Application of semi reverse innovative design for a boot’s shoes orthotic for children with club foot

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Abstract. Club foot is one of the foot deformities due to genetic factors, diseases, the condition of pregnant women is too small, or the result of a marriage that has a kinship. For every 1000 normal childbirths, there is usually one birth of a child with a leg like this. Children with this leg shape often have difficulty doing daily activities. In this paper, the prosthetic limbs used by children with clubfoot are very uncomfortable and often cause excessive pain. This paper comprehensively explains the process of designing boots for club sufferers using a semi-reverse innovative design (semi RID) method. The collaboration of 3D replica with Handyscan 700™ is used to get 3D mesh foot models. STl format that is truly precise and accurate. Computer-Aided Design (CAD) with PowerShape 2019i software is used in this paper to get a variety of shoe lasts and insole designs that are truly precise and accurate according to the foot contours of clubfoot children. The results showed the error tolerance geometry was less than 5.0 mm for each dimension.

Keywords: clubfoot, semi RID, 3D replica, 3D mesh, CAD

1. Introduction
Humans in their activities often need tools on their feet for comfort. This tool is useful to protect the sole from sharp objects and avoid trauma when walking. This tool is in the form of sandals and shoes. The development of the current shoe industry was able to be enjoyed well for people who have normal foot conditions. Normal people can choose and look for the shape of shoes according to their wishes. But for some people who are born with abnormalities in their feet, they certainly need a special sandal or shoe design. Leg deformity according to some previous researchers [1-4] consists of several types, such as diabetes; flat foot; metatarsalgia; high heel and clubfoot. According to many works [1,2,5] sufferers of foot deformities such as flat foot and diabetes can be made a special shoe design that adjusts the foot condition of the patient using computer-aided reverse engineering system (CARESystem) technology. With this technology, custom shoes specifically for patients with foot deformities can be realized perfectly and can answer complaints.
from several patients. The success of previous studies [2,6-8] to build a downstream product for custom orthotic footwear for deformity foot patients, the researchers continued in this paper on children with club foot patients (Figure 1).

**Figure 1.** Children of club foot: a) Ubaidillah (4 years old), b) View of right foot, c) View of left foot

**Figure 2.** Previous prosthetic leg products

Clubfoot is an abnormality in the foot caused by an incorrect baby’s foot position while still developing in the womb and causing one leg to be shorter than the other foot (see Figure 1). This makes it difficult for clubfoot patients to choose comfortable and appropriate footwear according to the shape of their feet as Anthony, et al. [8] in adult club foot patients. Club foot [9,10] are congenital or congenital conditions that occur in 1–2 children out of 1000. These conditions involve musculoskeletal disorders in the functioning of joints, ligaments, nerve muscles, and tendons, as well as the spine the characteristic of this patient is that they have shorter right leg lengths and clubfoot shaped, and have two fingers on the patient’s right foot (Figure 1). So far, patients are more likely not to wear normal footwear or existing prosthetic limbs due to economic factors and difficulty in finding shoes that fit the shape of the patient’s feet. The results of the initial discussion conducted by author’s with [8] the patient’s parents were still rare or very difficult to find the shoe industry or specialized orthotic laboratories that we’re able to design and fabricate footwear for patients with deformed feet with club foot type like this because most of this type of industry still uses manual foam box technology in making shoe insoles and shoe last. Important information also obtained by researchers from the patient’s parents, explains that manual prosthetic limbs
(Figure 2) results from the local prosthetic industry turned out to be more expensive, uncomfortable, inaccurate, narrow and often cause patients to suffer injuries due to friction between deformed limbs and artificial limbs.

Obstacles faced by patients like this (Figure 2), can only be overcome by the selection and use of appropriate design and manufacturing technology so that the orthotic shoes produced will be truly precise, accurate and comfortable according to the geometry of the patient’s feet as previously described by some researchers [6-8]. The technology capable of completing solutions in this paper is computer-aided design (CAD) based reverse engineering.

