DESIGN AND FABRICATION OF AN ORTHOTIC INSOLE BY USING KINECT® XBOX GAMING SENSOR SCANNER AND 3D PRINTER

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A thesis submitted in fulfillment of the requirement for the award of the Degree of Master of Mechanical Engineering

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JUNE, 2015

ABSTRACT

This project is to design and fabricate of an orthotic insole by using Kinect® XBOX 360 gaming sensor scanner and 3D printer. In order to fulfill medical requirement, it was invented to help medical field to overcome their problem of high 3D scanner cost, handcrafted fabrication, inventory problem, and long fabrication time. In term of process, author had proven the potential of Kinect® XBOX 360 gaming sensor as a 3D scanner, CAD as the method of the orthotic insole design, and Additive Manufacturing as the fabrication technique. In literature review, author had made deeply research in conventional orthotic insole fabrication which begins with plaster casting of the patient's foot, followed by handcrafted orthotic insole design until the fabrication process. Author also had made visitation to Rehabilitation Hospital Cheras for data procurement regarding orthotic insole design and fabrication processes. In analytical phase, author had done calculation for the accuracy of the Kinect® XBOX 360 gaming sensor and the results shows Kinect® XBOX 360 device is capable of producing 3D reconstructed geometry with the maximum and minimum error of 3.78% (2.78mm) and 1.74% (0.46mm) respectively. Besides, the higher the scanned model dimension, the less error can be achieved based on the complexity of the scanned model. The orthotic insole design process had been done by using Autodesk Meshmixer 2.6 and Solidworks 2014 software with Rehabilitation Hospital Cheras as the main reference in design process. Fabrication of the orthotic insole had been made by using Flashforge 3D printer and Filaflex (TPE) filament as the material of the orthotic insole. For validation of the fabricated orthotic insole, author had conducted form, fit, and function test. As the result, the fabricated insole design produced 0.29mm RMS error compared to designed dimension. Functionality of the orthotic insole had been justified by conducting the foot pressure scan and the results had proven the fabricated insole is capable of reducing the pressure especially in metatarsal area. Furthermore, the fabricated insole was fit very well on the candidate's foot.

ABSTRAK

Projek ini adalah untuk mereka bentuk dan menghasilkan pelapik dalam kasut ortotik dengan menggunakan pengimbas permainan Kinect® XBOX 360 dan pencetak 3D. Dalam usaha untuk memenuhi keperluan perubatan, ia dicipta untuk membantu bidang perubatan untuk mengatasi masalah mereka antaranya kos pengimbas 3D yang tinggi, fabrikasi buatan tangan, masalah inventori, dan masa fabrikasi yang panjang. Dari segi keseluruhan proses, penulis telah membuktikan potensi sensor permainan Kinect® XBOX 360 sebagai pengimbas 3D, CAD sebagai kaedah reka bentuk ortotik insole dan pencetak 3D sebagai teknik fabrikasi. Dalam kajian literatur, penulis telah membuat kajian mendalam dalam teknik fabrikasi pelapik kaki ortotik konvensional yang bermula dengan acuan plaster kaki pesakit, disusuli dengan reka bentuk pelapik kaki ortotik buatan tangan sehingga proses fabrikasinya yang juga buatan tangan. Pengarang juga telah membuat lawatan ke Hospital Rehabilitasi Cheras bagi perolehan data mengenai reka bentuk pelapik kaki ortotik dan proses fabrikasinya. Dalam fasa analisis, penulis telah melakukan pengiraan untuk ketepatan sensor permainan Kinect® XBOX 360 dan keputusan menunjukkan peranti Kinect® XBOX 360 mampu menghasilkan binaan semula geometri 3D dengan ralat maksimum 3.78% (2.78mm) dan ralat minimum 1.74 % (0.46mm). Selain itu, lebih tinggi dimensi model yang diimbas, ralat yang kurang boleh dicapai berdasarkan kepada kerumitan model yang diimbas. Proses reka bentuk pelapik kaki ortotik telah dilakukan dengan menggunakan perisian Autodesk Meshmixer 2.6 dan Solidworks 2014 dengan menjadikan Hospital Rehabilitasi Cheras sebagai panduan utama. Fabrikasi pelapaik kaki ortotik telah dibuat dengan menggunakan pencetak 3D jenama Flashforge dan Filaflex (TPE) filamen sebagai bahan pelapik kaki tersebut. Untuk validasi pelapik kaki yang telah dibina, penulis telah menjalankan ujian bentuk, kesesuaian, dan fungsi. Hasilnya, pelapik kaki yg dibina menghasilkan ralat dimensi sebanyak 0.29mm berbanding dimensi model yang direka. Fungsi pelapik kaki ortotik diuji dengan menjalankan imbasan tekanan kaki dan keputusan telah membuktikan ianya berupaya mengurangkan tekanan pada bahagian tertentu pada tapak kaki. Tambahan pula, bentuk pelapik kaki ortotik yang dihasilkan amat padan dan sesuai dengan kaki calon bagi ujian padanan.

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CHAPTER I

INTRODUCTION

1.1 Background of Study

In the little more than a year since its commercial release, the Kinect® XBOX 360 Gaming Sensor has enjoyed great success in the hands of researchers and hobbyists seeking to use the economical 3D camera for more than the gaming platform it was intended to be. A primary factor in this success has been its low price point compared to other competing technologies. In addition to this, the broad user base has contributed expertise for a wide range of applications, from robotic mapping to augmented reality. Besides that, with the rise of Additive Manufacturing, commonly known as 3D printing, there exists the exciting capability to print a scaled replica of any physical object on the same order of size as a person. While the primary uses of such technology have mainly been as an interesting novelty to reconstruct faces or statues, the wide range of users and easy accessibility shows that this technology has powerful applications to academic research.

