A Low Cost 3D Foot Scanner for Custom-Made Sports Shoes

Zahari Taha[1,a], Mohd Azri Aris*[1,b], Zulkifli Ahmad[1,c], Mohd Hasnun Arif Hassan[1,d] and Nina Nadia Sahim[1,e]

[1]Centre for Sports Engineering, Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

[a]zaharitaha@ump.edu.my, [b]azriaris9@yahoo.com, [c]kifli@ump.edu.my, [d]hasnun@ump.edu.my, [e]nina_nadia89@yahoo.com

Keywords: low cost 3D scanner; 3D model; anthropometry; sports shoes.

Abstract. Conventional methods to obtain foot anthropometry for custom made sports shoes using anthropometer, callipers and measuring tapes are inaccurate due to the complex anatomy and curvature of the instep, foot arc and related joints. They lead to poor repeatability and large variances, particularly when measurements are taken of different people. Measurements from 3D model have been claimed as a perfect tool to obtain anthropometric data. However a commercial 3D foot scanner to create a 3D foot model can be very costly. In this paper we propose a low cost 3D foot scanner system by integrating available image capture technology such as the Kinect®, appropriate 3D scanning software and a foot scanner rig. An experiment was conducted to compare the anthropometry data taken using conventional method and from the 3D model. The differences recorded for all regions were found to be less than 5%, suggesting that the 3D model produced by this method is accurate. The use of 3D scanner has also decreased the measurement duration, thus increasing the repeatability whilst decreasing human errors that normally occur during the measurement process.

Introduction

When purchasing new footwear, important factors that are taken into account include appearance, price, colour, and comfort [1]. However, the most significant practical aspects in choosing footwear are comfort and fit [2, 3]. It can be optimised by accurate and efficient measurement of anthropometric dimensions for pattern development [4]. Furthermore, anthropometric studies have shown that the shape of the footwear directly affects the level of comfort [5]. To produce a shoe that fits the user, custom-made shoe is the only option. However, development of a custom-made sports shoe such as football boot is very costly and possesses aesthetic limitations, which means that it is available only to a limited number of users.

Current shoe manufacturers and retailers use trial-and-error method to improve sports footwear fit, thus causing difficulties in finding a shoe with a perfect fit. Customers often face difficulties to find suitable shoes that will afford both comfort and performance. The measurement of the shoe size depends not only on the length, but also the width and circumference [6]. Foot dimensions are traditionally determined manually using tools such as flexible measuring tape, callipers, measuring boards and rulers. These tools are easy to use, small in size and inexpensive. However, the accuracy of the manual measurement is low due to the complex anatomy and curvature of the instep, foot arc, fingers and related joints. Hence, the repeatability of manual measurement is poor and measurement performed by different person will result in large variance [4].

Anthropometry is the scientific study of the measurements and proportions of the human body. It establishes the physical geometry, mass properties, and strength capabilities of a person [7]. Current technology offers the collection of highly accurate anthropometric data through 3D light-based body scanner. This significantly decreases the duration of the process and provides less error in measurement compared with the traditional method; hence it is very beneficial to be applied in the designing process [8].

Through 3D scanner, real objects are analysed and point cloud data is generated. The evolution of computer offers the ability to produce highly complex model. For post processing purpose, scanned images are often imported into various CAD/CAM software. Previous study has shown that 3D scanning method is a very significant method to obtain anthropometric data of human body parts [9]. 3D foot shape models have been studied in detail. Previous study has described which anthropometric measurement is the most relevant for shoe fitting [10]. Complete 3D foot shape has also been used for foot measurement purpose [11-13].

A major drawback of a 3D scanner is the equipment cost. 3D scanners are often very expensive. However, the launch of a motion sensing input device by Microsoft Corporation in 2012 known as Kinect® has offered a new possibility for researchers. Kinect® (Fig 1) was developed for the Microsoft XBOX 360, a video game console and also intended to be used on Windows PCs [14]. It allows the user to interact with the console through various gestures and voice commands. It eliminates the need for game controllers. Researchers are trying to find possible applications of Kinect® that go beyond the system's intended purpose of playing games.

Fig. 1: Kinect® sensor.