Engineering is the process of designing, manufacturing, assembling, and maintaining products and systems. There are two types of engineering, forward engineering and reverse engineering (RE). Forward engineering is the traditional process of moving from high-level abstractions and logical designs to the physical implementation of a system. RE is also defined as the process of obtaining a geometric CAD model from 3-D points acquired by scanning/digitizing existing parts or products [11]. The process of digitally capturing the physical entities of a component, referred to as reverse engineering (RE), is often defined by researchers with respect to their specific task [11, 12]. Abella et al. [13] described RE as, “the basic concept of producing a part based on an original or physical model without the use of an engineering drawing”. Yau et al. [14] also define the RE, as the “process of retrieving new geometry from a manufactured part by digitizing and modifying an existing CAD model”.

Reverse engineering is now widely used in numerous applications, such as manufacturing, industrial design, and jewellery design and reproduction. For example, when a new car is launched on the market, competing manufacturers may buy one and disassemble it to learn how it was built and how it works. In some situations, such as automotive styling, designers give shape to their ideas by using clay, plaster, wood, or foam rubber, but a CAD model is needed to manufacture the part. As products become more organic in shape, designing in CAD becomes more challenging and there is no guarantee that the CAD representation will replicate the sculpted model exactly by Vines and Fernandes [11]. The previous research by Singh [15] defined RE as a process that refers to modelling an existing physical object to produce a copy of the object, extracting the design concept of an existing model, or re-engineering an existing part or object. RE’s advantage for the industry, in general, is as a computer-aided design (CAD) model based on an object or physical model that already exists and can be used to study how the object is made.

RE technology, also very suitable to be applied in the footwear or orthotic shoe industry, this technology, when collaborated with computer-aided engineering (CAE), will be able to display the optimal design of CAD obtained from foot scanning as a physical object using reliable scanning tools. The results of this scanning are then transformed into a 3D mesh image which is then carried out by the RE process in the CAD into a shoe component in the form of insole and shoe last as was successfully carried out by previous researchers. CARESystem-based RE technology use by [1,2,8] to get appropriate, comfortable, and safe footwear or shoe products for consumers, especially for consumers with foot defects, whether born or due to accidents (diabetes, and club foot) adult. This paper explores the developing orthotic shoe designs in children with club foot from birth. Shoes that are designed consist of two main parts, namely insole and shoe last. To get a shoe design that is truly accurate and precise, a foot scanning process is carried out as a physical model using the 700TM Handyscann. The results of the scan are then carried out by the RE process with the help of CAD until 3D variations of the insole and shoe last patient models are obtained.

2. Material and methods
In this paper, clubfoot patients are 4.5-year-old children with foot deformities from birth (see Figure 1). To facilitate activities, patients from the age of two use prosthetic limbs made by local
orthotic companies (see Figure 2) and this is done because of differences in patient foot length. Amputation is not performed by the patient’s parents because of economic reasons. From Figures 1 and 2, it is seen that the patient can walk pretty well, but the existing prosthetic limb is not able to support the activities of patients who are included in the hyperactive category so that this tool is not optimal even tends to not be used at all by children because it is uncomfortable and often causes pain.

The semi reverse innovative design (Semi RID) method as has been successfully worked out by many works, e.g. [6 – 9], will be carried out in this paper. The physical model that will be scanned is not the real leg of the patient but the prototype of the foot of the 3D replica method (Figure 3). This process is carried out because the child’s condition is too hyperactive, making it difficult for engineers to scan using the Handyscann 700™. To produce a truly precise foot model, a foam box process is carried out using the 3D body replica method (Figure 4). This method is done by making a prototype of the patient’s foot using gypsum material which results can be presented in (Figure 4). This prototype will later be processed scanning.

Figure 3. club foot children’s feet: (a) real physical model; (b) prototype foot 3D body replica results

Figure 4. Stages of the 3D body replica process of the patient's foot with clubfoot

The current research begins with the 3D process of the patient’s foot implant using gypsum material (see Figure 4). These results are used as objects to carry out the scanning process using HandySCAN700. The scanning process in Figure 5a and Figure 5b is needed to virtualize the patient’s profile into a digital form so that it can be processed on a CAD PowerSHape 2019i device. Scanning output in the form of a fit and precise 3D mesh image model can be presented in Figure 5c. This image will later be processed into insole and shoe last. The curve base surface modeling method as described by [7, 8] is also used in this paper to obtain the insole and shoe last orthotic shoe design models. This process is carried out using the Autodesk PowerShape 2019i organic part software and can be presented in Figure 6.
Figure 5. Stages of process scanning using Handyscann 700™

Figure 6. Curve Base Surface Modelling of insole and shoe last for children with club foot.

