BigFoot: A Mobile Solution toward Foot Parameters Extraction

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***Abstract*—The ill-fitting shoes can cause many health implications, ranging from feet ache to feet sore, from back injury to back pain and so on. Due to the manufacturing variance and design consideration, shoes from different brands will vary in size and shape. Good-fit insoles and shoes are necessary to prevent users from ill-fitting problems. Hence, we propose a novel technique that can be used to calculate parameters of the foot from smartphone RGB camera inputs. Typically, we focus on estimating six main parameters of the foot, including foot length, foot width, foot back height, toe height, heel circumference and foot circumference. These six parameters will significantly help users to find the right shoes or order a tailor-made insoles that fits their foot condition so that they can sustain their foot health and avoid further damage. Therefore, we applied different mathematical formulas accordingly and designed algorithms to estimate foot parameters.**

I. Introduction

Foot is an important part of the human body. However, people often seem to underestimate the importance of the foot until they feel pain in the lower extremity, which is normally caused by ill-fitting shoes [1]. People usually wear ill-fitting shoes to make themselves outstanding during social events, or to make themselves look professional during business meetings, just to list a few. Such habit is not a good practice and can cause serious health related problems such as collapsed arches, back pain and joint pain. Treating these conditions often involves complicated and risky medical procedures, such as injections of anesthetics and surgery [2]. In the study done by Buldt et al. [3], at least 63% of their research's participants did not wear the correctly fitted footwear (either length or width). The result also shows that incorrect footwear fitting is associated with foot pain and disorders such as corns and calluses.

Understanding the foot shape structure will enhance the quality of foot care and help to prevent foot disorder in its early stage. People with foot disorders can benefit from understanding their own foot structure and find shoes that are suitable for their foot condition, in order to prevent it from getting worse. In the article ”Why Preventive Foot Health is Important” by Robert P. Thompson [4], he has stated three reasons why preventive foot health is important which include increasing life quality, improving work productivity, and enhancing human physical activities.

In this work, we ask the important question: “Can modern advances in Computer Vision be used to identify human foot shape?” More specifically, we will explore the semi-automated foot parameters calculation approach using the computer vision technology combined with the foot anatomy knowledge. The anatomical foot parameters will be useful with identifying human foot shape and help people find their correctly fitted footwear. There are various research studies involving foot sizes that give us an insight into parameters that define foot size critically. Qiu et al. [5] studies focus on the influence of foot sizes on human balance. In their work, foot length, foot width and foot circumference are selected as parts of the main components to determine the foot size. Besides, in the studies done by Price and Nester to accurately quantify the foot morphology of 5 adults who are overweight and obese [6], they have selected heel circumference as one of the main components to compute foot size for comparison between the obese group and the overweight group. This makes senses as human foot shape varies depend on people's habit and disease presence [7]. In addition, using the right fitted ballet shoe is utmost important to perform ballet. In the article led by Balletbox [8], they have provided a guideline for choosing the right point shoe. Among many parameters, toe height and heel back height are used to help determine the foot size. Because of their important role in determining the foot size, we will explore the method to determine the six foot parameters including foot length, foot width, foot circumference, heel circumference, toe height and foot back height.

II. Related Work and Limitation

There have been studies done in the past by various groups of researchers about the human foot structure [9]–[12]. Many of the researchers used the depth camera devices to provide the image data in depth (3D). Google's group has designed the depth sensor device named ”Structure Sensor” [13]. This sensor can be used by prosthetic and orthopedic professionals to reconstruct human foot images to 3D form, allowing them to study their patient's foot shape. This same sensor has also been used as a primary sensor by several smart phone apps such as the MASS3D [14], and the Design Studio [15] for foot orthotics. Even though such sensor can provide valuable computer vision information, its price comes to $379 which is expensive to be used personally by the general population. Besides the Google sensor, there is an app called "Wiivv" built by Wiivv wearable Inc. [16] to determine foot size. This smart phone app can help customers find correctly fitted custom insoles and scandals. To use this app, users will place their feet on the letter or A4 size paper with their heel against a wall. Then, the user takes pictures from the top and the medial side of their foot. The app will then analyze the foot structure based on the pictures. This app is quite economical and convenient to use. However, this app is only available solely for customers who have purchased merchandise from Wiivv, and provide users only a body-perfect insole. It does not provide numerical customized data about important parameters for users to know their foot measurement. This data can provide important reference for users for future shoe or insole purchases and for tracking their foot shape transformation through time.

