INNOVATIVE DESIGN OF INSOLE SHOES FOR ORTHOTIC PATIENTS WITH CLUB FOOT OR ANKLE DISPLACEMENT

[1] Ms. Sharmila P [2] Harini G B [3] Jyotsana K [4]Kavithazri G

[1] Associate Professor, Sri Sairam Institute of Technology

[2] [3] [4] Student, Sri Sairam Institute of Technology

Abstract- Clubfoot is a foot abnormality that can be caused by genetic factors, resulting in an irregular foot shape that hinders patients' ability to perform daily activities. One of the main challenges faced by patients with this condition is finding footwear that is both precise and comfortable to wear. This paper addresses the significant number of clubfoot patients in Indonesia and introduces a Reverse Innovative Design (RID) approach, which uses 3D mesh data to accurately capture the surface contours of the clubfoot. Computer-Aided Design (CAD) PowerShape 2019 was employed to generate a range of orthotic ankle-foot insole designs that are tailored to fit the clubfoot patient's foot. The outcome of this study includes three insole designs with a geometric error tolerance of 0.08 mm.

Index Terms— Case type, data type, data page, pega, property, portals, Human gesture recognition, Machine learning, Support vector machine, Random Forest, K-nearest neighbour

I.INTRODUCTION

Clubfoot, also known as club foot, is a congenital or genetic disorder that affects the shape of the foot, causing stiffness in the muscles and tendons on the inside of the foot. This results in shortening of the tendons, which pulls the foot inward. This condition can cause discomfort during daily activities, and it is difficult to prevent or cure early. Although the shoe industry is developing rapidly in terms of design and fabrication, it is still a challenge for individuals with clubfoot to find footwear that fits comfortably. The insole, shoe last, upper shoe, and outsole are the four main components of shoes, and the insole is the part that comes into direct contact with the foot. Therefore, designing and manufacturing insoles that fit the shape and size of the soles of the feet is crucial to ensure the comfort of the shoes. To achieve this, Reverse Engineering (RE) technology on a Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), and Computer Numerical Control/Rapid Prototyping (CNC/RP) basis is needed. This technology is commonly referred to as a Computer-Aided Reverse Engineering System (CARESystem), which has been reported to be successful in creating insoles that fit the shape and size of the soles of the feet in previous studies [7, 10-14]. The shoe last design and manufacturing process can be done manually or by using CARESystem. However, the fabrication process of shoes largely depends on the shoe last's shape, which is an important factor in determining the shoes' quality [5, 8-9].

Figure 1. The shape of the club foot patient's foot

II.RELATED WORK

Reverse engineering (RE) has been studied extensively in product design to create or modify existing products for improved function. However, there have been limited studies focused on using RE to design innovative orthotic shoe soles. In this paper, the authors implement the Curve Base Surface Modeling (CBS_Modeling) strategy using the Handyscan 700TM scanning tool to design shoe insoles for patients with club foot, a type of foot deformity. This strategy was chosen because it can cover various parts of curves, boundaries, and rooms to improve the curve editing process, resulting in a perfectly designed shoe insole surface. The paper begins by describing a 65-year-old patient with club foot, a type of foot deformity. The patient's right foot is twisted inward, making it difficult to walk, while the left foot has a changed bone structure due to being the main foundation when standing. Current manual shoes made by shoe craftsmen in Yogyakarta have shortcomings. The authors use the Semi RID method, which involves creating a physical model of the foot with gypsum that is then scanned using the Handyscan 700TM tool to create a 3D replica of the foot. This process allows the authors to design a 3D CAD insole model and shoe last for patients with club foot. The authors successfully apply CBS-modeling to obtain insole output and shoe lasts for patients with club foot. This method involves designing the shoe insole and last using 3D CAD models, which are then edited based on geometric tolerance to improve their fit. The methodology of the SemiRID orthotic shoe insole design for club foot patients is presented in a flow chart in the paper. The final result is a 3D CAD insole design model with variations based on geometric tolerance. Verification of the shoe design is conducted through a clinical trial with the patient.