3. Result and discussion

Clubfoot is a condition of birth defects or congenital that can occur in 1 to 2 babies from every 1000 births per year [8-10] and can be experienced by patients in this paper (see Figure 1), where one of the legs is not normal and has a foot shape that is not the same as a peer. The condition involves musculoskeletal disorders in the function of joints, ligaments, nerve muscles, and tendons, and the spine [10]. Congenital Talipes Equinovarus (CTEV) or club foot is a congenital foot deformity from birth with clubfoot or twisted legs such as sprains or improperly shaped [9,10] even do not grow normally alias deformed (see Figure 1b) with an incomplete number of fingers and shorter growth.

In this paper, the patient is a small child who suffered from club foot conditions from birth. The condition of the right foot is curved backward with only two fingers on the right foot. This foot is shorter than the left foot that looks and functions like a normal child in general (see Figure 1c). To support daily activities, patients are made with prosthetic limbs (see Figure 2) which in reality, prosthetic limbs cannot make a significant contribution to the patient and even tend to make it difficult for the patient when walking or other activities. These constraints make the patient uncomfortable because his right leg is like being pinched on a prosthetic leg and experiencing extreme pain when going to step. After all, there is no pedestal on the inside of the prosthetic limb (Figure 7). It is like a solid object that is only inserted in a pipe. Without a soft footing by the shape
of the patient's leg, it will certainly result in the emergence of pain which results in discomfort when using this prosthetic product. The most practical solution is not to make a prosthetic foot (Figure 2), but a shoe made of insole, shoe last and upper shoe can hold the patient's right leg well.

Complaints felt by patients are also almost the same as patients who have been reported by [8] in adult club foot patients. The RE carried out in this paper begins with the process of scanning the prototype of a patient's foot using the 700™Handyscann scanning tool as previously done by previous researchers [3, 6-9,14]. The results of scanning in the form of 3D foot mesh in STL format. The results of true-bean scans look very similar, precise, and accurate to real foot models and prototype 3D foot replicas from patients. The RE method according to Singh [15], has an advantage in the industrial field that is to create a computer-aided design (CAD) model based on existing physical objects or models and can be used to study how the object is made. Even previous research [2,6,8] proposed the use of Computer Aided Reverse Engineering System (CARESystem) technology to make it easier to acquire design knowledge and creative ideas through reverse innovative design (RID) to obtain insole design variations based on Computer analysis results aided engineering (CAE) and maximized in the manufacturing optimization process using computer-aided manufacturing in CNC machines by [16-18]. In this paper, the CAE stage has not yet been carried out so that it can be said to be a Semi Reverse Innovative Design (Semi RID) as has also been successfully done by Anthony et al. (2019). The output of the Semi-RID in this paper apart from being an insole design model, shoe last and boots also an error of the size variation that has been determined by researchers based on the results of brainstorming with the orthotic shoemaking industry and patient's parents and the results can be seen in Figure 8.

![Figure 7](image1.png)

*Figure 7. The right leg of a patient who uses a prosthetic foot often causes discomfort and excessive pain*

![Figure 8](image2.png)

*Figure 8. 3D CAD model insole, shoe last and model boots shoes orthotic for children with club foot*

The Semi RID output of orthotic shoes produced in this paper was designed using CAD Autodesk PowerSHAPE 2019i software until the insole and shoe last forms were obtained. The stages of developing the latest semiRID method in orthotic shoe insole designs for deformity foot
patients are demonstrated in detail in Figure 6. This stage can be used as a general standard for engineers or other orthotic experts who want to study the design process and manufacturing of orthotic shoes.

The design of boots produced in this paper is orthotic boots which are special footwear to help children with clubfoot type deformity foot as in Figure 1 and Figure 3 in carrying out daily activities and can provide comfort when used and quickly in mounting shoes on the sufferer's feet. This shoe is considered to reduce pain so that it can cause a sense of comfort when used because the shape of the insole, shoe last, and the upper shoe are designed to be accurate, precise, and precise by the shape of the foot and contour of the foot of the patient. These shoes will also be designed not to burden the patient as to when using prosthetic prosthetic devices (see Figures 2 and 7) because they use soft EVA Foam rubber material which will later be processed using a CNC machine that is designed according to the contours of the patient's feet.