This project will present a specific procedure of designing insole using Kinect® XBOX 360 Gaming Sensor as the foot scanner and fabricate using 3D printing. The implementation presented makes use of existing tools to create an economical, straightforward procedure which can suit medical field.

Additive Manufacturing is a new technology introduced in the medical field of producing medical devices compared with other engineering field that already implements the Additive Manufacturing technology long time ago. Nowadays, various researches have been reported on implementing Additive Manufacturing technology in the medical field. There are some example applications of Additive Manufacturing in medical field such as medical instrumentation design, tissue engineering (implantation), mechanical bone replication, anthropology, forensic, prosthetic and orthotic. For prosthetics and orthotics, Additive Manufacturing technology has proven to be beneficial to the patients as the production of certain support devices which can help patients improve their comfort and stability. The device was designed based on patient anatomy and the foot problems characteristic. Usually, patient has their own specific size or special need cause by the foot problem or genetic. With the help of Additive Manufacturing technology would be easier to produce orthotics devices according to the specific size of the patient with a reasonable price.

The conventional method on getting the patient foot geometry is by plastering, molding and scanning. 3D scanner is the best way to get the overall foot geometry because of time less consuming and better accuracy. The latest 3D scanner design nowadays comes with high technology features using full axial laser scan which is highly expensive. Kinect® XBOX 360 Gaming Sensor is a line of motion sensing input devices designed by Microsoft for XBOX 360 and XBOX One video game consoles and Windows PCs. It consists of a horizontal bar connected to a small base with a motorized pivot and designed to be positioned lengthwise above or below the video display. The device features an RGB camera, depth sensor and multi-array microphone running proprietary software, which provides full-body 3D motion capture, facial recognition and voice recognition capabilities shows in Figure 1.1.

Figure 1.1: Kinect® XBOX 360 Gaming Sensor (Wikipedia, 2014)

This project will be conducted using Kinect® XBOX 360 Gaming Sensor as the scanner used to scan patient foot in order to get the overall foot geometry and the geometry will be converted into CAD format for custom insoles design using CAD software. The CAD files will be converted into .STL format for fabrication using 3D printer. This proposed method will be much cheaper compared to other conventional method such as plastering and molding. This method also perhaps can help poor people to have better treatment for their sore feet without spending more on money.

1.2 Problem Statement

Most of the population will experience foot problems at some point during their life's journey. The foot bears the entire weight of the body and function as our foundation. Some foot problems can be difficult to recognize. Patient need to consult with a medical professional for diagnosis and it will cost a lot of money for the treatment and procedure. One of the treatments for orthotic foot problems is to custom made an orthotic insole for the patient.

An orthotics insole is helpful in various ways. It helps to restore an ability to walk, run, and jump by reducing pain and swelling, and it also helps to increase the stability of unstable joints and provide better arch support. Custom made foot orthotics can be used to treat many conditions that affect the entire body, such as lower back or hip pain, shin splints, Morton's neuroma, corns or calluses, knee pain, Achilles tendonitis, claw or hammer toes, high arch or flat feet, lower limb muscle pain, plantar fasciitis, bunions and diabetes. It also eases problems in other parts of the body, such as the back and hips. The entire foot problem that related to the orthotics is shown in the Figure 1.1 below.

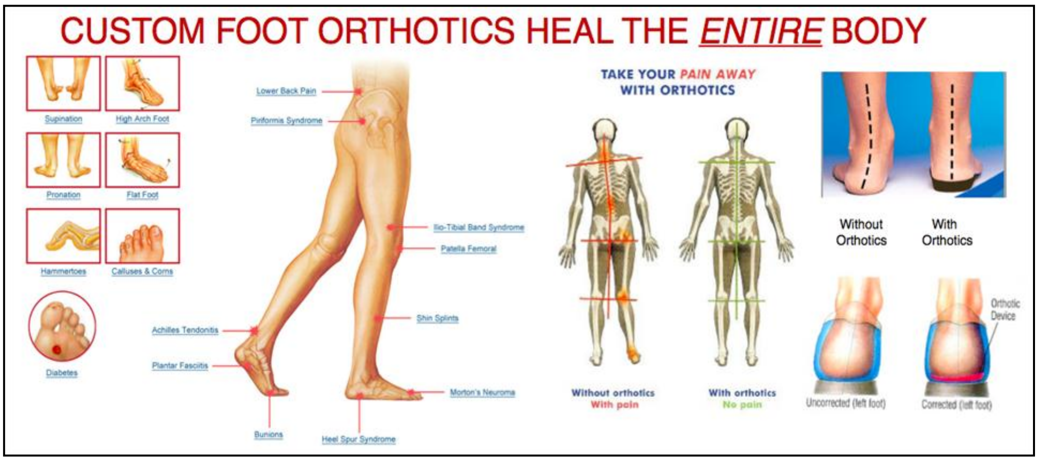

Figure 1.2: Type of foot problem related to Orthotics (Jenn, 2009).

Most of the hospitals are still using the traditional method for custom made insole which is using plaster of paris and mold. This kind of method requires a high skilled worker and the plaster and mold are not reusable. It will contribute to the inventory cost whereby the hospitals need to keep all the patient foot geometry in the form of plaster and mold in their storage. If hospitals use 3D scanner like Magnetic Resonance Images (MRI) or Computed Tomography (CT) scan, patient foot geometry data will be stored in the hospital data base via computer system. In this case, the inventory cost can be reduced. But the cost for full MRI or CT scan system is totally expensive. Well established hospitals afford to invest but some other hospitals are lack of budget for investment and they prefer the traditional method rather than using Computer Integrated System (CIS).

