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Plantar Pressure Evaluation using Harris mat footprints

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Abstract

Harris mat footprint is a simple mechanical device which offer the potential to measure and record foot pressure pattern and foot indexes in qualitative data that left an inked print on the paper. In this study, the image-based rapid pressure-measuring system was applied to evaluated the foot pressure in quantify data from the mat. The results were compared with a commercial pressure platform and existing image-base pressure measuring system in percentage disparity (PD). The comparison of the evaluation results of the mat to the commercial pressure platform showed maximum PDs of 10.49%, -29.11% and 25.92% at forefoot, mid-foot and heel, respectively. For overall, the experimental results of the mat using the image-base pressure measuring system showed close relationship to the commercial pressure platform and better performance than the existing image-base pressure measuring system. In addition, some limitations also discussed for future work.

***Keywords**:* Harris mat footprints, Image-based pressure measurement system, Plantar pressure.

1. Introduction

A useful of Harris mat footprints (HMF) first described in 1947 by Harris and Beath [1]. The mat is simplistic, inexpensive, noninvasive method of classification of foot types and recording plantar/ground pressure patterns in qualitative data to assist clinical diagnosis and decision making [2-4]. With plantar pressure patterns, one can easily recognize the pressure distribution by eye, judging from grid differences. It consists of multiple protrusion (as shown in Fig. 1(a) and (b)), containing a smaller grid inside for indicating the plantar pressure distribution. The plantar pressure distribution is indicated by the size and density of ink areas within the print. However, the mat footprints yield only qualitative data [5]. Moreover, the Harris mat footprints in quantitative accuracy of the plantar pressure have not been largely examined.

Based on Computer-Aided Design and Manufacturing of Customized Insoles, Huang and et al developed the image-based rapid pressure-measuring system by scanner (SC) works with a body weight scale [6]. The system transforms the plantar pressure from an image of the sole during body weight bearing. Nevertheless, the scanner of the system involves the complexity of the software and mechanisms that may time-consuming and bulky.

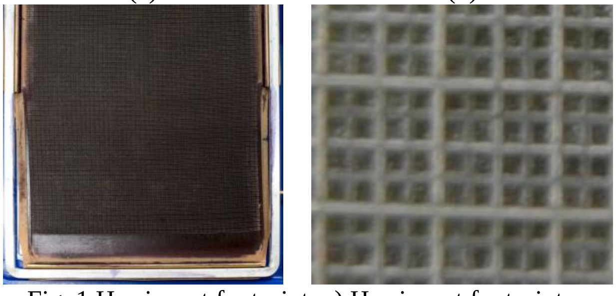

Fig. 1 Harris mat footprint: a) Harris mat footprint with platform and b) multiple protrusion

Therefore, the aim of this study is to evaluate the foot pressure in quantify data from the mat by applying the image-based rapid pressure-measuring system. The performance of foot pressure evaluations were compared with a commercial pressure platform (CPP) as a reference and existing image-based rapid pressure-measuring system.

2. Materials and methods

2.1 Mathematical model

In this study, the image-base pressure measuring system was applied to evaluate the plantar pressure from the HMF. The core of the image-base pressure measuring system has been described by Huang et al [6]. The system indicates the plantar pressure from the blood capillary of the sole during body weight bearing. The whiter color is, the higher pressure is. When applying to the mat, it provides grid densities of pressure varying when the higher grid density represents higher pressure. When convert the footprint image into gray scale system (digital binary 8 bits), the higher grid densities, the lower gray intensities (close to back color in shades of gray). It can be assumed that the lower gray intensity is, the higher pressure is. Thus, the sum of the complement image of the gray scale values (g_{ij}) is directly proportional to the body weight in all regions of the foot area. The gray value (G_k) of the interested k-th region of the foot can be determined as:

$$G_k = \sum_{i=1}^{m}\sum_{j=1}^{n}(255 - g_{i,j}) \qquad (1)$$

where the term of 255 is the complement of the in grayscale system, i and j are the x and y coordinates, and m and n are the maximum values in the x and y coordinates in the k-th region. Then, the total body weight (W) can be distributed to k-th region (W_k) as:

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

where, N denotes for the number of interested regions. Thus, W_k can be found as follow:

$$W_k = f\left(\frac{G_k}{\sum_{i=1}^{k} G_k}\right) W \tag{3}$$

where, f is an adjustment factor based on conditions such as the specific physical activity, the person's health and error calibration. In the study, the f was set at 1 due to study the characteristic of the method.