Recently, Kinect® sensor has been used as controlling device for quadrocopters [15], home smart shopping, clinical analysis [16], gesture-based computer interaction [17] and also as 3D scanner. This paper proposes a low-cost 3D foot scanner incorporating the Kinect® sensor as a device to measure foot anthropometry. By rotating the scanner around the subject’s foot, a perfect 360° image can be obtained. Hand-held scanner is impractical due to vibration caused by the hand as a result of muscle fatigue, inconsistent scanning radius or minimum distance between the object and the sensor during the scanning process. Thus, an automatic rotating rig is required to overcome the abovementioned problems.

Methodology

A scanner rig was designed and fabricated for the system. The design is made of a triangular frame mounted on three wheels at each apex. By adjusting any two of the three wheels, the rig rotates with a constant radius with the centre being the object to be scanned. The Kinect® sensor is placed on a tripod on top of the rig. A radio-controlled motor is installed on the rig to enhance the workability of the rig to rotate the rig around the foot during scanning process.

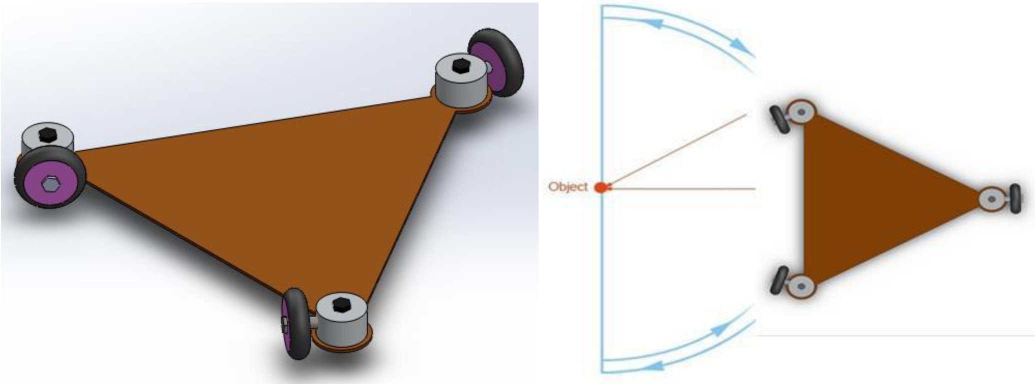

Fig. 2: Final design of 3D scanner rig

Commercial 3D scanning software is used to scan the foot. It takes less than 30 seconds to complete a foot scanning process. The scanned image is then processed to produce a watertight 3D model. The model is then converted into STL format. The file is then imported into a CAD software for measurements to be taken. In this study, six foot anthropometry measurements were performed. Conventional foot measurements using anthropometer and measuring tapes [18] were conducted for validating the measurements from the 3D model.

Results and Discussion

The solid 3D model of a foot produced is shown in Figure 3.

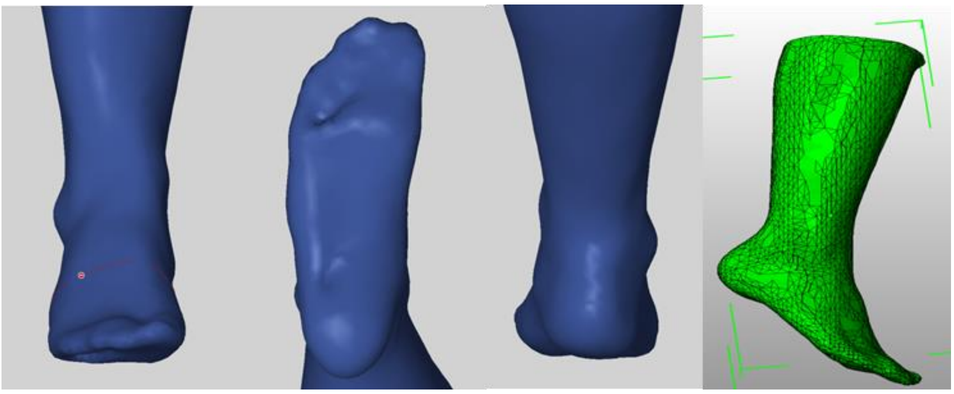
Fig. 3: Scanned foot model

The differences between conventional and 3D model measurements are shown in Table 1.