For hospital that already using high technology scanner like MRI and CT scan, the problem return back to the patient whereby they are not afford to pay for the treatment, procedure, diagnose and medications. Many people not afford to have medical card, medical insurance and other medical support. With this project perhaps can give benefit to both side hospital or medical field and poor patient where economical element is the first priority in this project.

1.3 Objective

The main objectives of this project are:

i. To utilize of Kinect® XBOX 360 Gaming Sensor as a 3D scanner for foot geometry scanning.
ii. To manipulate the scanned foot geometry from the Kinect® XBOX 360 device for orthotic insole design using CAD software.
iii. To explore the feasibility of the orthotics insole fabrication using Additive Manufacturing Technology.

1.4 Scope of Study

The scope of this project subjected to several matters such as:

i. Kinect® XBOX 360 as the 3D foot scanning device.
ii. Software that been use to operate the Kinect® XBOX 360 device are:
    - Kinect® for Windows SDK Version 1.8.
    - Kinect® for Windows Developer Toolkit Version 1.8 (Kinect® Fusion Explorer).
iii. Utilize CAD software which is Autodesk Meshmixer 2014 and Solidworks 2014 for orthotic insole design process.
iv. Make use of Flashforge Fused Deposition Modeling (FDM) Machine to fabricate the orthotic insole product.
v. Filaflex (TPE) filament as the material for the orthotic insole.

1.5 Significant of Study

With this method proposed, the cost for poor people to get the better treatment for their orthotics problem can be reduced since the scanning process not involved any high technology devices like MRI Scanner, 3D Optical Digitizing System, CT scan and any other expensive 3D scanner devices available in the market. For the insole fabrication, 3D printer such as Fuse Deposition Modeling are widely use because of the low cost and fast fabrication process compared to other conventional technic like plaster of paris and mold, which required high human skill level on fabrication the insole and longer time needed on trimming and finishing the finished insole product.

With the implementation of this method also can give benefit not only for poor patient, it also can give highly benefit to medical field as well. For instant, hospital can lower their investment rather than invest on high technology device like MRI and CT scan. This method only needs Kinect® XBOX 360 Gaming Sensor, high performance computer, and 3D printer. Besides that, this method can save much time compared to other conventional method like plastering and molding.

1.6 Gantt Chart Master's Project 1

GANTT CHART MASTER PROJECT 1
DESIGN AND FABRICATION OF AN ORTHOTIC INSOLES BY USING KINECT® XBOX GAMING SENSOR SCANNER AND 3D PRINTER

Topic	Sub-Topic	Description	September	October				November				December		
			w3	w4	w5	w6	w7	w8	w9	w10	w11	w12	w13	w14
			28/9/2014	9/10/2014	12/10/2014	19/10/2014	26/10/2014	9/11/2014	16/11/2014	23/11/2014	30/11/2014	7/12/2014	14/12/2014	21/12/2014
Meeting with supervisor	Project Title Discussion													
	Proposal Form Submission													
	1.1 Background of Study													
	1.2 Problem Statement													
	1.3 Objective													
	1.4 Scope of Study													
	1.5 Significant of Project													
	1.6 Gantt Chart	Master Project 1												
		Master Project 2												
Literature Review	2.1 Introduction													
	2.2 Foot Orthoses													
	2.3 Selection of Insole Materials													
	2.4 Customized Orthoses Insole	Foot Geometry Structure												
		Orthoses Insole Design												
		Othoses Insole Fabrication												
	2.5 Kinect® XBOX 360													
Methodology	3.1 Introduction													
	3.2 Project Flow Chart													
	3.3 Project K-Chart													
	3.4 3D Foot Scanning Process	Scanning Process												
		Geometry Validation												
	3.5 Orthoses Insole Design Process	Eggert Design Method												
	3.6 Orthoses Insole Fabrications Process	Fused Deposition Modeling												
		Design Validation												
Report Preparation														
Report Submission	Supervisor	PM Dr. Mustaffa b. Ibrahim												
	Evaluation Panel	Dr. Ng Chuan Huat												
		PM Dr. Erween bin Abd Rahim												
Presentation	Hikmah Room 17, UTHM Library	12.30 PM - 1.00 PM												

Reference:
- To be done
- Done

1.7 Gantt Chart Master's Project 2

GANTT CHART MASTER PROJECT 2
DESIGN AND FABRICATION OF AN ORTHOTIC INSOLES BY USING KINECT® XBOX GAMING SENSOR SCANNER AND 3D PRINTER

Topic	Sub-Topic	Description	March					April			May					Jun	
			w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12	w13	w14	w15
			1/3/2015	8/3/2015	15/3/2015	22/3/2015	29/3/2015	5/4/2015	12/4/2015	26/4/2015	3/5/2015	10/5/2015	17/5/2015	24/5/2015	31/5/2015	7/6/2015	14/6/2015
Literature Review	2.6 Rehabilitation Hospital Cheras Visitation																
Result and Dicussion	4.1 Preliminary Scan	Accuracy Validation															
	4.2 Actual Foot Scanning Process	Geometry Enhancement															
	4.3 Orthoses Insole Design Process	Unwanted Geometry Removal															
		Surface Smoothness															
		Mesh Size Simplification															
		Mesh to Surface Model Conversion															
		Bottom Foot Subtraction															
		Offset Cut															
		Foot Arch Preservaton															
		Sharp Edges Removal															
	4.4 Orthoses Insole Fabrication Process	Flashforge 3D Printer															
		Filaflex (TPE) Filament															
	4.5 Design Validation	Form, Fit, and Function Test															
		Foot Pressure Scan															
Report Preparation																	
Report Submission	Supervisor	PM Dr. Mustaffa b. Ibrahim															
	Evaluation Panel	Dr. Ng Chuan Huat															
		PM Dr. Erween bin Abd Rahim															
Presentation	Exploration Room 13, UTHM Library	11.00 AM - 11.30 AM															

