Identification of Foot Posture using *Foot Posture Index-6* (FPI-6) based on Image Processing

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**Abstract.** Legs and ankles have an important role in daily life for activities. unconsciously often the leg posture becomes abnormal due to the bad habits, so the risk of injury. Assessment of the type of leg posture can be done by various methods, both uni-planar and multi-planar.

This study developed the FPI-6 method as a multi-planar tool based on image processing. The data used are 30 reference data and 20 test data from the age of 19-23 years. The results of this study are image processing systems that can identify the type of leg posture automatically quickly and accurately.

### 1. Introduction

The comfort of activities using legs such as walking and running is very much influenced by the type of posture of one's feet. Abnormal leg posture will reduce the efficiency of leg movement and increase the risk of injury [1]. Diagnosis and rehabilitation of abnormal leg posture are increasingly needed to maintain leg posture. However, the amount of money that must be spent to diagnose this type of foot posture by experts becomes an obstacle for the community. Therefore we need test equipment that can diagnose this type of leg posture effectively and efficiently without having to pay a large fee.

In general, there are two assessment tools, namely uni-planar and multi-planar. There are two studies on uniplanar devices, namely radiography and anthropometrics. Radiographically, studies of the normal range of joint motion have been carried out using computed tomography (CT) [2]. Whereas anthropometrically, studies of leg posture types have been carried out with Rear Foot Arch (RFA) measurements using goniometer [3], Medial-Longitudinal Arch Angle (MLAA) measurements [4], and Navicular Position Test (NPT) which evaluates the position of the navicular bone [5]. In the latest research, the RFA assessment was carried out using image processing technology and was considered capable of increasing efficiency [1], [6]. In multi-planar tools, Foot Posture Index-6 (FPI-6) and FPI-8 methods have been found [7], [8]. FPI-6 assesses the type of leg posture based on six criteria [7]. Multi-planar assessment using FPI-6 is considered the most reliable and can validate leg posture simply and quickly [9]. Therefore, there is an opportunity to develop FPI-6 as the most reliable multi-planar tool, using image processing technology that can improve efficiency.

This study proposes a GUI system that can identify foot posture using the FPI-6 method based on image processing. The identification process uses Otsu's thresholding segmentation to recognize the characteristics of each of the six criteria. The output of the FPI-6 system made is in the form of three types of foot posture, namely normal, pronation, or supination.
2. Methodology

2.1. Foot Posture Index-6 (FPI-6)
FPI-6 is a multi-planar tool that is judged to be fast and reliable for determining human foot posture. The FPI-6 assessment is based on six observation criteria. Before observing the FPI-6, patients are required to stand in a relaxed position. Then various foot regions will be observed based on six criteria. Figure 1 shows an illustration of the FPI-6 criteria [10].

![Figure 1. Six Criteria of FPI-6.](image)

In the six observations, each criteria will be given an index value according to its position. For each criteria, values +1 or +2 are given for pronation positions, values -1 or -2 are given for supination positions, and a zero score is given for normal or neutral positions. Furthermore, the six indexes of each criteria are added up to produce a total index score as the basis for the classification of foot posture types. A score of 0 to 5 can be classified as normal. More than five are classified as pronated, and less than 0 are classified as supination.

2.2. Experimental Setup
In this study, data were taken in the form of right foot images from 50 Telkom University students ranging in age from 19-23 years. Of the 50 students, 3-foot images were taken each from a different perspective. So that the total number of images used in the system is 150-foot images with details of 50 rear foot images when the lateral position is straightened to a 90-degree angle, 50 rear right foot images when the standing position is relaxed, and 50 side foot images in the inside.

2.3. System Specification
In designing a foot posture identification system, hardware, and software that support the system are needed to work properly and optimally. The software needed is the MATLAB R2018a program, while the hardware used is a device with specifications, namely Processor Intel® Core™ i3-5005U CPU @ 2.00GHz, Memory: 4GB (RAM), Operating system: Windows 10 Pro 64-bit. Also, some equipment that is used for primary data collection is needed, including the following Camera Canon D3100, Tripod, two light stands, two lamps 45W, two white umbrellas, and Black Box 40 × 45 × 40 cm.

3. System Design
In general, the design and implementation stages of the system consisted of the stages of image acquisition, image pre-processing, quantification using FPI-6, and classification based on the index obtained from the quantization stage. Figure 2 displays a block diagram of a foot posture identification system.

![Figure 2. Block Diagram of Foot Posture Identification System.](image)
3.1. Image Acquisition

The acquisition process uses an image object in the form of a photo of the back right foot and the right side of the inside using a digital camera with dimensions of 1708 × 1139 pixels and a resolution of 96 dpi. The image is taken by inserting the foot object into a black box measuring 40 × 40 × 45 cm. Subjects were asked to stand up straight for foot photographs. The camera is placed parallel to the object at the height of 50 cm above the ground. The distance of the object to the lens is set at 25 cm because it is considered quite clear and not too far away. Two light stands with 45W lamps are used, each on the right and left side of the camera. The light from the two lights is filtered using a white umbrella, so the results are even and do not cause disturbing shadows. How to capture the right rear foot image is shown in Figure 3. Three points of view of the foot image can be seen sequentially in Figure 4.

