributions. Figs 4(c) and 4(d) show the transformed pressure results corresponding to the raw footprint input images. The transformed pressure results were further used for the purpose of comparisons on the analysis of three main contact areas.

Table 2 lists the experimental results with the performance indices: mean ($\overline{X}$) and standard deviation (±SD), MSE, and NAE, for plantar pressure performance calculation in different measurement systems. In the experiment, the values of the sensor-based TP system was used as the reference benchmark. As shown in Table 2 and Figs. 5(a), 5(b), 6(a), and 6(b), it can be observed that the PIB system showed a slightly better performance than the SM system on the forefoot area. For the calculated plantar pressures on the mid-foot region and heel region, the performance of the PIB system was closer to the reference of the TP system than that of the SM system (as shown in Figs. 5(c), 5(d), 5(e), 5(f), 6(c), 6(d), 6(e) and 6(f)). It can be found that the performance on the heel region of PIB system was significantly better than the others (regions of forefoot and mid-foot). This is because the plantar image captured by the proposed PIB system truly represented the original color of the blood from the soles' capillaries. However, the SM system cannot provide a similar plantar image, due to the light source being located beside that of the sensor. Thus, it is possible to assume that the color of the blood from the soles' capillaries may affect the output image with white tone when using the SM system. Given that, the gray levels of the three main contact regions were almost the same. According to Eq. (6), if the gray level ratio on each contact region is similar, then their corresponding pressure will be similar under the same body weight conditions. When compared to the TP

Table 2 The performance indices of mean±SD, MSE, and NAE for the plantar pressure performance calculation (N/cm^2) on different measurement system.

	Left foot			Right foot		
Method	Forefoot	Mid-foot	Heel	Forefoot	Mid-foot	Heel
TP (reference)	0.46±0.06	0.25±0.14	0.66±0.16	0.43±0.06	0.24±0.13	0.67±0.14
SM	0.40±0.04	0.42±0.05	0.41±0.05	0.36±0.04	0.41±0.05	0.40±0.05
MSE	0.95	5.23	8.71	0.88	4.91	9.2
NAE(%)	16.81	127.76	37.1	17.69	148.88	38.52
PIB	0.40±0.04	0.41±0.07	0.48±0.06	0.36±0.04	0.37±0.08	0.48±0.07
MSE	1.01	3.21	5.92	0.87	2.63	5.51
NAE(%)	15.74	100.58	28.66	15.78	106.36	27.77

Table 3 The percentage disparity value (%) of plantar pressure using the TP group as the reference.

	Left foot			Right foot		
Method	Forefoot	Mid-foot	Heel	Forefoot	Mid-foot	Heel
SM	14.64%*	-70.74%	38.41%*	15.05%*	-74.56%*	40.83%*
PIB	14.74%*	-63.01%*	27.05%*	15.06%*	-59.11%*	27.51%*

* Indicates statistically significant (p value < 0.05).

system, the SM system had more coverage areas in the measurement error at the heel region due to the larger pressure region. The SM system could not capture gray level well enough, therefore the produced measurement pressure was likely to become inaccurate. In short, according to the experimental results in Figs. 5-6 and Table 2, the proposed PIB system could provide more accurate data for plantar pressure calculation than the SM system in all comparison regions.

Figure 7 shows the comparisons of percentage disparities among the three different systems in each region, where the details are listed in Table 3. As for the percentage disparities for the image-based group as indicated in Fig. 7 and Table 3 for both the PIB system and the SM system were nearly 15% when compared with the reference sensor-based TP system on the forefoot region. However, in the mid-foot region and the heel region, the percentage disparities for the SM system were larger, up to 74.56% and 40.83%, respectively. According to Fig. 7 and Table 3, it can be observed that the percentage disparities of the

