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Design and Production of Subject Specific Insole Using Reverse Engineering and 3D Printing Technology

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Abstract: *In this study, a biomechanical application of three dimensional (3D) printing method was implemented to produce a subject-specific insole. It was aimed to design and manufacture a customized total-contact insole operating a free mobile application that enables to create 3D scans of an object and a 3D printer device in this application. First, two dimensional pictures of a subject's foot sole was taken from various angles and these photos were uploaded to the server of the software which use photogrammetry technology to create a 3D model out of multiple pictures taken by the user. Next, 3D scanning data was transferred to a CAD software and the model was modified to represent the geometrical properties of the subject's foot most appropriately. Then, the model as an STL format imported to a 3D printer device. Finally, the model of subject-specific insole was printed and examined by placing into the shoe of the subject. It was shown with sequential processes that a subject-foot geometry based insole could be designed and manufactured benefitting from new facilities of technological advances with a low level of cost. Furthermore, the use of custom made biomechanical instruments, which make easy to carry out daily tasks, could likely be increased by utilizing educational and practical applications regarding 3D scanning and printing technologies.*
Keywords: *Insole design, 3D printer, 3D CAD data, subject-specific design*

I. Introduction

Insoles are devices inserted into shoes to support feet and to absorb shock effect in a comfortable manner besides correcting congenital abnormalities of foot and providing proper propagation of force during walking. The insoles are useful tools to reduce some difficulties due to the defects causing from human foot shapes such as presented in Fig. 1. Furthermore, the insoles, known generally as custom insoles, should be designed and manufactured according to foot shape and biomechanical needs of individuals to satisfy functional expectations such as less pressure acting on foot surface [1]. There are many studies investigating the design and effect of insoles especially the effect of insoles on plantar pressure reduction and their quantitative evaluations [2, 8]. A mold of foot sole is prepared and insole is produced utilizing this mold's geometric shape in the traditional method of the custom made insole manufacturing. Therefore, the insole exactly fits to the surface of the foot. A subject-specific insole has total contact characteristic that provides more appropriate pressure distribution and thereby reducing the pain. Also custom insoles can be modified considering some kind of deformities such as varus/valgus, and, in this way, such insoles can improve the posture by supporting the foot in a neutral position [9, 10]. Moreover, complaints such as hip, knee and lower back pains caused by poor foot function could be reduced using custom made insoles restoring the abnormal foot function.

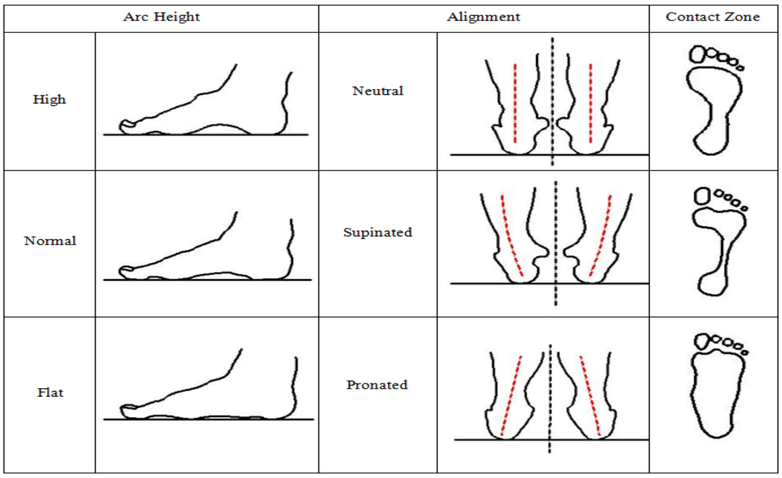


Figure 1. Human foot structures and contact zones

With recent developments in 3D printer technology, solid body models of objects from 3D CAD data could be easily and quickly produced with less labor, time and cost. Comparing with the conventional manufacturing methods of human foot insoles, 3D printers that use various additive manufacturing methods lead to shorter and more efficient production, especially for manufacturing prototypes and custom-made objects. 3D printer technology has been used for manufacturing the orthotic devices in some novel studies [11-13]. The insoles that are designed by employing a CAD software could also be produced by 3D printing. The customized CAD model of an insole can be derived from a CAD model of the foot sole of an individual. The CAD model of foot sole can be captured by scanning the surface of a person's foot sole geometry with a 3D scanner system. In this study, an open source and android based "123D catch" software, which is a free mobile application, was used to capture the 3D scan data of the foot sole. In this method, insoles are produced without the molding procedure and insole model can be modified before manufacturing.

3D printing technology, which is a prominent tool for the last decades, enables to print 3D models of any real objects specifically for customized molds and prototypes [11, 14]. The design and production industry of custom insoles has been highly affected by the advances of 3D printing technology. This method, which is time, labor, cost and source saving, is performed using different kinds of materials such as PLA (Polylactic Acid) and ABS (Acrylonitrile Butadiene Styrene). 3D printing is also known as additive manufacturing that uses a number of additive processes, such as selective laser sintering (SLS), direct metal laser sintering (DMLS), fused deposition modeling (FDM), selective laser melting (SLM), stereolithography (SLA) and laminated object manufacturing (LOM).