![Figure 3. Image Acquisition.](image)

![Figure 4. Three Foot Viewpoints Used in the System.](image)

Each subject was only taken the image of his right foot, with three angles of the field, namely when the back foot in the lateral position was straightened to a 90-degree angle, when the right rear foot in a relaxed standing position, and the right inner foot. Figure 4 shows the image (a) needed to see the 2nd criteria in FPI-6, image (b) for the 3rd and 6th number criteria, and image (c) for the 5th criteria. The pictures (a) and (b) are the images of the back foot. Still, the difference is that in picture (a) the lateral part of the foot is positioned to be straight at an angle of 90 degrees to the camera position. The aim is to get clearer information about supra and infra lateral curvature. Whereas in picture (b) is the position of the feet when standing relaxed.

3.2. Image Preprocessing

Digital imagery can be expressed as a two-dimensional function \( f(x, y) \) with \( x \) or \( y \) being the coordinate position and \( f \) is the amplitude at position \((x, y)\) which is often known as grayscale intensity [11], [12]. This research used several image pre-processing stages, including resizing, grayscaling, Otsu thresholding [13], [14], noise removing [15], and filling holes [14]. This stage is used for each criteria before feature extraction is performed in the next process. Figure 5 displays the flow diagram of the FPI-6 image pre-processing system stage.

![Figure 5. Block Diagram of the FPI-6 Image Preprocessing System.](image)

The image size of 1708 × 1139 pixels is resized by 25% to 427 × 285 pixels. Then the image is converted into an RGB color space grayscale. Each image is converted to binary using the Otsu thresholding method [15]. In the separation of background images and grayscale objects with thresholding, there is still a background that is read as an object so that it forms certain areas that are undesirable or referred to as noise. Therefore, to eliminate noise levels, a threshold value for noise removal is performed for each criteria. The noise removal stage is removing the background pixel area...
that is read as an object. Therefore, the hole filling process is carried out to fill the black hole with a pixel of 1 value.

3.3. Feature Extraction

3.3.1. Criteria 2 (Supra and Infra Lateral Malleolar Curvature). The amount of curvature can be seen from the position of the pixels at the maximum infra and supra lateral curvature. The pixel position can be compared by finding the distance between the two. The output of this first step is the two coordinates \((x_1, y_1)\) represent the maximum supra lateral arc position, and \((x_2, y_2)\) the infra lateral maximum arc position. Then, to find out the distance of \(x\) coordinate between the two maximum arches (SI) obtained, the reduction of \(x\) infra lateral coordinate \((x_2)\) is reduced by supra lateral \(x\) coordinate \((x_1)\). The output of this stage is the feature value of criteria 2 in the form of the \(x\)-coordinate distance between the two maximum arches (SI).

3.3.2. Criteria 3 (Inversion or Eversion Calcaneus). In this criteria, the three angular slopes formed by the center of the calcaneus are calculated against the surface of the plane. Figure 6 shows the steps to get the Calcaneus feature [16].

![Figure 6. Feature Extraction Block diagram in the calcaneus.](image)

This stage starts by storing information in the form of pixel positions on the right and left side of the calcaneus object. Then from the pixel position of the right side \((x_2, y_2)\) and the left side \((x_1, y_1)\), the pixel midpoint \((x, y)\) is searched by calculating the mean coordinates of \(x\) from the right and left sides of the calcaneus (Figure 7(a)). Figure 7(b) shows the results of the plotting line marked with a red line with \((x_1, y_1)\) as the top point and \((x_2, y_2)\) as the bottom point. The angle is calculated by first looking for \(x\) as the difference \(x_2 - x_1\), as well as \(y\) as the difference \(y_2 - y_1\). Then the values of \(x\) and \(y\) that have been obtained as follows

\[
\tan \alpha = \frac{y}{x} \quad \alpha = \tan^{-1} \left( \frac{y}{x} \right)
\]

Furthermore, the angle \(\alpha\) in units of degrees becomes the value of the system output results in criteria 3, which will then be quantized. Figure 7(c) illustrates the process of obtaining an angle (\(\alpha\)).

![Figure 7. Feature Extraction of Calcaneus.](image)

3.3.3. Criteria 5 (Congruence of the Medial Longitudinal Arch). The medial elongated arch height is obtained by storing pixel information at the bottom of the foot object and then detecting pixels. The pixel position of the leg curve is obtained by finding the upper, lower, right, and left boundaries first. From this boundary, the lower boundary is drawn for the plot. After that, we can see the maximum
point formed by the MLA chart. The maximum MLA curve is calculated from the distance to the surface of the foot. High MLA is the value of the system output feature in criteria 5.