Therefore, the plantar pressure in k-th regions is the ratio of the body weight by ground contact area (A_k) can be found as follow:

$$P_k = \frac{W_k}{A_k} \tag{4}$$

2.2 Participants

The Fifteen healthy male participated in this study. The average±SD of age, mass and height was 24.2±2.3 Year, 67±10.8 kg and171.5±6.6 m, respectively. The participated had no serious injury on their lower limp.

2.3 Equipment

Since the measurement systems are different in this study, the information were provide in Table 1. All measurements were performed on CPP, SC system and the HMF.

The CPP (Tactilus, Pressure Mapping System, Madison, USA) was used to investigate the plantar pressure as the reference in this study. The specification of sensor size, sensor point size and number of sensor array is 40.894 cm × 40.894 cm, 1.278 cm × 1.278 cm and 32 × 32 units, respectively.

The SC system that equipped with the image-base pressure measuring system has been described by Huang et al [6]. The scanner works with a weight scale to record the foot image bearing the weight of the body by designing the software that measures the plantar pressure distribution on the basis of the scanned image.

Fig. 2 Harris mat footprint: a) Harris mat footprint with platform and b) multiple protrusion

The HMF (Good Arch Ltd., Taiwan) as shown in Fig. 4, the principle is that when the pressure applied though the mat which much higher pressure it will appear inner grid layer. The mat rubber pad dimension is 355 mm x 165 mm, 1.5 mm in thickness and height from ground 6 mm.

The HMF was obtained by a pad of the mat impregnated with ink and the surface was rolled by a rolling. To obtain left footprint, the subjects stood until stable at the front of the mat (Fig. 3(a)), placing right foot on the supporter (Fig. 3(b)) and placing left foot on the pad of the mat slightly (Fig. 3(c)), respectively. During the subject stand stable with full body weight, the subject kept looking at the point same as eyes level. After acquisition right footprint, the subject slightly removed left foot (Fig. 3(d)) and right foot to the floor (Fig. 3(e)), respectively [7].

2.4 Data acquisition

MATLAB (MathWork, U.S.A.) was used to calculate the plantar pressure according to mathematical model in section 2.1. After obtained the HMFs, it was scanned by scanner in dimensions of 1275x1755 on the JPEG (Joint Photographic Experts Group) format. Then, the images were converted into grayscale format. To obtain the area of the foot print, the footprints were calibrated from the resolution of the scanner.

In order to measure the performance of the evaluation results, the disparity in estimation between the methods was calculated by the mean value of each system in the form of percentage disparity (PD) value as follows:

Table 1 The comparison of plantar pressure measurement systems.

Equipment	Technique	Output	Price	Time consumption	Data transfer	Resolutions*
CPP	multi sensor arrays	raw pressure data	high	real time	wire	-
SC (Huang et al)	scanner	image	medium	<10min.	wire	1168 x 1670
HMF	multiple protrusion	document	low	<10min.	scanning	1275 x 1755

*The resolution performed in this study.

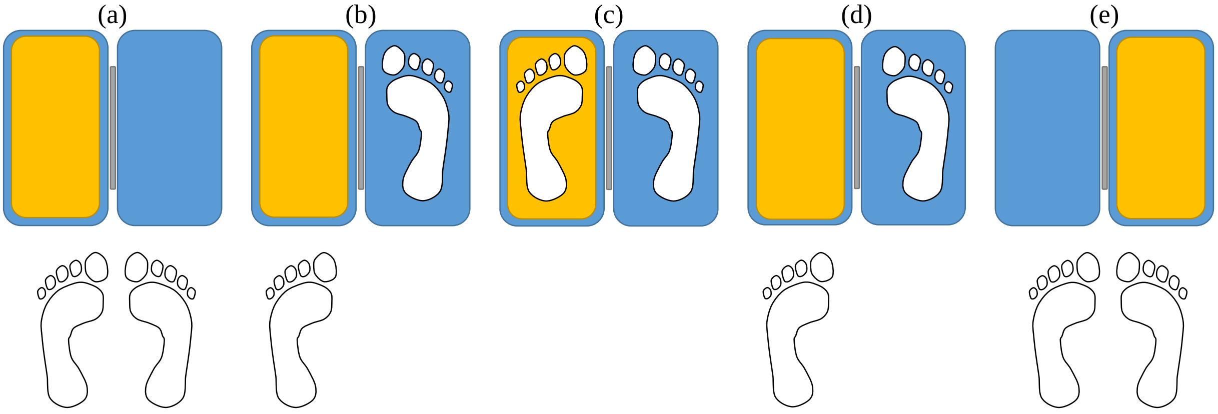

Fig. 3 Harris mat footprint acquisition for left foot

$$PD(\%) = \frac{1}{n} \times \frac{\sum_{i=1}^{n} y_i - \sum_{i=1}^{n} f_i}{\sum_{i=1}^{n} y_i} \times 100 \qquad (5)$$