Figure 2. Patient *club foot* shape

Figure 3 Footwears

III.METHODOLOGY

The paper presents a novel approach to designing orthotic shoe insoles for patients with club foot deformities using 3D scanning tools and the .STL format. The scanning process involves using HandySCAN700TM and takes approximately 30 minutes. The method differs from a previous study where a 3D prototype of the patient's foot was scanned instead of the actual foot. Club foot is a congenital condition characterized by stiffness in the foot muscles and tendons, leading to inward foot bending. Early detection is possible during pregnancy through ultrasound, but many patients do not seek further care due to limitations. The patient in Figure 2 has abnormalities in both legs, causing discomfort and pain, and making walking difficult. The patient has resorted to modifying their shoes themselves by adding thick cloth to the right foot and altering their shoes, as shown in Figure 2, to carry out daily activities.

The device we have developed is a Counterbalance Support System for individuals with clubfoot. This system is designed to provide improved support and stability for clubfoot patients by utilizing a combination of advanced sensors and data logging technology. The support system is designed to monitor foot pressure and movement, as well as generate variable voltage through piezoelectric sensors.

The data from these sensors is then sent to a DC Buck booster, which stabilizes the ramping voltage gained from the foot pressure. To ensure that the system is always powered, we have implemented a free energy rack and pinion mechanism, which recharges the system hardware. This allows for continuous and uninterrupted use of the device. One of the key features of our system is the ability to export data logs to our server in real-time. This allows for the fabrication of shoes to be improved based on the physical practice of the individual using the system. The data logs are analyzed to predict future supportive design requirements for clubfoot patients. Overall, the Counterbalance Support System is a complex and sophisticated device that is designed to improve the lives of individuals with clubfoot. With its advanced sensors, data logging technology, and energy-efficient design, it provides a reliable and effective solution for those in need of additional support and stability.

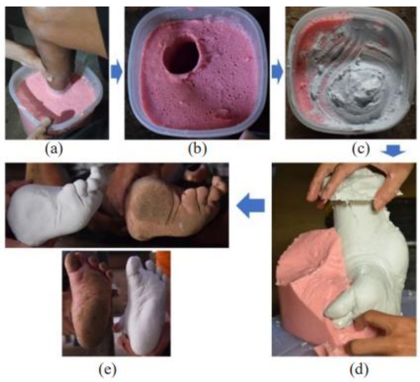


Figure 4 Making of plastic mould

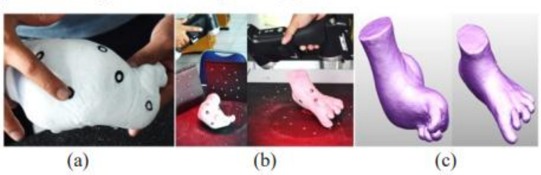


Figure 5 Scanning process

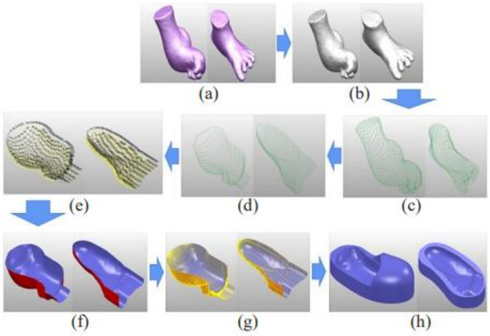


Figure 6 Stages Scanning process

IV.EXISTING MODEL

Shoemakers in the Bantul area of Yogyakarta developed semi-orthotic shoes that somewhat conform to the shape of a patient's foot. However, these shoes still pose difficulties for patients, especially during the rainy season when the flat insoles crafted by the shoemakers cause patients to slip. According to [7, 18, 21], the comfort of a shoe depends not only on its geometry and strength but also on the shape and geometry of the shoe insole. A precisely designed insole that matches the shape of the patient's foot can provide a sense of safety and comfort while walking. To prevent slips during rainy seasons, an insole surface similar to the sole of the foot can be created with protrusions that serve as a foot holder and cushion. Figure 3 displays three types of shoes that have been manufactured and utilized by patients for daily activities.

This paper proposes a solution to address the challenges faced in designing orthotic shoe insoles for club foot patients by utilizing 3D CAD technology and the CARESystem. The technology involves reverse engineering through scanning tools and applying the Reverse Innovative Design (RID) method for optimal design geometry. However, this paper only focuses on the semi reverse innovative design (SemiRID) method up to the stage of orthotic shoe insole design for club foot patients. The SemiRID method uses the curve base surface modeling method (CBS-modeling) to create a 3D model of the patient's orthotic foot and shoe insole. The development stages of the latest SemiRID method are elaborated in Figure 7, which serves as a general standard for engineers and orthotic experts interested in the design process and manufacturing of orthotic shoes.