A. Proposed Approach

In this paper, we propose a novel approach, which requires users to take pictures from the top and medial view of the foot using a smart phone with the RGB camera. These pictures will be useful to identify human foot shape. We demonstrate a computer vision solution which is accurate, precise and works in real-time. More specifically, we employ mathematical formulas to extract the human foot shape parameters based on the foot anatomy. We consider six aspects to study the human foot shape: 1). foot length, 2). foot width, 3). toe height, 4). foot back height, 5). foot circumference, and 6). heel circumference. Our contributions are as follows:

- We propose a novel and economic foot parameters calculation approach based on pervasive smartphone and optimized computer vision algorithms.
- We implement the system on the smartphone to achieve the real-time foot analysis for convenient daily usage.
- We conduct a pilot data collection of human foot shape from 15 volunteers, and comprehensively evaluate the estimation performance of our system upon the six parameters.

III. METHODOLOGY

In our proposed method, we determine foot shapes by computing the main six parameters including foot length, foot width, foot back height, toe height, heel circumference and foot circumference. To begin, we perform image processing, and calculate foot length and foot width. Then, we collect key points for other parameters' calculations.

A. Input Images

In our proposed methodology, two images with specific color marks on certain points are served as our inputs, and are required to compute all these six parameters. First input will be user's right foot on a paper with foot heel aligns with the bottom edge of the paper. Tilted image is also acceptable. Second input is taken from the medial view of the foot horizontally.

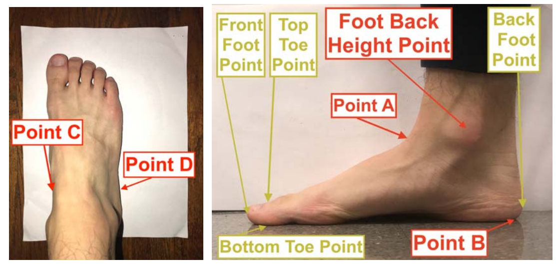


Fig. 1. Marks' locations from Top(left) and Medial(Right) view.

Participants have to put red markers on Point A, Point B, Point C, Point D and Foot Back Height Point, and yellows markers on Front Foot Point, Back Foot Point, Top Toe Point and Bottom Toe Point.

B. Length Reference

In order to calculate foot length and foot width, we use the known paper size as length reference. In order to calculate toe height, foot back height, foot circumference and heel circumference, we use pre-calculated foot length as reference.

$$LR = \frac{fL}{fLP}, \tag{1}$$

where LR is *length reference*, fL is *predicted foot length in cm* and fLP is the *predicted foot length in pixel unit.*

C. Image Pre-processing of Top View and Medial View Images

Gaussian Filter is applied on both images to reduce image noise. Canny edge detection [17] will be applied to top view image to first extract paper edge and then foot edge. Color detection will be applied to medial view image to filter out colors.

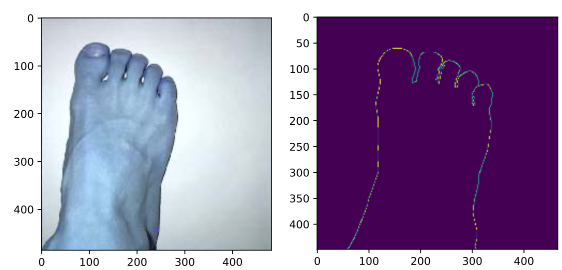


Fig. 2. After A4 Paper Extraction (left) and Foot Edge Extraction (right).