In this study, in order to improve the teaching methods and to increase the practical applications of aforementioned novel technologies with educational and functional concerns, a subject-specific customized mold insole was designed and manufactured. The study represents an educational application which includes the main steps of insole design and production using up-to date technologies, so that interested people and especially students could adapt to latest developments.

II. Methods

This study involves a series of steps which are critical for production of custom made insoles that is aimed to improve the poor gait functions and posture of people. As a starting step, in order to obtain 3D geometrical data of the subject foot, a series of photos were taken using mobile phone which operates Autodesk 123D Catch open-source software (Fig. 2). In this system there are two row camera positions that provide to take images at varying heights. The photos should be taken in an angle interval of 0 and 360 degrees, so that one tour around the object was needed to be completed for each row. During taking photo, zooming in and out could distort images and also, transparent and shiny surfaces could confuse the system. Therefore, it is important to avoid zooming operations and objects with extreme glare. Atmosphere should be arranged according to this conditions that do not lead to shining and require zooming. Objects also should be stable when capturing for a clear 3D converting process, otherwise shape of the object will be distorted or the software will give an error. Light around the object and contrast between the object and surface should be enough to produce images with high quality.

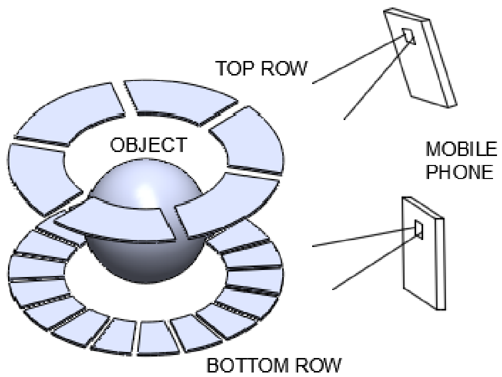


Figure 2. The Method of Taking Images

The software required time duration about 60 minutes to process the photos. The model constituted by the software could include some defects originated from environment in which photos or foot were taken. It is necessary to perform a cleaning operation to discard these undesirable defects. The operation could be achieved using various open-source software. In this study, Autodesk Meshmixer which is also an open-source software, was used to carry out this task. The modified foot sole is still a rough surface. The smoothness operation was performed to refine the surface quality and this step was also implemented using Meshmixer software tool, as well. The outer surface of foot sole and the inner surface of the designed insole should have the same topology to sustain a good adaptation and to satisfy the subject specificity. In order to obtain the same shape of foot for insole design, 123D Design, which is a reverse engineering and also open-source software was used. The output of this step is still a surface in stereolithography (STL) file and should be transformed to a CAD file in order to perform required solid body operations. The surface of the insole, which has the same topology with the foot surface, was then converted to a solid body using a conventional solid body modeling program. After a series of operation, including fillet, radius, extrusion and cutting, the model was ready to print. Above mentioned process is visualized in Fig. 3.

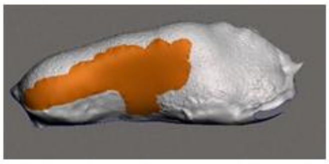
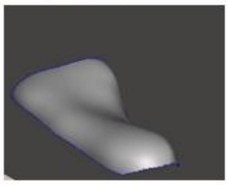
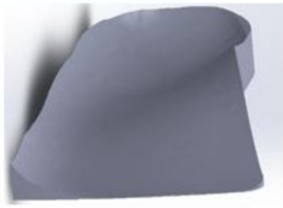
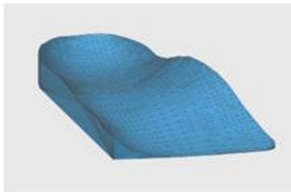
Task	Process	Output
Taking photos		
Cleaning & surface operations		
Solid body operations		

Figure 3. Process and outputs of design steps

Manufacture of the insole model was carried out using a 3D printer device (Ultimate 2 Extended) and based on fused deposition modeling technique (FDM).

FDM, one of the most popular 3D printing technologies, implies a production technique employing a moving nozzle that is heated to melt and extrude the material (Fig. 4). As material is extruded from the nozzle, it is supplied with filament by a spool. The nozzle is moved according to shape of objects by a numeric control system. Therefore objects are built layer by layer in precise measurements.

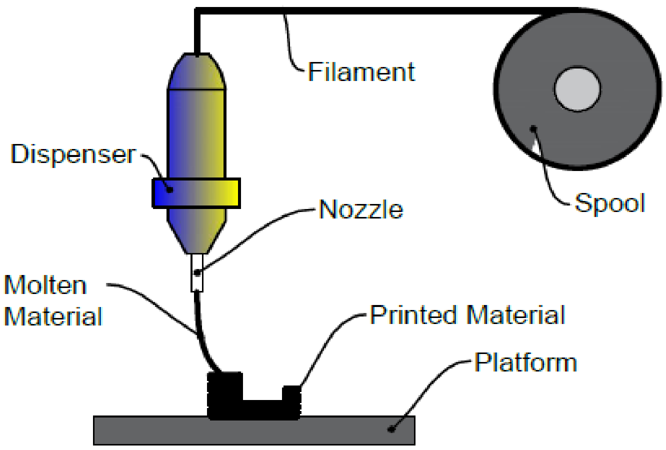


Figure 4. FDM process.