Figure 7 Flow chart of stages

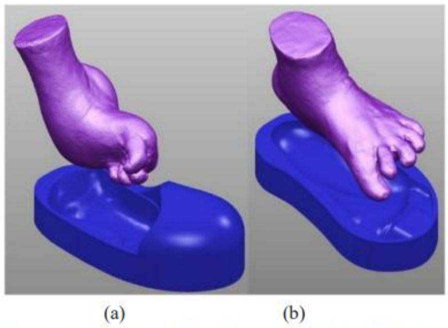


Figure 8. 3D solid insole shoes for patient's foot club foot: (a) right foot insole; (b) left foot insole

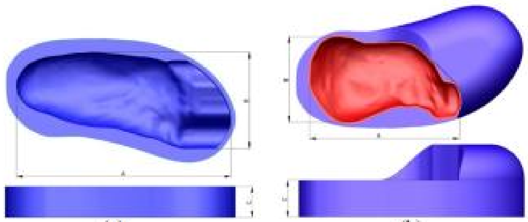
V.PROPOSED DESIGN

The Counter Balance Support system is a highly advanced and sophisticated device that is designed to provide superior support and comfort to individuals with clubfoot. It is equipped with cutting-edge technology that allows for real-time data monitoring and analysis, making it an invaluable tool for the fabrication of custom shoes and orthotics. The device incorporates a number of advanced features, including a free energy rack and pinion mechanism that ensures the system's hardware is always fully charged and ready for use. This innovative energy system is highly efficient, allowing for extended use without the need for frequent recharging. Piezoelectric sensors are also integrated into the system, allowing for the generation of variable voltage that is used for data transmission. These sensors are highly sensitive and can detect even the slightest pressure changes, making them ideal for use in a foot support system.

To ensure the stability of the ramping voltage gained from foot pressure, the device also features a DC Buck booster that helps to stabilize the voltage output. This ensures that the system is always functioning at optimal levels, providing maximum support and comfort to the user. One of the most significant features of the Counter Balance Support system is its ability to export data logs to a central server base in real-time. This data can then be used to improve the fabrication of shoes and orthotics based on the physical practices of the user. This ensures that each individual receives a customized support system that is tailored to their unique needs and requirements. In the future, the system will be able to use real-time server data logs to predict supportive design needs for fabrication. This will allow for even more precise customization and support, making the Counter Balance Support system a truly revolutionary tool in the field of orthotics and prosthetics.

Tabel 1. Variation in geometric tolerance of orthotic shoe insoles for patient with club foot

Geometry Tolerance (mm)	Left Foot Patient Club Foot without Material Added			Right Foot Patient Club Foot without Material Added		
	Dimension (mm)			Dimension (mm)		
	Lenght of ISO (A)	Wide of ISO (B)	High of ISO (C)	Lenght of ISO (A)	Wide of ISO (B)	High of ISO (C)
0.00	224.6	104.30	35.03	179.4	101.00	42.42
0.75	226.0	105.77	35.03	180.9	102.50	42.42
2.00	227.5	107.26	35.03	182.4	104.00	42.42



(a) (b)

Figure 9. Geometry of insole dimension

Tabel 2. Measurment foot of patient with club foot

Number of Measure	The Measure of Actual Foot from Patient with Club Foot		The Measure of 3D Replika Foot from Patient Club Foot		Error	
	Right Foot (mm)	Left Foot (mm)	Right Foot (mm)	Left Foot (mm)	Right Foot (mm)	Left Foot (mm)
1	179.50	224.70	179.40	224.60	0.06	0.09
2	134.50	160.10	134.50	160.00	0.08	0.08
3	155.90	104.40	155.80	104.30	0.07	0.08
4	89.52	81.06	89.45	80.99	0.07	0.07
5	101.10	196.70	101.00	196.60	0.05	0.08
6	84.23	87.47	84.15	87.41	0.08	0.06

VI.FEATURES

The device uses advanced algorithms to analyze data collected from the piezoelectric sensors, allowing for precise and accurate measurement of foot pressure and weight distribution.