Table 1: Foot anthropometry data measured using hand and 3D measurement software

Foot Anthropometry	Hand Measurement (mm)	3D Measurement (mm)	Differences (%)
Foot length	249.00	248.44	0.22
Foot width	95.10	91.05	4.26
Heel width	55.10	54.83	0.49
Lateral malleolus height	78.10	80.12	2.59
Foot width circumference	236.70	244.06	3.11
Lateral malleolus height	97.40	100.52	3.20

It is observed that the values from manual and 3D scanner measurements are in a good agreement. The differences recorded for all regions are less than 5%, suggesting that the 3D model produced by this method is accurate. The use of 3D scanner has also decrease the measurement duration, thus increase the repeatability whilst decreasing human errors that normally occur during the measurement process.

Conclusion

A novel approach to obtain a 3D model of a foot for custom-made sports shoes by integrating a commercial imaging technology, appropriate software and a scanner rig was successfully developed in this study. The low cost 3D scanner was proven to be accurate in measuring human foot anthropometry. The scanner will be valuable in producing a custom-made sports shoe such as football boots at a much lower cost. A perfect fitted and comfortable sports shoe can help improve performance and reduce injuries.

Acknowledgement

The authors would like to thank the Universiti Malaysia Pahang and the Ministry of Higher Education, Malaysia for providing the funding for this research under the grant RDU110702.

References

[1] Kos L. and Duhovnik J.: *A system for footwear fitting analysis*. (International Design Conference, 2002).

[2] Miller, J.E., et al.: *Influence of foot, leg and shoe characteristics on subjective comfort*. (Foot & Ankle International, 2000).

[3] Rupérez, M.J., et al.: *Contact model, fit process and, foot animation for the virtual simulator of the footwear comfort*. (Computer-Aided Design, 2010).

[4] A. Yu, et al.: *2D and 3D anatomical analyses of hand dimensions for custom-made gloves*. (Applied Ergonomics, 2012).

[5] Wang, C.-S.: *An analysis and evaluation of fitness for shoe lasts and human feet*. (Computers in Industry, 2010).

[6] R.S. Goonetillekc, A.Luximon, and K.L.Tsui: *The Quality of Footwear Fit: What we know, don't know and should know*. (2000).

[7] Jinky Leilanie and Prado-Lu: *Anthropometric measurement of Filipino manufacturing workers*. (International Journal of Industrial Ergonomics, 2007).

[8] R.E. Sims, et al.: *Collection of anthropometry from older and physically impaired persons: Traditional methods versus TC2 3-D body scanner.* (International Journal of Industrial Ergonomics, 2011).

[9] Rocchini, C., et al.: *A low cost 3D scanner based on structured light*. (Computer Graphics Forum, 2001).

[10] Rossi W. A. and R. Tennant: *Professional shoe fitting*. (National Shoe Retailers Association, New York, 1984).

[11] Mochimaru M, Kouchi M, and D. M.: *Analysis of 3-D human foot forms using the Free Form Deformation method and its application in grading shoe lasts*. (Ergonomics, 2000).

[12] Luximon A., Goonetilleke R. S., and T. K.-L.: *Footwear Fit Categorization, The Customer Centric Enterprise*. (Advances in Mass Customization and Personalization, 2003).

[13] Borchers R. E., et al.: *Numerical Comparison of 3-D shapes: Potential for application to the insensate foot*. (Journal of Prosthetics and Orthotics, 1995).

[14] Wikipedia: *Kinect*. (2010). Available from: http://en.wikipedia.org/wiki/Kinect#cite_note-Natal_101-9.

[15] Sanna, A., et al.: *A Kinect-based natural interface for quadrotor control*. (Entertainment Computing).

[16] de Albuquerque, A., et al.: *Kinect Sensor Used as A Support Tool in Clinical Analysis*. (Journal of Biomechanics, 2012).

[17] Boeykens, S: *3D Scanning using Kinect and Free Software*. (2012). Available from: http://cad-3d.blogspot.com/2012/06/3d-scanning-using-kinect-and-free.html.

[18] Center, D.H.R.: *Anthropometry Manual*. (2010).