Reference:
- To be done
- Done

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The project literature review will begins with the study of foot orthoses. All the insole type will be discussed in this chapter. Then, followed by insole material that usually been used in fabrication process. Next would be the custom insole processes which begin with foot geometry structure. Foot geometry imaging structure can be divided into two which is plaster based and 3D digital foot scanning. This is where author want to implement the use of Kinect® XBOX 360 Gaming Sensor as the scanning device for 3D digital foot geometry capture, how Kinect® works and followed by software that integrated the Kinect® XBOX 360 Gaming Sensor with the computer. After the 3D geometry structure, next would be the smoothing process of the scanned foot geometry. Software than can enhanced the scanning result would be discussed like Meshlab and Meshmixer. After the foot geometry had been enhanced, the foot geometry would be used in orthoses insole design process by using any available CAD software. Finally, the Fuse Deposition Modeling (FDM) machine would be used for fabricating the designed orthotic insole.

2.2 Foot Orthoses

Taken from the Greek ''ortho'', meaning ''straight'', an orthosis is a device that is applied externally and is used to improve quality of movement. The orthosis aims to correct biomechanical and postural inaccuracies, thus improving function. Orthoses can be applied to many parts of the body, mainly to the limbs such as knee–ankle–foot orthoses (KAFO) and upper extremities. This project will concentrate on foot orthoses as these are the most prevalent orthotic devices and can be prescribed for a number of reasons such as to relieve pressure or pain in the foot, as a treatment to reduce the risk of ulceration for diabetic patients and to correct biomechanical inefficiencies and deformities.

A foot orthotic insole is a correctional insert, placed within the shoe in the form of an insole. Foot orthotic is a device that is placed in a person's shoe to reduce or eliminate pathological stresses to the foot or other portions of the kinetic chain including stresses caused by muscular–skeletal deformities and an inability to absorb shock. Orthotics and shoe inserts are often prescribed for sporting applications in an attempt to achieve correct skeletal alignment, thus reducing the risk of overuse injury due to poor biomechanics. Orthotics can be prescribed in an attempt to minimize muscle work. If an orthotic intervention supports a more economical movement pattern then it is fair to assume that stabilizing muscles will have to work less than when inefficient movements are used.

Orthotics can be classified in many different ways and these methods include their rigidities, production methods and applications. Orthotics classified due to their physical rigidity can be soft, semi-rigid or rigid devices. Rigid orthosis decreases forefoot and rear foot pain in subjects with early onset of rheumatoid arthritis (RA). The rigid devices also decrease the level of foot deformity in rheumatoid arthritis with hallux valgus. It is a common belief among podiatrists that a correctly fitting rigid device has no need for impact attenuation due to the correct biomechanical alignment of the skeletal structure. However, there is also contrasting opinions that suggest impact absorption should be a feature of sporting orthotics, due to the large forces experienced at the foot during physical activity, which can be up to five times body weight.

In terms of their manufacturing methods, there are three basic types of foot orthoses:

I. **Prefabricated**

These are mass produced and can be bought off the shelf and they typically provide general arch support or cushioning to areas of the foot without any specific personalized features and are the cheapest to purchase.

II. **Customized**

A customized orthoses is typically a modified prefabricated component. Often these can be produced through a modular design such as the addition of a metatarsal pad to relieve pressure in a specific area, or the introduction of a heel lift for the treatment of leg-length discrepancies. These features can be added to a polypropylene off-the-shelf shell. A cover is then applied to the whole device for comfort, usually either a low-density foam or leather material.

III. **Custom-molded**

An orthotic manufactured from a cast or mold of the patient’s foot. These often provide the best-fitting orthotics and give the best results. A custom-molded orthoses is bespoke to the user.

These types can be further categorized into accommodative or functional orthoses. An accommodative, or total contact device, will accommodate and protect a rigid foot or a specific deformity without correction, whereas a functional device provides joint stability, controls motion and corrects the function of the foot. The mold taken from the foot is often adapted to enhance alterations made to the final device, for example taking material off a positive cast will increase the arch height of the orthotic.

There are many types of foot orthotic available and these can be prescribed and used for a number of different purposes. The required use of an orthotic insole will fall into one of three main categories. These are then subdivided into further groups, shown in Figure 2.1. Orthotics used for sports, these are most commonly manufactured for running, other sporting examples include insoles for court sports such as basketball. Orthoses are also prescribed for medical purposes such as the prevention of sores for diabetic patients and also the treatment of rheumatoid arthritis by realigning foot deformities. The final subsection is comfort orthotics and these are designed for dress shoes and can be shaped into a slim design to fit into narrow shoes. Currently there is orthotics available for sports, however these do not offer specificity to movements experienced in the chosen sport and so an improved assessment and prescription method is required.

