Development and Application of Image-base Plantar Measurement System

Hsien Chung Lo, Guo-Xiang Pan, Hui-Ling Chang, and Chong-Ching Chang
Graduate Institute of Mechatronic System Engineering, National University of Tainan, Taiwan
Email: changjeff0718@gmail.com

Abstract. The foot pain affects daily life function about 14-42% of adults over the age of 45 years old, since feet bear all the weight of the body. The most foot problems come from a great impact on the human body. It affects not only bone structures, but also the organs. Plantar information can be checked through the plantar pressure and arch index. The plantar pressure distribution is related to the walking balance, while the arch index can understand the foot bone structure. The paper aims to develop a system of plantar self-detection which is economical and easy to carry and operate. The system has built up two parts: one is the image capture equipment; another is the data analysis software. The portable scanning platforms can obtain high-resolution image, scanning work area is 216x356mm which the resolution is 1200dpi image. It only needs 10 seconds, using the wireless transmission to the plantar image through the pad for data analysis, calculated the plantar pressure distribution and arch index. The whole system price is less than one-tenth of the market selling pressure pad, providing a general system which is designed for plantar self-detection.

1. Introduction
Researches indicate that foot pain affects 14-42% of the adult population at ages above 45 [1]. Foot pain affects the functions of daily life. Additionally, as the population gradually becomes more aging, foot pain probably does not only produce poor balance, but also increase stumbling risk among the elderly people. It may also be combined with chronic diseases to cause worse harm. For example, 50% of patients with diabetes are hospitalized owing to diabetic feet [2]. Seemingly, foot pain is a problem unallowable to be neglected.

Both feet endure body weight and they act like the foundation of human bodies. It is the most direct connection between the body and the ground. It provides the functions of support and shock absorption. If there is any problem happening to feet, it will not only affect bone structure, but also impede organ functions. Foot problems can be known mainly through foot pressure and the arch index. The pressure distribution of feet let us know the balance of human bodies, while the arch index gives us the information to know the structure of human bodies.

If pressure is concentrated in a certain zone, it will not only affect the balance of human bodies, but also cause other diseases owing to poor blood circulation. Therefore, plantar pressure should be uniform to make good pressure distribution achievable. According to the judgment method published by the Cavanagh research team in 1987, the arch index is determined to be normal between 0.21 and 0.26 [3]. However, researches’ pinpoint roughly 10-15% of the global population belongs to the group of a high arch [4] and 6.6% belongs to the group of a low arch [5].

Generally, people do not particularly care about foot problems. They often start paying attention after those problems happen. However, with the advancement of medical care and the rise of individualism, people begin paying attention to health problems [6]. Various medical test devices and customized products start appearing
on markets. In 2015, T. Kaewwichit [7] developed a measurement system functioned with the automatic detection of plantar images. The plantar pressure measuring system is developed application software for image-based plantar pressure measurement and the database of foot correction [8].

Foot health care is bound to be a focus. It is extremely required to develop a set of testing software and equipment particularly designed for feet. This paper aims to develop an economical and portable foot self-detection system. This system is divided into two parts: the image acquisition instrument and the software of data analysis. High-resolution plantar images are obtainable through a portable scanning platform. Information such as foot pressure and arch index can be used to rapidly understand the information about feet through analysis results. It is available to understand the problems of body balance through the maps of foot pressure distribution and the bone structure problems of arch index. Moreover, it is an economical system helpful to implement foot self-detection.

2. Experimental method

2.1. Introduction to system functions

This system is divided into two parts: an instrument and the software of data analysis. The image acquisition instrument is a portable scanning platform (Fig. 1a) wherein the outer frame is mainly made of wood with a 10 mm tempered glass placed on the frame. The platform size is 36×48×16 cm functioned to obtain the images of users’ feet through the scanner. The working area is 21.6×35.6 cm and the color image acquisition with 1200 resolution takes 10 seconds only. Scanning results are sent to a tablet for analysis through wireless transmission. Analysis software is functioned to analyze high-resolution image results through programs, calculate data such as arch index and foot pressure distribution, and provide a user-friendly operation interface for users. In the Figure 1b, We cooperated with MIRDC (Metal Industries Research & Development Centre in Taiwan) to commercialize the plantar pressure and arch index measurement system that wins the silver of Edison Awards 2018 honoring innovation, excellence in design, development, marketing & launch of new products.

![Portable scanning platform for plantar measuring system in the prototype.](image-url)
2.2. **Data collection method**

Foot cleanliness of experimental subjects should be firstly determined to avoid the influence on analysis results caused by dirt. Experimental subjects stand upright on the portable scanning platform with bare feet. Soles touch tempered glass with the principle similar to rubbing. When people naturally stand without being affected by external forces, the weight of whole body will be concentrated on soles. The lighter the color of the area with soles touching glass it is, the greater the pressure it is. On the contrary, the deeper the color it is, the smaller the pressure it will be. Therefore, experimental subjects should avoid unnecessary movement. Movement should ensure the body remains relaxed with eyes opened to observe the reference point located 3 meters ahead and the eye level as well as obtain the information about the plantar images of experimental subjects.