The orthotic boots developed in this paper consist of three main parts, namely: insole, last shoe, and upper shoe obtained from the results of the Semi-Reverse Innovative Engineering (RID) process using an accurate and precise scanning tool with an error of less than 0.01 mm followed by the design process of insole and shoe last with PowerSHAPE2019i Computer-Aided Design (CAD) software and will continue to the manufacturing process in CNC machines with the help of software PowerMill 2019 as a Computer Aided Manufacture (CAM) technology.

### Table 1. Error dimension of the left foot of a child suffering from club foot

| Code | Size of a 3D body Replica foot (mm) | Foot size results from the scanning process (mm) | Last shoe size for left foot (mm) | Error shoe last with 3D body replica (mm) | Error shoe last with scanning process (mm) |
|------|-----------------------------------|-----------------------------------------------|----------------------------------|------------------------------------------|------------------------------------------|
| A1   | 147.90                            | 148.20                                        | 169.79                           | 21.89                                    | 21.59                                    |
| B1   | 52.20                             | 52.65                                         | 53.75                            | 1.55                                     | 1.1                                      |
| C1   | 61.90                             | 62.65                                         | 63.55                            | 1.65                                     | 0.9                                      |
| D1   | 37.20                             | 37.54                                         | 38.16                            | 0.96                                     | 0.62                                     |
| E1   | 46.50                             | 46.95                                         | 59.67                            | 3.17                                     | 2.57                                     |
| F1   | 56.50                             | 57.10                                         |                                   |                                          |                                          |

### Table 2. Error dimension of the right foot of a child suffering from club foot

| Code | Size of a 3D body Replica foot (mm) | Foot size results from the scanning process (mm) | Last shoe size for left foot (mm) | Error shoe last with 3D body replica (mm) | Error shoe last with scanning process (mm) |
|------|------------------------------------|-----------------------------------------------|----------------------------------|------------------------------------------|------------------------------------------|
| A2   | 103.80                             | 104.65                                        | 101.41                           | 2.39                                     | 3.24                                     |
| B2   | 71.40                              | 72.01                                         | 72.84                            | 1.44                                     | 0.83                                     |
| C2   | 23.10                              | 23.79                                         | 24.00                            | 0.90                                     | 0.21                                     |
| D2   | 44.70                              | 44.74                                         | 40.73                            | 3.97                                     | 4.01                                     |
| E2   | 41.10                              | 41.49                                         | 36.30                            | 4.80                                     | 5.19                                     |
| F2   | 42.10                              | 42.44                                         |                                   |                                          |                                          |

The results of the insole and shoe last design (Figure 8) were designed by researchers by the shape of the feet with some adjustments after discussions with the last shoe engineer and the boots engineer. Size verification is also done by comparing the difference in size between the
design of the last CAD shoe design with the size of the 3D replica results and the scanning results with the results in Tables 1-2. The design size of the CAD shoe last has a large difference or error due to some adjustments made during the design conducted with a group discussion forum with several parties involved in this research.

Difference in size error between computer aided design (CAD) design with 3D replica results and large scanning results as shown in Table 1-2 is caused by the adjustment process carried out to make shoe last and insole design according to the patient’s foot shape by considering the results of shoes which is comfortable and in accordance with the normal shape of shoes as described by Witana et al. [19]. The difference in error in the comparison of the size of the replica 3D results and the scanning results has a small error and not up to 1 mm, while the size comparison between the results of the replica 3D and the results of scanning with shoe last design that is made has a large error with the largest error can reach 21.89 mm. This large error is due to the process of making shoe last designs that require adjustments to the shape, thus making the error bigger than the error between the replica 3D results with the scanning results. These results after going through a process of discussion between the researcher and the last shoe engineer team and the orthotic shoe insole, it can proceed to the manufacturing stage using a CNC machine.

4. Conclusion
The application of a modern technology care system based on semi RID which was applied in this paper is proven to be effective and efficient in solving problems faced by children with foot deformities with club foot type. This technology can get a set of orthotic boots design consisting of insole and shoe last that is precise and accurate. Deviation of the resulting error between the design and the prototype of the foot gives the average geometric accuracy, mm in the patient’s foot. In the future, the semi RID output will be further developed by researchers of the fabrication process and due diligence of these orthotic boots on patients so that the results of this research can be utilized as much as possible for the orthotic and prosthetic medicine industry as well as in all patients with foot deformities of the club foot type.

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