D. Parameters Extraction

1) Foot Length: Foot length calculation will be the distance between tip toe and heel positions:

$$fLP = (y_{heel} - y_{tiptoe}), \tag{2}$$

where fLP is foot length in pixel, and (y_{heel}), (y_{tiptoe}) are the coordinates of heel and tiptoe position in y-axis respectively. The foot length in centimeter conversion is as the following:

$$fL = \frac{fLP * PL}{PL_{pixel}}, \tag{3}$$

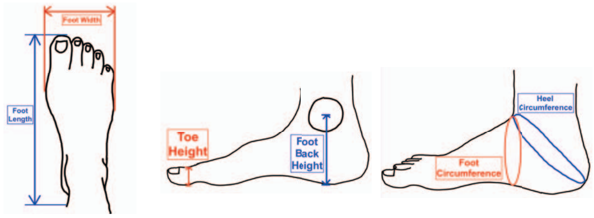


Fig. 3. The Measurement of 6 Parameters.

where fL is foot length in centimeter, fLP is foot length in pixel, PL is paper length in cm and PL_{pixel} is the paper length in pixel.

2) Foot Width: Calculation of foot width is similar to foot length's. We look for the rightmost and leftmost part of the foot edge:

$$fWP = (x_{right} - x_{left}), \tag{4}$$

where fWP is foot width in pixel, and $(x_{right}, y_{right}), (x_{left}, y_{left})$ are the coordinates of rightmost and leftmost position of the foot edge respectively. The foot width in centimeter conversion is as the following:

$$fW = \frac{fWP * PW}{PW_{pixel}}, \tag{5}$$

where fW is foot width in centimeter, fWP is foot width in pixel, PW is paper width in cm and PW_{pixel} is paper width in pixel.

3) Toe Height: Toe height is calculated by distance between *Bottom Toe Point* and *Top Toe Point* after yellow markers detection:

$$fTP = (y_{BottomToePoint}) - (y_{TopToePoint}), \tag{6}$$

where fTP is toe height in pixel, $y_{BottomToePoint}$ and $y_{TopToePoint}$ are y-axis coordinates of *Bottom Toe Point* and *Top Toe Point* respectively. From this parameter onward, we will use LR to convert our pixel into centimeter unit. We convert the toe height value into centimeter as the following:

$$fT = \frac{fTP}{LR}, \tag{7}$$

where fT is toe height in centimeter, fTP is toe height in pixel and LR is length reference.

4) Foot Back Height: Foot Back Height is calculated by vertical distance between *Foot Back Height Point* and *Point B*:

$$fBP = (y_{FootBackHeightPoint} - y_{PointB}), \tag{8}$$

where fBP is foot back height in pixel, and $(y_{PointB}), (y_{FootBackHeightPoint})$ are the y-axis coordinates of the *Point B* and *Foot Back Height Point* respectively. As described previously in (7), we can convert the foot back height value into centimeter as the following:

$$fB = \frac{fBP}{LR}, \tag{9}$$

where fB is foot back height in centimeter, fBP is foot back height in pixel and LR is length reference.

5) Foot Circumference: The shape of foot circumference looks similar to half circle from the front view of foot. We apply a half circle perimeter equation using foot arch width as the diameter of the circle with multiplication of a deviation coefficient α, which is equivalent to 1.3 from our training data set. The foot arch width is the distance between *Point C* and *Point D*:

$$fU = \frac{\pi * facP}{2}, \tag{10}$$

where fU is the upper part of foot circumference in pixel and $facP$ is foot arch width in pixel.

Then, we compute foot circumference by adding the above value with foot arch width:

$$fcP = (fU + facP) * \alpha, \tag{11}$$

where fcP is the foot circumference in pixel, fU is the upper part of foot circumference in pixel, $facP$ is foot arch width in pixel and α is deviation coefficient.

$$fc = \frac{fcP * PW}{PW_{pixel}}, \tag{12}$$

where fc is the foot circumference in centimeter, fcP is the foot circumference in pixel, PW is the width of paper in centimeter, and PW_{pixel} is the paper width in pixel.