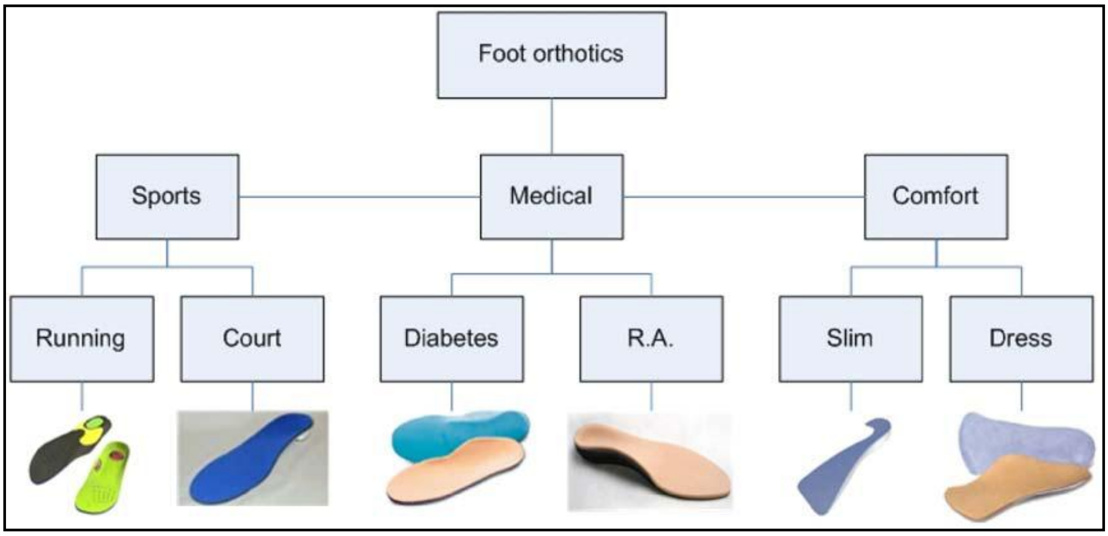

Figure 2.1: Classification of foot orthotics (Crabtree, et al.,2009).

2.3 Selection of Insole Materials

There are numerous methods for the fabrication of foot orthoses which depend on the material chosen. As mentioned there are a number of classifications for the devices such as rigidity and function and the physical properties of the orthotic materials contribute to these characteristics. While there are contradictions over classification methods, there is a general agreement between professionals with regard to the important physical characteristics within orthotic fabrication. These include their response to temperature, elasticity, hardness, density, durability, flexibility, compressibility and resilience. Density and hardness are of particular interest as it is these attributes that affect the impact attenuation of the device and a high density material will have little cushioning and so will provide a rigid, often controlling structure whereas a material of low density will absorb shock. The hardness of the material reflects its resistance to indentation, thus a hard material will not absorb the shock. Although the first step has little to do with a physician's prescription or biomechanical exam, the entire success of the orthotic may well depend on the patient's weight, shoe style, and lifestyle. Figure 2.2 shows the flow chart on how the insole material selection process is conducted.

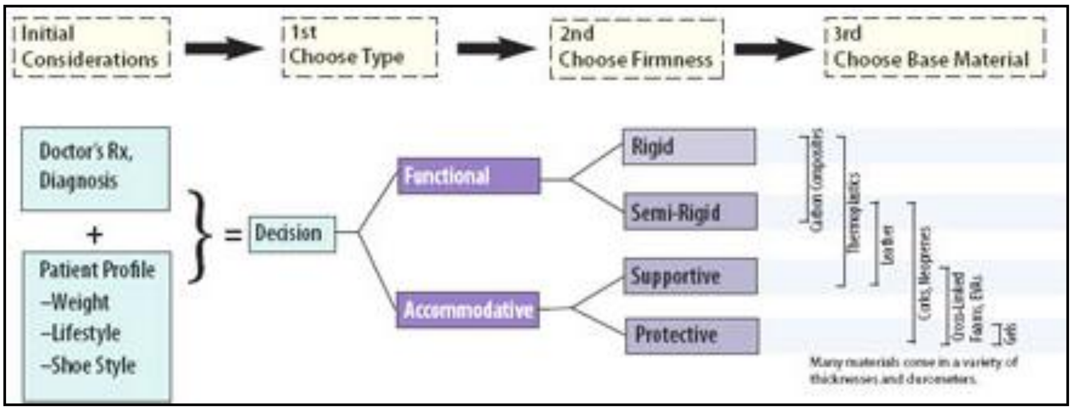

Figure 2.2: Foot orthotics insole material selection flow chart (Kennedy, 2008).

In general, foot orthotics fall into one of two broad categories which are functional or accommodative. Functional orthotics seek to control the subtalar joint (STJ) and foot biomechanics, while accommodative orthotics minimize changes to foot function while providing relief and/or protection to specific areas of the foot. Functional foot orthotics is usually made from thinner, firmer materials. Subortholen, polypropylene, copolymer, and the carbon graphite composites are all good choices for functional devices. Usually they will incorporate a deep heel cup and a good medial longitudinal arch. Among other diagnoses, functional devices are used to treat pronation, plantar fascitis, and heel spur syndrome. The materials commonly used for orthotic manufacture are:

I. **Thermoplastics**

   Materials that soften when heated and harden when cooled. There are several groups of plastics used in the orthotic industry, and they are sold in many different thicknesses, strengths, and colors.

II. **Polypropylene**

It is a plastic material with a low specific gravity and high stiffness. This combination of light weight and high strength makes it ideal for manufacturing rigid foot orthotics although any notch or groove on the finished shell can create a stress point that may eventually crack.

III. Subortholen Family

Officially known as high-molecular-weight, high-density polyethylene (HMW-HDPE), Subortholen is a wax-like, inert, flexible, and tough polymer. These characteristics ensure a high melt strength and deep draw without thinning. It is also easily cold-formed; i.e., hammered, allowing for adjustments after the heating and vacuum process.

IV. Acrylic

Rohadur, Polydur, and Plexidur are some of the more common trade names for this class of material. Made from methyl methacrylate polymers, these were among the first of the man-made (synthetic) materials used for rigid orthotics. They were prone to cracking. The search for alternatives took on urgency when it was discovered that the Rohadur production process was carcinogenic.

V. Composite Carbon Fibers

Combining acrylic plastic with carbon fibers creates a rigid sheet material. Known by various trade names such as Carboplast, Graphite, and the TL-series, the "carbons" are good for thin, functional orthotics. They are a little more difficult to work with, requiring a higher softening temperature, faster vacuuming, and complete accuracy during the "pull," as they do not re-work easily.