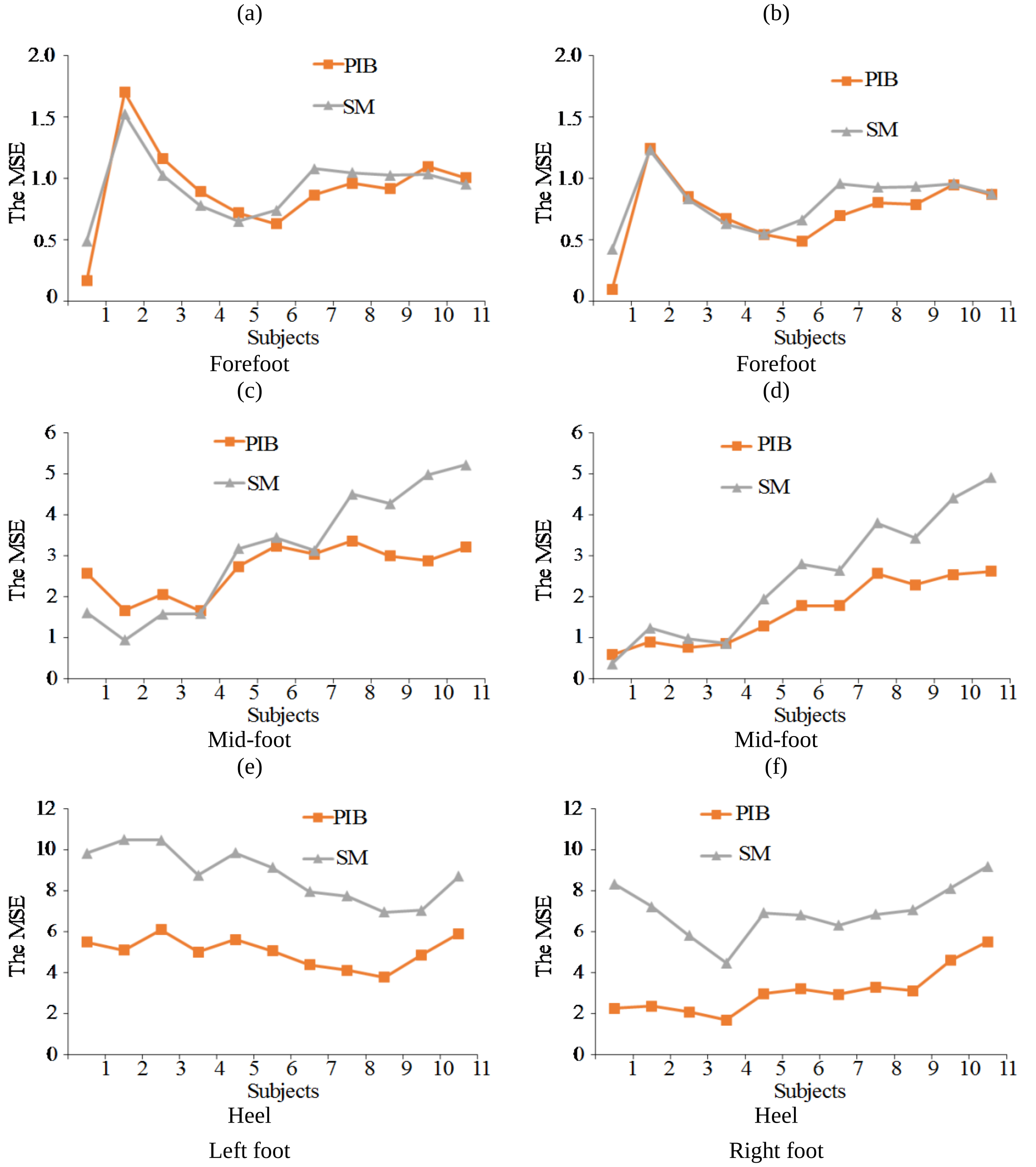


Fig. 5 Illustrating the MSE vs. trials on each system with the reference of TP group: (a) Forefoot region of the left foot. (b) Forefoot region of the right foot (c) Mid-foot region of the left foot (d) Mid-foot region of the right foot (e) Heel region of the left foot (f) Heel region of the right foot.

PIB system were almost smaller than the SM system even on the areas that did not have enough image information (i.e. gray intensities) at the mid-foot region or heel region, on both feet. In most cases, higher plantar pressure were usually located at the regions of heel and forefoot; lower pressure at the mid-foot region (Kellis, 2001). In this paper, the experimental results obtained by the reference TP system (as shown in Table 2) also indicate this situation. The TP system, as a sensor-based system with higher sensitivity of measurement, can provide the actual pressure based on sensor devices. In this paper, the image-based measurement system obtained the pressure through the gray image of the blood from the soles' capillaries. Generally, when using the sensor-based TP system, the measured pressure at the region of mid-foot was very low, therefore, it is difficult to obtain the pressure. Conversely, the characteristic of image-based systems (PIB and SM, indicated in Fig. 4(a) and 4(b)) is that it could capture