6) Heel Circumference: Heel Circumference looks like an eclipse. Because of that, we calculate it by using the perimeter of an ellipse:

$$a = \frac{x_{PointD} - x_{PointC}}{2}, \tag{13}$$

$$b = \frac{\sqrt{(x_{PointB} - x_{PointA})^2 + (y_{PointB} - y_{PointA})^2}}{2}. \tag{14}$$

After we determine the radius on both major and minor axis, we can apply the eclipse circumference formula as the following:

$$hcP = \pi * (3(a+b) - ((3a+b) * (a+3b))^2), \tag{15}$$

where hcP is the heel circumference in pixel, and a is a vertex on major axis in pixel, and b is a co-vertex on minor axis in pixel. Finally, we can convert its value to centimeter by:

$$hc = \frac{hcP}{LR}, \tag{16}$$

where hc is the heel circumference in centimeter, hcP is the heel circumference in pixel and LR is the length reference.

IV. Experimental Results

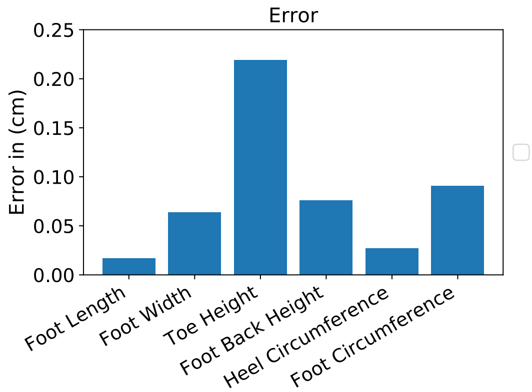
A. Participants

15 participants (8 male and 7 female), from ages of 18 to 45 years old, volunteered to join the research. Firstly, participants took picture of their right barefoot from the top, with an A4 paper underneath. Secondly, participants took picture of their right foot from the medial perspective. After that, participants put red and yellow marks on specific locations as described in Fig. 1. Also, we received the ground truth values by manually measuring their feet.

B. Software Tool

We have implemented and tested it on Macintosh OS and Linux OS. Because of using Python 3 with OpenCV packages, it is available on most operating systems.

C. Performance Overview



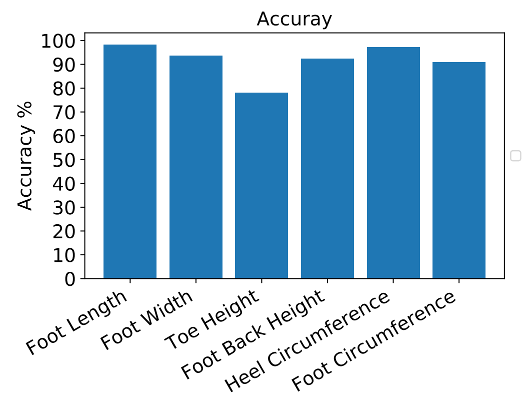


Fig. 4. Error and Accuracy of the six parameters.

As shown in Fig. 4, calculations of six parameters perform well with both high accuracy rate and low error. The validation results of foot length, foot width, foot back height, heel circumference and foot circumference perform with each accuracy goes above 90% along with error lower than 0.10 centimeter. Toe height, on the other hand, provides the least accuracy rate compared to other 5 parameters with the result just below 80% and the error is higher than others approximately at least 0.15 centimeter. The reason behind this lower accuracy is that the range of toe height is way smaller than other parameters, thereby deviation within a small amount of units could result in little bit larger error and lower accuracy. However, such error is minimal that it does not affect overall foot size measurement. Apart from that, standard deviations of error of foot length, foot width, toe height, foot back height, heel circumference and foot circumference are 0.2cm, 0.3cm, 0.3cm, 0.6cm, 0.8cm and 0.8cm respectively. It shows the robustness of our algorithms among different people.

Overall, the system performs effectively and can precisely predict the value ± 0.1 cm. It shows the potential of being applied to sneakers apps to help the people select their most fitting shoes.

V. Conclusion

In this paper, we present BigFoot, a novel and economic foot parameters analysis approach based on smart phone and the optimized computer vision algorithms. The system will perform real-time calculation and analysis. Data could be used as reference for buying a good fitting shoes. The validation results show that there is no statistically significant difference between calculations' values and ground truth values. The questionnaires provided after all experiments reveal positive responses from participants because of the run-time efficiency and accuracy. Further development of the system offers an improvement in health implications caused by ill-fitting shoes.

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