VI. Cork

This natural material can be combined with rubber binders to create an excellent thermo-formable sheet. Thermocork comes in many weights and thicknesses and vacuums well to provide a firm but forgiving orthotic, which is easily adjusted with a sanding wheel.

VII. Leather

This was the original material used for "arch supports." Shoemakers took sole leather and wet-molded it to casts. These devices typically had high medial flanges to support the middle foot, and relatively low heel cups. Leather laminates are still used today when patients want good support but cannot tolerate firmer plastics. Their bulk and weight usually necessitates an extra-depth shoe, work boot, or sneaker.

VIII. Polyethylene Foams

This is a very broad category of materials that are in widespread use. These closed-cell foams are ideal for total-contact, pressure-reducing orthotics although some are subject to compression with continued wear.

2.4 Customized Orthoses Insole

Orthotic is a medical field associated with the use of an external device to support or correct foot function of the body. Foot orthoses liner tool is used to correct footwear biomechanics abnormal or irregular when walking. This is an external device used to alter or adjust the structural or functional characteristics neuromuscoskeletal system. Orthoses goal is to improve the function of redistributing pressure from the body in a controlled manner to protect and provide assistance to parts of the body. Requirements for foot orthoses arise from biomechanical foot disease, congenital defect, sports injuries, and diabetes.

The fabrication process for custom foot orthoses insole consist of three processes which the first process is foot geometric structure. Foot geometric can be divided into two categories which are plastered based technique and 3D digital scanning. The second process is orthoses insole design and also can be divided into two categories which are traditional insole design and computer aided insole design. The last process is orthoses insole fabrication. For insole fabrication, there are several method can be choose such as handmade or handcraft, machining and additive manufacturing. In this case study, Additive manufacturing are selected for insole fabrication and the method that had been chosen is Fused Deposition Modeling.

2.4.1 Foot Geometry Structure

When capturing the geometry of foot for production of custom foot orthoses, the majority of practitioners take a negative cast just as it has been done for the past 50 years using plaster strips to form a non-weight bearing negative cast of the foot. Capturing foot geometry can be classified into two categories which are the plaster based technique and 3D digital foot scanning. For plaster based technique, the conventional methods of capturing foot geometry are Plaster of Paris, Plaster Slipper, and Bio-Foam Impression discussed as follow.

a) Plaster of Paris

The use of plaster of paris is a robust technique and it has been widely used to obtain foot geometric structure. This technique is a manual process to identify foot structures where it requires high skills and sufficient training to get a consistent and accurate geometry as shown in Figure 2.3. The steps involved in this process are:

I. The patient is seated with knees pointing forward position. Foot ends need to be slightly lowered in line with the patient neutral position.

II. The gauze fabric would moisten the inside layer of plaster of paris and been wrapped on the patient's foot, covering the ankle and heel of the foot then proceed towards metatarsal bandage and clearance was added to ease of removing the unwanted material.

III. The next step is using other gauze fabric to wrap the patient's foot again, but now wrapping started at the front of the patient toe. By using the back of hand, gauze line will be rubbed pointing outward direction of the foot in order to get a smooth surface and to ensure gauze bandage surface is in contact with the surface of the foot.

IV. Place the plaster of paris on the surface of the gauze fabric and leave it for almost 30 minutes for drying process. Make sure the position is in the same state.

V. The last step is to remove the mold that has been dried from the foot. In this step make sure the mold is taken out with the same shape of the foot and then the mold would be checked and assessed for the accuracy.

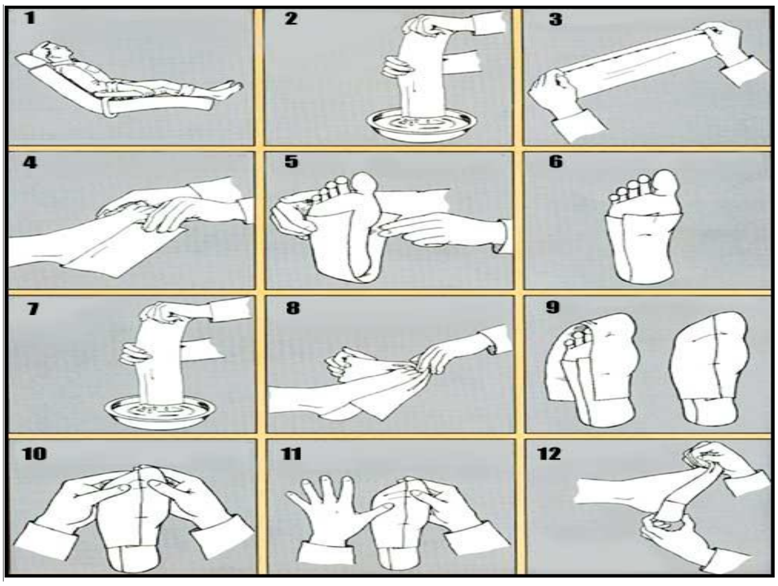

Figure 2.3: Process of obtaining the patient's geometrical foot structure by using plaster of paris (Kennedy, 2004).

b) Plaster Slipper

This technique is less of tidiness compared to plaster of paris technique, but the process is much faster than plaster of paris. In this technique, the stocking material can easily absorb resin and drying effect is more quickly as shown in Figure 2.4. The resin can absorb quickly, as well as subtracting the mold prepared time and also reduce the labor cost. The steps involved in this process are:

I. Make sure the position of the patient's leg in a comfortable position with the knees straight forward.

II. A transparent plastic bag will be wrapped around the legs before plaster slipper socks worn on the patient's foot. Plastic bags used to prevent resin stick to the patient's foot.