This data can be used to optimize the design and function of custom shoes and orthotics, improving overall comfort and support for the user. The Counter Balance Support system is designed to be user-friendly, with intuitive controls and easy-to-read displays.

Users can easily adjust settings and view real-time data feedback, allowing for greater customization and control over their support system. The device is made from high-quality materials and components, ensuring durability and longevity even with frequent use.

This makes it a cost-effective and practical choice for individuals with clubfoot who require ongoing support and care. In addition to its use in orthotics and prosthetics, the Counter Balance Support system has potential applications in sports medicine and physical therapy. By providing precise measurement of foot pressure and weight distribution, it can help athletes and patients recovering from injuries to optimize their movements and prevent further injury.

The system is fully customizable, with a range of settings and options that can be tailored to meet the specific needs of each user. This flexibility ensures that the device can provide optimal support and comfort for individuals with a wide range of foot conditions and deformities. The Counter Balance Support system is designed to be used in conjunction with other orthotic and prosthetic devices, such as AFO shoes and ankle braces. By providing precise and accurate support, it can help these devices function more effectively and provide greater overall benefit to the user.

VII.PROCESS INVOLVED

According to [10], the design process of 3D modeling for foot components begins with wireframe, surface, and solid modeling. Although the RE results in .stl format can easily be processed, it requires CAD software that can perform effective surface editing to achieve perfect results. CAD PowerShape 2019i is one of the software that is capable of solving design issues on organic part components, as successfully demonstrated by [7]. To create the insole based on the 3D mesh scan of the foot, CBS_Modeling (Figure 6) is used. The 3D mesh foot is first converted into a solid 3D form before being used as the basis for insole production. As shown in Figure 6, the solid 3D results are utilized to obtain a complete wireframe model, and the surface is formed based on the foot scan shape, resulting in an accurate and appropriate shape. The surface produced is further refined by reconstructing the curve arising from the surface formation results. This reconstructed result is then used to create the full insole according to the patient's foot shape and the desired shoe form. The measurement of geometric dimensions for club foot patients in this paper was carried out by measuring two types of patients' feet. The foot measurements are based on [19-20], and six foot measurements are used as baselines: foot length, arch length, heel to fifth toe, foot width, bimalleolar width, and height at 50% foot length. The measurement results are presented in Table 1, using mitutojo caliper dial with a tolerance of 0.02mm. Table 2 presents the comparison of measuring dimensions for each foot measurement, with an accuracy of 0.068 mm for the left foot and 0.077 mm for the right foot. These results indicate that the exact tolerance is less than 0.1 mm and greater than 0.08 mm (66%) compared to the research carried out by [7]. However, these results can still serve as a reference for insole manufacturing, shoe last, and orthotic shoes in the shoe industry.

The article presents the application of SemiRID technology to address the challenges faced by club foot patients in obtaining orthotic shoe insoles that are accurately shaped according to the patient's foot. The 3D modeling design process using Kaki software, coupled with the CBS_Modeling technique, was used to create a wireframe and surface model of the foot, which was then refined to produce an accurate insole. The manufacturing process for the insole was carried out using machining parameters recommended in previous studies, resulting in the production of ankle foot orthotic insoles (AFO insole) for club foot patients. The article concludes that the SemiRID technology, combined with the CARESystem, has the potential to design and manufacture customized AFO shoes products for patients with various foot deformities. Future research will focus on manufacturing shoe lasts for club foot patients using CNC machines to produce orthotic ankle foot shoes (AFO shoes). The accuracy of the SemiRID method was confirmed through visual inspection and measurement confirmation, with an average geometric accuracy of 0.08 mm for each foot measurement. The authors hope that this technology will improve the design and manufacturing process of customized orthotic shoes, benefiting patients and the shoe industry as a whole.

VIII.CONCLUSION

In conclusion, the Counter Balance Support system is a remarkable device that offers a range of advanced features and benefits to individuals with clubfoot and other foot conditions. With its cutting-edge technology, real-time data monitoring, and precise measurement capabilities, it has the potential to revolutionize the field of orthotics and prosthetics. Its flexibility and customizable features ensure that it can be tailored to meet the unique needs of each user, providing optimal support and comfort. Whether used in sports medicine, physical therapy, or everyday life, the Counter Balance Support system offers a practical and effective solution for individuals seeking to improve their foot health and overall well-being.

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