Where f_i is the prediction, y_i is the true value (or the reference value) and n is the number of trials. As a result, positive value indicated that the plantar pressure distribution was overestimated by the reference method; by contrast, negative value meant the plantar pressure distribution was underestimated by the reference method.

3. Results

Forty-five image results (15 participant x 3 replication) obtain from the mat were used in this study. A sample of HMF image is shown in Fig. 4. A sample of the plantar pressure evaluation from the proposed method and its corresponding pressure from CPP are shown in Fig. 5(a) and Fig. 5(b), respectively. In order to comparison purpose, the regions of the foot contact area are divided into five areas in advance. However, only three main contact areas need to be considered in this study: forefoot, mid-foot, and heel.

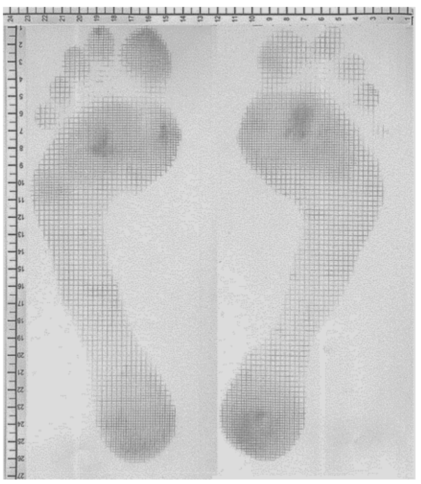

Fig. 4 A sample of the Harris mat footprints image.

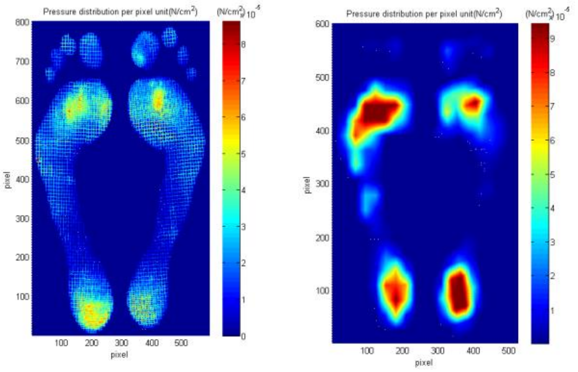

Fig. 5 A sample of the plantar pressure evaluation: a) the proposed method and b) its corresponding pressure measure from CPP.

Table 2 lists of the mean±SD of mean plantar pressure for different measurement systems on different regions. Also, Fig. 6 shows the comparison of the performance index PDs for different measurement systems with the reference system CPP on both feet. As shown in Table 2 and Fig. 6 for the forefoot area, the measurement difference between the SC and the proposed was small (less than 5.36 of the PD value on left foot). The measurement differences between the SC (PD=-74.57 on left foot) and the proposed (PD=-29.11 on left foot) were large at the mid-foot which the proposed provided better agreement to the CPP. In this case, the SC may not provide enough varying in the gray intensity value. While the HMF provide the gray intensities due to applied pressure. Similarly, the results obtained at the heel area indicated that the proposed method exhibits better ability than the SC. This was because the proposed method can directly transfers the load through the rubber pad that included multiple protrusion. Therefore, the HMF equipped with the proposed can provide better results in all regions than SC. Thus, the proposed method equip with HMF could provide simple method and lower operation cost.

Table 2 The plantar pressure distribution (N/cm^2) results in the means and PDs of experiments result compared with the reference CPP.