III. In the next step, plaster slipper socks were pulled from the patient’s foot and soaked the foot in the water. Then, put the clip on the foot to ensure the stockings with plantar flexion and foot contour is always connected.

IV. The next step is to hold the foot in a neutral position or desired in order to dry or hardened the resin.

V. The last step is to carefully remove the mold from the patient's leg.

Figure 2.4: Casting feet using plastic slipper (Sneyd, 2013).

c) Bio-Foam Impression

A foam box is used to capture the foot impression as shown in Figure 2.5. This semi-weight-bearing process is used when a patient is unable to lie down for a plaster cast due to a medical condition or injury, or if the patient does not have fore foot to rear foot misalignment. Foam box impressions are often used for creating accommodative inserts for patients with severe arthritis or diabetes. The process is quick with minimal to no mess. Some practitioners use a foam box impression with a weight-bearing technique where the patient is standing during the process. However, most medical professionals do not recommend this technique since it can flatten the medial, lateral, and transverse arches of the foot, creating an inaccurate impression. The steps involved in this process are as follow:

I. The patient is seated with the foot in a neutral position.
II. The foot is gently placed on the foam surface in the middle of the foam block.
III. The medical professional gently and slowly guides and presses the foot into the foam with equal pressure on the heel and the ball of the foot while keeping the patient's lower leg straight up and down.
IV. The patient presses their foot into about two inches of the foam, without grasping the foam with their toes.
V. The patient's foot is then removed, leaving an impression of the foot in the foam.

Figure 2.5: Casting feet using bio foam box impression (Kramer, 2014).

Currently, a very small percentage of practitioners are using 3D digital technology to capture the foot geometry. However, there are several technologies that allow digital imaging and the most promising of which is optical scanning. Comparison between optical scanning to plaster casting, showed an overwhelming benefit to the use of optical scanners. For plaster casting technique including preparation, casting, prescription writing and cleanup took approximately 11 minutes but only 2 minutes required for an optical scanner. Cost comparisons also weighed heavily on the side of scanner.

Given the great cost and efficiency benefits, the number of digital imagers being used is likely to grow rapidly over the years. Prediction can be made that within five to ten years from now, most practitioners will capture the image digitally. The digital imager or scanner should allow the practitioner to prescribe an orthoses that allows for all prescription variables, including medial and lateral heel skives, inversion, sweet spots, and medical flanges. The best way to look at this is that the digital imager should in no way limit the prescription options that would be available when using plaster. There are many different methods for capturing the 3D measurements of a physical part and thus, many different types of scanners.

a) 3D Laser Scanner

3D Laser Scanning or 3D Laser Scanners can generally be categorized into three main categories which are laser triangulation, time of flight and phase shift. These laser scanning techniques are typically used independently but can also be used in combination to create a more versatile scanning system as shown in Figure 2.6. There are also numerous other laser scanning technologies that are hybrids and combinations of other 3D scanning technologies such as accordion fringe interferometry or conoscopic holography.

I. Laser triangulation

Laser triangulation is accomplished by projecting a laser line or point onto an object and then capturing its reflection with a sensor located at a known distance from the laser's source. The resulting reflection angle can be interpreted to yield 3D measurements of the part.

II. Time of flight laser scanners

Time of flight laser scanners emit a pulse of laser light that is reflected off of the object to be scanned. The resulting reflection is detected with a sensor and the time that elapses between emission and detection yields the distance to the object since the speed of the laser light is precisely known.

III. Phase shift laser scanners

Phase shift laser scanners work by comparing the phase shift in the reflected laser light to a standard phase, which is also captured for comparison. This is similar to time of flight detection except that the phase of the reflected laser light further refines the distance detection, similar to the vernier scale on a caliper.

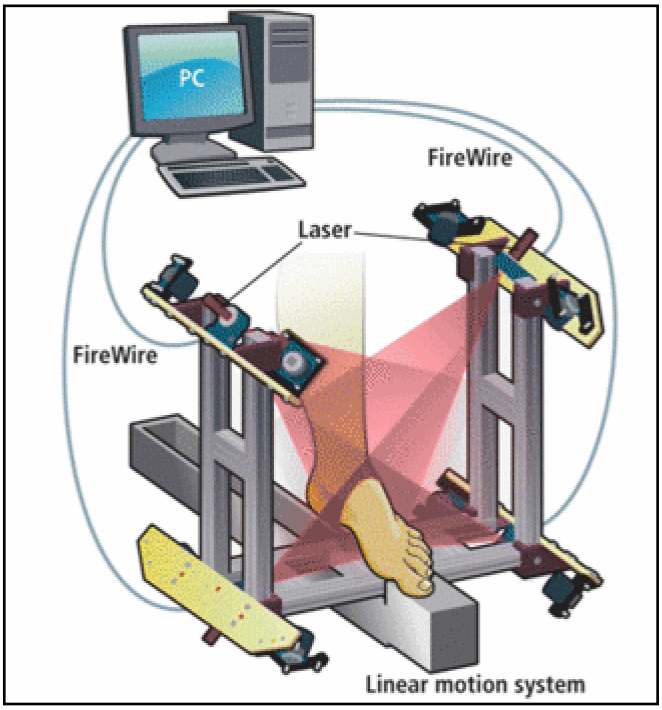

Figure 2.6: 3D foot scan by using laser scan triangulation method (Richmond, 2009).

b) Structured Light Scanner

White Light Scanning (structured light scanning) is used to describe a wide range of 3D scanning devices. The basic technique is to project a known pattern of white light and CCD cameras as a sensor to capture images of the object with the patterns projected on it as shown in Figure 2.7. In order to capture 3D information, multiple patterns or multiple sensors can be used. If multiple patterns are projected, the software uses referencing and the change in shape of the known pattern to interpret 3D measurements. If multiple sensors are used the software uses the known pattern and referencing between image angles to determine the 3D measurements.