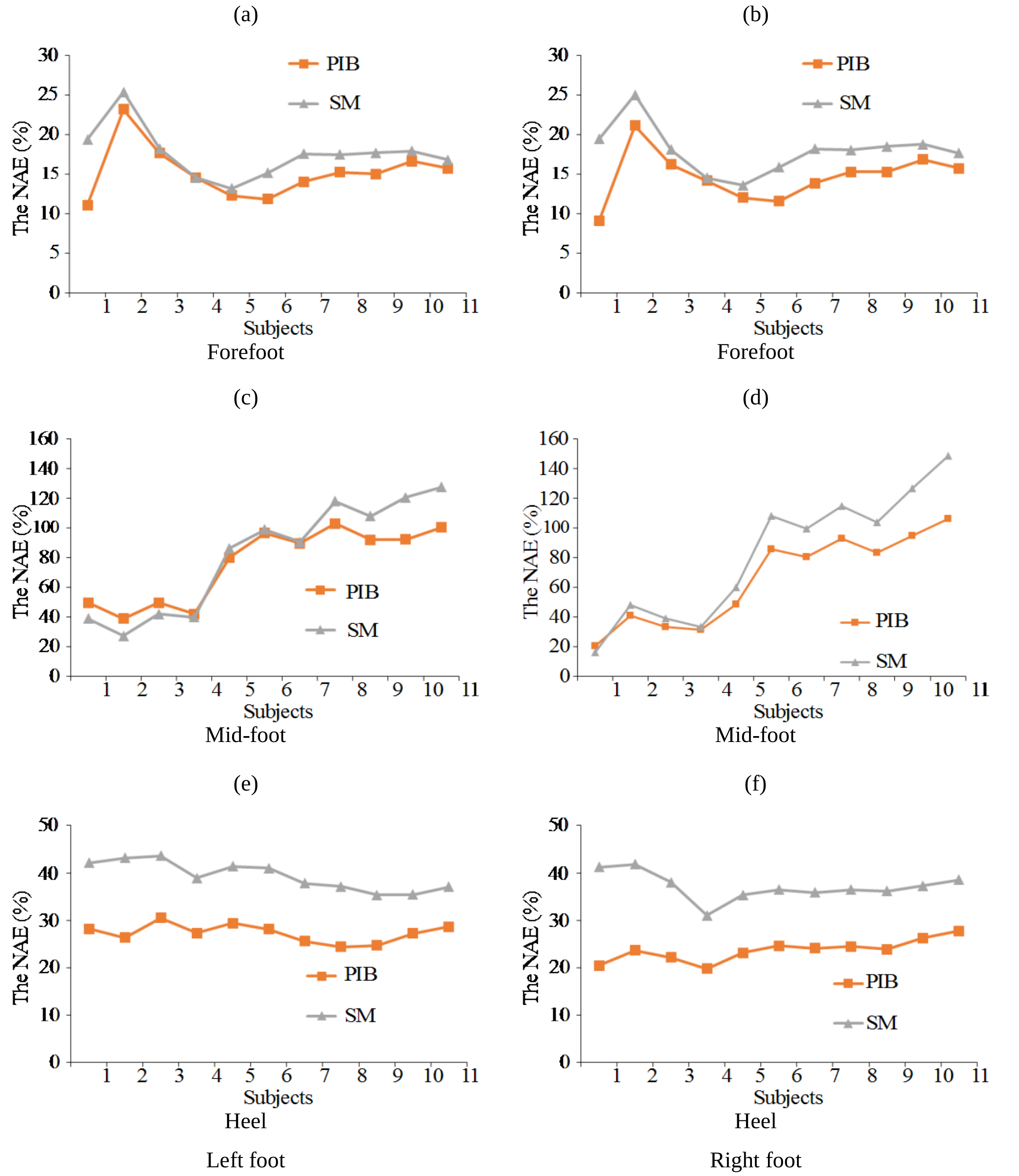
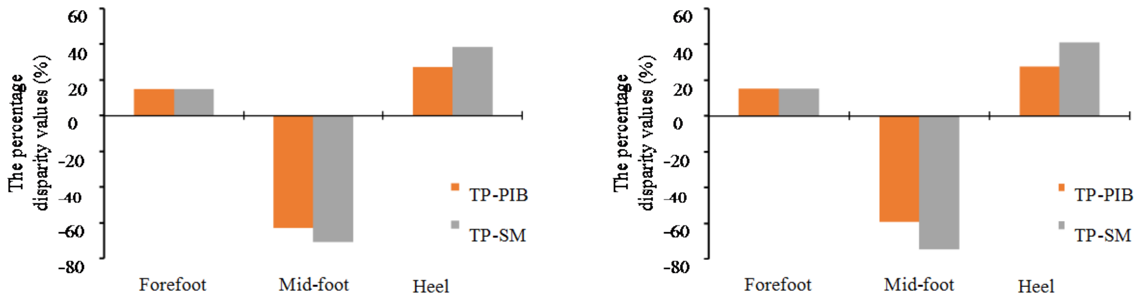