Method	Left foot			Right foot		
	Forefoot	Mid-foot	Heel	Forefoot	Mid-foot	Heel
CPP (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
SC	0.39±0.04	0.43±0.05	0.41±0.05	0.37±0.04	0.42±0.05	0.40±0.05
PD (%)	14.64	-70.75	38.42	15.05	-74.57	40.84
HMF (proposed)	0.41±0.10	0.30±0.07	0.52±0.0.08	0.39±0.09	0.31±0.07	0.46±0.11
PD (%)	10.49	-21.88	21.7	9.69	-29.11	25.92

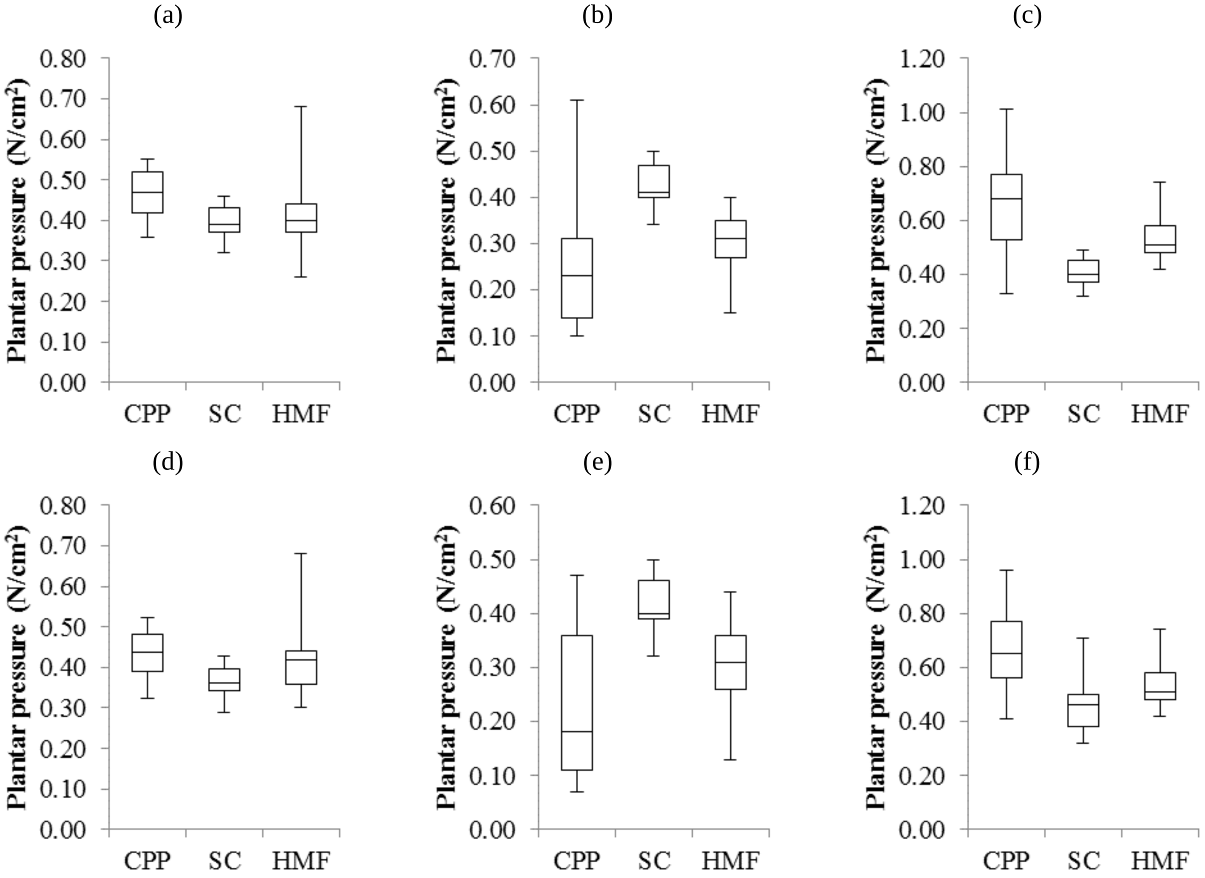

Fig. 6 Comparisons of the plantar pressure among experiment results for three main contact areas: (a) Left forefoot; (b) Left mid-foot; (c) Left heel; (d) Right forefoot; (e) Right mid-foot and (f) Right heel.

However, there are some limitations in this study. Since the f is an adjustment factor is included, it should be include in further study to obtain the exact values for precise measurement. During footprint acquisition, only single foot can be obtain which may take operation time. In addition, the footprint must be clear, otherwise it may affect to the evaluation result.

4. Conclusion

In this study, the Harris mat footprint is equip to evaluate the foot pressure in quantify data by applying the image-based rapid pressure-measuring system. The experimental results reported close relationship to the commercial pressure platform and better performance than the existing image-base pressure measuring system. Therefore, the proposed method equipped with Harris mat footprint can evaluate the plantar pressure in in quantify data which can assist in clinical diagnosis and decision making.

5. References

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