3.3.4 Criteria 6 (Abduction or Adduction of the Forefoot on the Rarefoot). Abduction is the appearance of the forefoot on the lateral side of the foot (outer side), and adduction is the appearance of the front foot on the medial side of the foot (the inside). Both will be sought the difference by reducing abduction by adduction. If the result is positive, the feet are more abducted, so pronation tends. And conversely, if more foot adduction will tend to supination. The result is a feature value in the form of the difference in the magnitude of the abduction and induction distance.

3.4 Quantization Using Scoring Foot Posture Index-6 (FPI-6) Rules
In this study, image processing was not carried out for criteria 1 and 4 due to image limitations that can only detect two dimensions. Quantization using the FPI-6 rule is performed on the value of features that have been obtained in the extraction process. There are five indexes of -2 to +2 given to the six criteria of qualitative standards that are in line with FPI. The six indexes of each FPI criteria are then added up to get a total value. Based on this total value, the classification is done. Total values for normal legs range from 0 to +5. If more than +5, prone foot posture. The posture of fewer than 0 feet can be called supination.

4. Result and Discussion
System validation is carried out by bringing ten subjects to the expert for manual FPI-6 assessment. Because FPI-6 assessment is qualitative, the m01 is repeated by three experts in each subject so that the assessment can be more objective. Each criteria will have three index values based on the assessment of each expert. From the total index value, the foot posture is classified based on the FPI-6 assessment rules. In this study, testing was carried out on 50 subjects. Another 40 subjects were validated based on the foot image taken. However, validation is only on criteria 2, 3, 5, and 6, considering criteria 1 and 4 must be palpated (touched) directly.

4.1 Otsu Threshold Testing
In criteria 2 and 6, the information to be extracted is the amount of curvature of the supra and infra lateral. Otsu thresholding can separate objects and backgrounds more perfectly using the multiplier coefficient (k). The value k = 0.7 is chosen so that the object does not lose much information. Calcaneus information can be seen starting at k = 1.4, but at this value, calcaneus still joins with the rest of the foot. The best threshold is obtained when Otsu thresholding is multiplied by the value of k = 1.7 in Criteria 3 and 6. In criteria 5, the threshold value is automatically obtained when the multiplier coefficient is one. The MLA arch is clear and doesn't lose information. Figure 8 displayed the best threshold value in criteria 2, 3, and 6.

4.2 Noise Removal Testing
The results of thresholding in the previous process still leave noise in the background in the form of white dots that have a certain area. In this test, the threshold value of noise (N) removal for the noise in the image will be chosen. A value of N = 10000 is used for each criteria in the FPI-6 system. Figure 9 displays the results of the noise removal process with N=10000 in criteria 2 and 3.

4.3 Testing the Results of the FPI-6 System
A total of 20 test data will be tested on a system that has previously been set parameters based on reference data. Table 1 is the result of an assessment of 20 test data tested on the FPI-6 criteria 2 system.
Figure 8. Threshold testing (a) k = 0.7 in criteria 2, and 6, (b) k = 1.7 in criteria 3, and 6, (c) k = 1 in criteria 5.  

Figure 9. The Noise removal threshold N=10000 (a) criteria 2, (b) criteria 3. 

Table 1. Accuracy of FPI-6 systems on test data. 

| Verification by | Foot Posture | Number of valid indexes | Index Verification | Accuracy (%) |
|----------------|--------------|-------------------------|--------------------|--------------|
| 6 Criteria of FPI-6 | Normal | 17 | 16 | 1 | 95 |
|                  | Pronation | 3 | 3 | 0 | 95 |
|                  | Total | 20 | 19 | 1 | 95 |
| 4 Criteria of FPI-6 | Normal | 17 | 15 | 2 | 85 |
|                  | Pronation | 3 | 2 | 1 | 85 |
|                  | Total | 20 | 17 | 3 | 85 |

A comparison is performed on testing the total accuracy of the FPI-6 system by six criteria and 4 FPI-6 criteria. A total of 20 results of test data validation were tested on testing six criteria (including criteria 1 and 4), and then the index of each criteria was added up. Based on the range of values classified type of foot posture, likewise, in testing four criteria (without criteria 1 and 4), but classified with a different range of values. Table 1 shows a comparison of the results of the verification of foot posture classification using six criteria and 4 FPI-6 criteria. Based on the verification of 20 verified test data, the accuracy of the 6 FPI-6 assessment values is greater than the 4 FPI-6 criteria, which is 95%. In comparison, the accuracy of the assessment by four criteria is 85%.

5. Conclusion 
This study proposes a system to identify the type of leg posture using FPI-6 automatically based on image processing. Pre-processing stage in the form of resizing, grayscaling, Otsu thresholding, noise removal, and filling holes. Based on the experiment obtained 95% system accuracy in classification based on six criteria (4 criteria automatically and two criteria by palpation by a doctor), and 85% accuracy in classification based on four criteria.

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