Fig. 6 Illustrating the NAE vs. trials on each system with the reference of TP group: (a) Forefoot region of the left foot. (b) Forefoot region of the right foot (c) Mid-foot region of the left foot (d) Mid-foot region of the right foot (e) Heel region of the left foot (f) Heel region of the right foot.

(a) (b)



Left foot Right foot

Fig. 7 Comparisons of the percentage disparity value (%) using the TP group as reference: (a) The left foot (b) The right foot.

pale skin colors completely, even in the lower pressure concerned area such as the mid-foot region reacted to the ground contact. The gray values generated in this area indicated that the pressure was also generated. When comparing with the TP system, the data in the mid-foot area could have significantly larger coverage than the other regions. It should be noted that the statistically significant difference ($p < 0.05$) in this paper is identified between the reference sensor-based TP and the image-based system.

Based on the statistical MSE, NAE and percentage disparity values analysis, it is shown that the measurement error of plantar pressure using the PIB system was smaller than that of the SM system. Therefore, it is suggested that the developed PIB system in this paper can be effectively used as an alternative for plantar pressure measurement.

CONCLUSION

The portable PIB was developed to enhance the quality of the acquired plantar image, simplify the operation of measurement hardware and, most importantly, lower operating cost when compared to the sensor-based commercial TP system. The experimental results showed that the performance of the PIB system, in terms of measurement accuracy, closely agreed with the TP system and was better than that of the SM system. As we are approaching an aging society, the application of this portable PIB may be of vital help for the elderly who usually experience difficulties with locomotor performance. Being a simple device compatible with all kinds of digital devices such as a smartphone and a digital camera can allow anyone to measure his/her foot pressure at any time without expert consultations. The results of the portable PIB can be further developed to serve the need of the “cloud” society, where any kind of information can be downloaded in any corner of the world as an “instant” answer.

ACKNOWLEDGMENTS

The authors would like to thank the National Science Council of the Republic of China, Taiwan, for support of this research under Grant Nos. NSC 101 2221-E-024-002 and MOST 103 2221-E-024-018. In particular, the authors would like to thank Dr. Prapai Jantrasakul for her assistance in English proofreading.

REFERENCES

Chang, C.C., and Lee, M.Y., "Adaptive multi-airbag foot pressure redistribution insole design using image-based rapid pressure measuring system," In Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, Washington, D.C., USA, October 5-8, vol. 3, pp. 2909-2914(2003).

Chang, C.C., Lee, M.Y., and Wang, S.H., "Customized foot pressure redistribution insole design using image-based rapid pressure measuring system," In Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, Quebec, Canada, October 7-10, pp. 2945-2950(2007).

Cheng, Y. L., and Liang, Y. C., "Application of Rapid Prototyping Technology in Development of Continuous Implanters for Dermal Papilla Cells," Journal of The Chinese Society of Mechanical Engineers, vol. 34, no. 3, pp. 243-250 (2013).

Chevalier, T. L., Hodgins, H., and Chockalingam, N., "Plantar pressure measurements using an in-shoe system and a pressure platform: A comparison," Gait & posture, vol. 31, no. 3, pp. 397-399 (2010).

Femery, V., Moretto, P., Renaut, H., Thévenon, A., and Lensel, G., "Measurement of plantar pressure distribution in hemiplegic children: changes to adaptative gait patterns in accordance with deficiency," Clinical Biomechanics, vol. 17, no. 5, pp. 406-413 (2002).

Hills, A. P., Hennig, E. M., McDonald, M., and Bar-Or, O., "Plantar pressure differences between obese and non-obese adults: a biomechanical analysis," Journal of the International Association for the Study of Obesity, vol. 25, no. 11, pp. 1674-1679 (2001).