Printing is the last stage of whole process. Schematic representation of work flow is given in the Fig. 5.

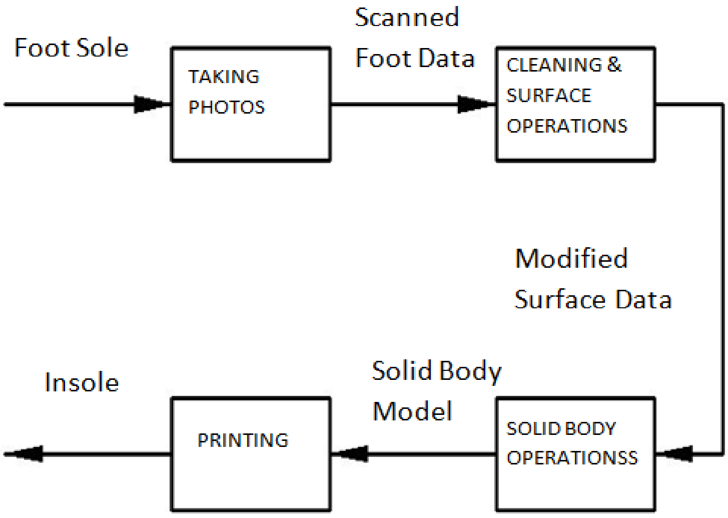


Figure 5. Schematic representation of work flow

The PLA material was fed to the 3D printing device in our laboratory which is extensively used for biomechanical purposes. Although numerous materials were proposed to be used in 3D printing technique, considering human foot sole-insole interaction, the PLA material was chosen due to being non-oil based material. Accordingly, produced insole model is shown in Fig. 6.

Figure 6. Fresh insole model after printing process

III. Results And Discussion

Human foot can be categorized in three classes in terms of the arc height as high, normal and flat arched foot. Foot shapes are also often classified considering the foot alignment including neutral, supinated and pronated foots. It is important to note that, even though, the foot shapes are classified into a few general clusters, each foot class represents different and unique shape and foot size. An insole is described as a device that is placed into the shoes to correct the alignment of the lower limbs and to provide comfort for different locomotion conditions. Insole designs could be implemented according to subject-specific foot geometry. These types of insoles sustain total-contact characteristics and are generally called customized insoles. Reducing pain as distributing the pressure to a larger area and improving the foot functions are the main benefits of total-contact insoles. In order to design and produce a proper total-contact insole, foot geometry of a specific subject is critically necessary. Traditionally, obtaining the geometry of foot could be achieved using molding process. Recent developments in scanning technology, revealed a new way of taking 3D CAD (three-dimensional computer-aided-design) models which represent the shape and dimensional data belonging to targeted objects. Solid body model of the targeted object could be imported to numerous educational or commercial software and can be employed to obtain specific geometries for different purposes. Thus, labor, process duration and costs that are related to molding process are noticeably reduced by operating 3D scan technology. Various commercial 3D scan tools and devices are being utilized to gather 3D data of objects. However, these facilities require high cost and qualified users. The process of scanning is hard to those who have not background relating design and production processes. To address this issue, free image capturing programs integrated in mobile phone could be utilized.

In this study, the design procedures of subject-specific insoles were performed and the production of insoles by benefitting from 3D printing technology was evaluated. Design and manufacturing processes were completed in accordance with the functional requirements such as total contact, customizable, labor and cost effective and easily producible. In addition, the produced insole has shown a good match to the foot surface of the subject. Since adaptation of foot sole to insole surface is critical for comfort in posture and gait, an appropriate match is a crucial result for the study. Moreover, it was also shown that improvements in science and technology would provide effective solutions on production processes of subject specific designs and products.
The study also shows that from STL to CAD part, there are many steps that must be carefully done using open-source and commercial software. The actual geometry of foot could be reflected in the computer model by benefiting from capabilities of those programs.
Additive materials technology has been utilized in the study and it is clearly experienced that this kind of technology is prominent and also promising for biomechanical and educational purposes.
For future research directions, insoles could be manufactured via different materials such as flex PLA and the comfort levels could be compared to determine which materials provide better support for subjects. Furthermore, designing insoles with multi-layer structure and using different materials such as PLA and silicon in one design could be subject of another examination. Besides all aspects listed above, a quantitative evaluation and validation of good total contact between foot and insole surface are required. Finite element analysis can be implemented to investigate the mechanical properties of insoles during being subjected to distributed loads originating from human body under different conditions.

IV. Conclusion

This study was undertaken to design and produce a custom-made and subject-specific insole and to evaluate the benefits of 3D printing technology besides novel advances in scanning techniques, as well. Returning to the question posed at the beginning of this study, it is now possible to state that the improvement of science and technology could provide effective solutions on production processes of subject specific designs and products. This study presents the main steps in a sequence for design and manufacture of insoles.

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