2.3. **Experimental process**

In this research, plantar images are firstly obtained by the portable scanning platform, and then these images are sent to a tablet for calculation through wireless transmission. The relevant background of experimental subjects is not required and the software can be simply operated through a touch panel. The analysis results of plantar data are displayed and stored in a tablet. Through this system, users can rapidly conduct data analysis. The flow chart is shown as follows:

- **Plantar images obtained by the portable scanning platform**
- **Plantar images calculated by numerical scheme to get the plantar pressure distribution and arch index through wireless transmission**
- **Save the results in database for Big Data use**

**Figure 2.** Flow chart for measuring plantar system.
3. Data analysis

3.1. Analysis of arch index
The information of plantar images is binarized and plantar positions are found through touching areas. Furthermore, the area touched by toes is removed and the remnant area is the plantar area required to determine arch index. The arch determination in this research is conducted in accordance with the judgment method proposed by the Cavanagh’s team in a literature published in 1987 [3]. As shown in Figure 2, foot length is found through both the uppermost and the lowermost tangents of plantar edges. Foot length is divided into three equal parts, namely Zone A, B and C. The area of the Zone B means the area touched by foot arch divided by the total area touched by feet as shown in equation (1). It indicates the group of high foot arch is determined when the arch index is below 0.21; the group of normal foot arch is determined when the arch index is between 0.21 and 0.26 and the group of low arch is determined when the arch index is above 0.26. The arch index equation is shown as follows:

\[
\text{Arch Index} = \frac{B}{(A+B+C)}
\]  

(1)

![Figure 3. The segmentation map of arch index [3].](image)

3.2. Analysis of plantar pressure
Plantar pressure is obtained with the weight of the area divided by the area of the zone. As shown in the equation (2), it is obtainable through image processing. The principle is meant to convert the color gradation of foot images into binary digit codes. By corresponding to the order from white to black, the values of color gradation are changing from large to small. The larger the color gradation value it is, the larger the area it is stressed [8]. Otherwise, the smaller the area it is stressed. By using the matrix, gray scale values are obtained through reading all the binary values in images. Zone weight is obtained with the weighting values of regional gray scales multiplied by actual weight. Zone areas are regional weight values multiplied by the actual area of images, so that the area of every zone can be calculated.

\[
P_{z} = \frac{W_{z}}{A_{z}}
\]  

(2)

P : Pressure distribution, N/cm²
W: Weight loading, N
A : Area, cm²
K: k zone

4. Results and discussion
The plantar images of the first experimental subject (Figure 4) are obtained by using a portable scanning platform. After data analysis is finished, the software show results by means of charts and tables. Through Table 1, experimental subjects can confirm their own analysis results by checking basic information to avoid confusion with other experimental subjects when storing data. When checking records, it is allowable to know
the results of your own foot detection at different times and you can check them out later. Figure 5 provides a comparison with data and images allowing experimental subjects to understand the status of their own pressure distribution and body balance. The pressure profile of the first experimental subject shows that the pressure is concentrated on forefoot. Table 2 shows the arch index, arch status and foot length of both feet. Users can understand the problems of skeletal structure through arch index. The arch index of both left and right feet for the first experimental subject is above 0.26 according to the judgment method proposed by the Cavanagh team in 1987 [3] wherein the first experimental subject belongs to the group of low foot arch (flat foot).

**Figure 4.** The plantar images of experimental subjects.

**Table 1.** Basic information and BMI value.

| Information   |   |
|---------------|---|
| Name          | No.1 |
| Age           | 20  |
| Height (cm)   | 160 |
| Weight (kg)   | 60  |
| BMI           | 23.4 |

**Figure 5.** The map of plantar pressure distribution.
Table 2. Arch index and plantar length value.

|                | Left       | Right      |
|----------------|------------|------------|
| AI (Arch Index)| 0.2729     | 0.2972     |
| Arch type      | Low Arch   | Low Arch   |
| Contact area ($cm^2$) | 17.79 | 17.95 |
| Plantar length (cm) | 26.24 | 26.35 |
| Plantar width (cm)  | 10.01 | 9.97 |

5. Conclusion
The main contributions in this research are to develop a foot self-detection system combined with plantar image capture hardware and a set of foot pressure and arch index analysis software. Users can obtain the results of high-resolution plantar images without using invasive instruments. Through the analysis software the both important information on foot pressure and arch index have been combined. The users can specifically understand the problems of his body balance and bone structure.

Because of scanning plantar image, it can avoid the fish-eye effect caused by photographing with accuracy improved. Analysis results are used to combine arch index and the information of plantar pressure and it is a system especially dedicated to foot self-detection. Users also can use measuring results to desire customized insoles and shoes. Besides, the price of this system is less than one tenth of those of the pressure pads currently on markets. It is economical and easily portable. It also provides the reference available for medical diagnosis or producing foot aids. The whole system is commercialized and won the silver of Edison Awards 2018 honoring innovation, excellence in design, development, marketing & launch of new products.

6. References
[1] H.B. Menz, Maturities, 91, 110(2016)
[2] J. Ahmad, Clinical Research & Reviews, 10, Issue 1, 48(2016)
[3] P.R. Cavanagh and M.M. Rodgers, Journal of Biotech, 20, 511(1987)
[4] W. Martha and H.J. Fan, Foot & ankle international, 2, 379 (1998)
[5] K. Gatzoulis, et al., Foot and ankle Surgery, 4, 75,(2009)
[6] R.R. Azevedo, E. S. da Rocha, P. S. Franco and F. P. Carpes, Physical Therapy in Sport, 24, 39(2017)
[7] T. Kaewwichit, GIMSE, National University of Tainan, Taiwan, PhD. Dissertation, (2015)
[8] C.N. Huang, M.Y. Lee and C.C. Chang, Computer Graphics and Applications, IEEE 31.2, 77(2011)
[9] W.C. Wang, K.H. Su and C.C. Chang, International Conference, MDEATED (2014)
[10] T. Kaewwichit, C.H Tseng, C.C. Chang, KMUTNB: International Journal of Applied Science and Technology. 7(2),77 (2014)