White light scanners are usually tripod-mounted, where a fringe pattern is generated by scanner's projector and is laid over an area at a time over the scan object. Within the scanning time, the fringe is modified in width and phase and the 3D scanner extracts the 3D coordinates from calculating the returned patterns. The term “white light” comes from the fact that the bulb is a white light generator. Recently, blue LED light is being used as a replacement so the term may need to accommodate blue light scanning. A more general description is called structured light scanning, which covers all colors.

Figure 2.7: An object scan by using white light scanner (Tong, 2011).

c) Photogrammetry

Photogrammetry is a technology based on standard photography and projective geometry and was originally used to digitize large objects such as buildings, oil rigs and warehouses. The principle behind photogrammetry is to take multiple images of objects and manually or automatically reference common points in each photograph. Points can be added automatically or manually to create 3D measurements of the desired elements of the part. Photogrammetry is often used with other 3D scanning technology to provide full surface measurements of parts and to retain tight tolerances over large areas. Figure 2.8 shows an example of 3D scan using photogrammetry method where the blue boxes indicate the position of the camera.

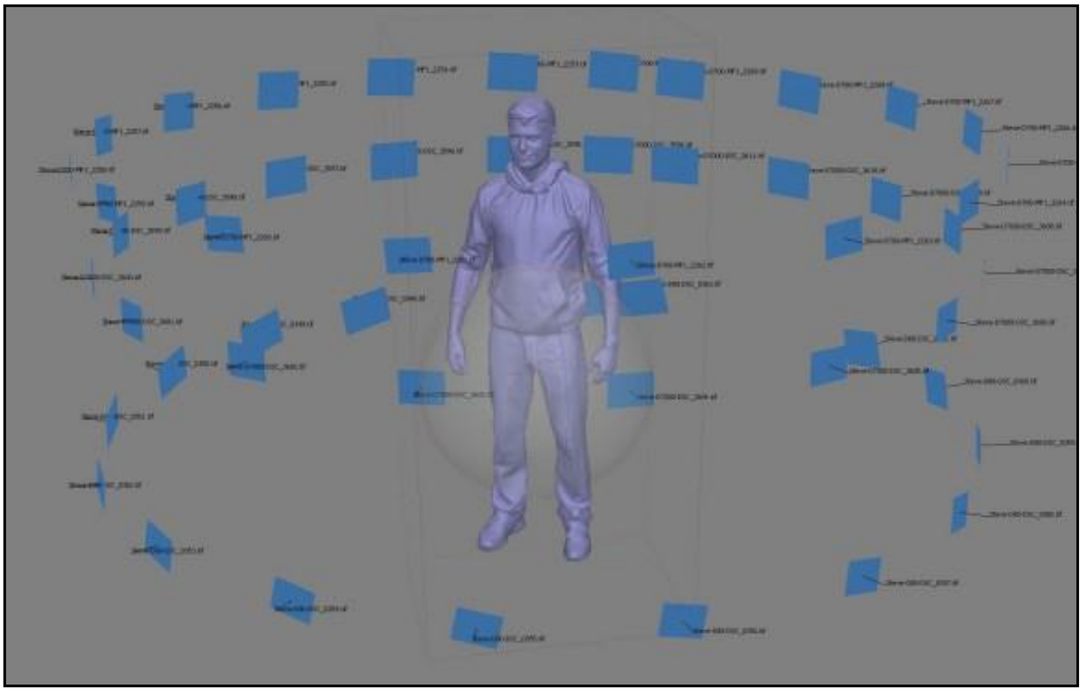

Figure 2.8: Full body scan using photogrammetry method (Florquin, 2010).

d) CT or MRI Scanner

3D CT or MRI scans are obtained by stacking a series of CT (computed tomography) or MRI (Magnetic Resonance Imaging) scans on each other in software. This is typically done by precisely controlling the steps in between each sectional CT or MRI scan. The resultant data is a 3D model of the object and contains all of its physical measurements. This technology was originally developed for the medical field, as you may know, but is now growing into manufacturing and industrial applications as well.

MRI is a diagnostic scanning technique based on the principles of magnetic resonance. MRI uses no radioactivity or X-rays which is why it's often described as being such a safe modality. The human body is predominately made of water molecules which contain hydrogen protons. When patient is placed in a strong magnetic field the tiny magnetic fields of the hydrogen protons, which normally move around randomly, are aligned to the magnetic field. A brief radio pulse is rapidly switched on and off. This makes the protons' magnetic fields spin round in unison and emit a weak radio signal. By altering the timing of the radio wave applications it's possible to produce images which show up the various body tissues as shades of grey. The contrast on MRI images is very good and the operator can change the parameters to give images that demonstrate the anatomy of the area and also, in many cases, highlight common disease processes. Figure 2.9 shows a patient having an MRI scan.

Figure 2.9: A patient having an MRI scans (Todd & Edmonds, 2010).

A CT scanner is a special kind of X-ray machine. Instead of producing an image (radiograph) from a single direction, the X-ray source is rotated around the patient and acquiring a cross-sectional image (tomogram) from many angles as shown in Figure 2.10. The X-rays from the beams are detected after they've passed through the body and their strength is measured. Beams that have passed through less dense tissue such as the lungs will be stronger, whereas beams that have been absorbed by denser tissue such as bone will be weaker. A computer can use this information to work out the relative density of the tissues examined. The computer processes the results, displaying them as a two-dimensional picture shown on a monitor.

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