Huang, C.N., Lee, M.Y., and Chang, C.C., "Computer-aided design and manufacturing of customized insoles," Computer Graphics and Applications IEEE, vol. 31, pp. 74-79 (2011).

Kellis, E., "Plantar pressure distribution during barefoot standing, walking and landing in preschool boys," Gait & posture, vol. 14, no. 2, pp. 92-97(2001).

Lin, C. C., Chung, K. C., Chang, C. H., Wu, C. L., and Liao, I. C., "Gait evaluation of biofeedback balance training for chronic stroke patients.," Journal of the Chinese Institute of Engineers, vol. 26, no. 6, pp. 845-852 (2003).

Nakajima, K., Kakihana, W., Nakagawa, T., Mitomi, H., Hikita, A., Suzuki, R., Akai, M., Iwaya, T., Nakamura, K., and Fukui, N., "Addition of an arch support improves the biomechanical effect of a laterally wedged insole," Gait & posture, vol. 20, no. 9, pp. 208-213(2009).

Putti, A. B., Arnold, G. P., Cochrane, L. A., and Abboud, R. J., "Normal pressure values and repeatability of the Emed® ST4 system," Gait & posture, vol. 27, no. 3, pp. 501-505 (2008).

Razeghi, M., and Batt, M. E., "Foot type classification: a critical review of current methods," Gait & Posture, vol. 15, no. 3, pp. 282-291(2002).

Shu, L., Hua, T., Wang, Y., Li, Q., Feng, D. D., and Tao, X, "In-shoe plantar pressure measurement and analysis system based on fabric pressure sensing array," Information Technology in Biomedicine, IEEE Transactions on, vol. 14, no. 3, pp. 767-775 (2010).

Urry, S.R., and Wearing, S.C., "A comparison of footprint indexes calculated from ink and electronic footprints," Journal of the American Podiatric Medical Association, vol. 91, pp. 203-209(2001).

Witana, C. P., Goonetilleke, R. S., Xiong, S., and Au, E. Y., "Effects of surface characteristics on the plantar shape of feet and subjects' perceived sensations," Applied Ergonomics, vol. 40, no. 2, pp. 267-279(2009).

NOMENCLATURE

ρ	The calibration factor (cm/pixel)
θ	The rotation angle (degree)
A_k	The plantar surface k-th region (cm)
f	An adjustment factor based on condi¬tions such as the insole material, the specific physical activity, and the person's health
f_i	The prediction value
$g_{i,j}$	The values of gray image pixels
G	The sum of the gray value in all regions
G_k	The gray level within the k-th region
L_a	The actual length of known actual scale (cm)
L_p	The length of pixel (pixel)
MSE	The mean square error
NAE	The normalized absolute error
P_k	The pressure at the k-th regions (N/cm2)
W	The total body weight (kg)
W_k	The distributed body weight in k-th regions (kg)
y_i	The true value (or the reference value)

以影像為基礎之可攜式足壓量測系統開發

Thossaporn Kaewwichit
泰國北曼谷先皇科技大學機械工程技術系
曾建勳
崑山科技大學資訊工程學系
蘇科翰
逢甲大學自動控制工程學系
張仲卿
國立臺南大學機電系統工程研究所

摘 要

足壓為人類日常生活中，裸足與地面接觸之壓力，足壓量測指標常見於人類之步態與姿勢分析、鞋類設計及其他健康相關應用，如下肢治療或傷害預防等。因而如何能正確的量測出足壓，一直以來為許多研究所致力探討的課題，為能有效且便利地取得並分析足壓值，本文發展出一套以影像為基礎之可攜式足壓量測系統。此系統可藉由任一種攜帶式照相裝置來擷取所需之高解析度足底影像，操作上相當簡易及方便。本文於實驗驗證過程為透過11位受測者所擷取之198張足底影像進行不同系統之數值分析比較，其中參考基準對照組為Tactile足壓量測系統。實驗結果說明本文所提出之足壓量測系統相較於市售高價位之足壓掃描器系統可達較佳之量測特性，且更能接近參考基準系統之量測值。綜上所述，本文所發展的以影像為基礎之可攜式足壓量測系統，確實可獲取高可信度之足壓資訊，相信可提供鞋類設計者或客製化鞋墊等輔具製造商一個經濟且可行之參考選擇。