BIO CAD MODELING OF CUSTOMIZED EXOSKELETON FOR REHABILITATION OF MYOPATHIES AND ITS FABRICATION USING ADDITIVE MANUFACTURING

G.ARUMAIKKANNU[a]

Department of Manufacturing Engineering,
Anna University, Chennai-600025, India

P.BALAMURUGAN[b]

Department of Manufacturing Engineering,
Anna University, Chennai-600025, India

[a]arumai@annauniv.edu ,[b]mechbala2009@gmail.com,

ABSTRACT: Additive Manufacturing (AM) is a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies [1]. This paper proposes the benefits of additive manufacturing (AM) within prosthetic device manufacturing, especially for the customization of exoskeleton for Muscular Disorder patients. This work starts with the patient's CT scan data of the lower limb in DICOM format. This is exported into MIMICS software to stack 2D scan data into 3D model. Then 3D models are imported in to 3matic software, for modeling a Top and Bottom braces with suitable scaling factor, and creates a connecting structural arrangements in proper dimensions. Wall thickness analysis has been carried out in 3matic software, to find out the standard deviation of top and bottom braces, was found to be 1.65mm.The data from clinical gait analysis were determined as, a 100kg system, the torque required for knee extension during stair climbing was 140 Nm and 50 Nm during walking [2]. Through this promising technique the actual process of prosthesis design in rehabilitation technology is improved by applying reverse engineering and additive manufacturing technologies. The outcome of this work is a personalized prosthesis building procedure that should allow an exoskeleton best fit and avoid the numerous iterations done until a proper fit is obtained with traditional methods.

Keywords— Additive Manufacturing, Lower limb Exoskeleton, Prosthetic, Rehabilitation, Bio CAD modeling. Muscular Disorder

INTRODUCTION

In 1960s, the research groups in United States and Yugoslavia began their research in powered exoskeleton [3]. Though, the researchers was initially focused on advancing technologies to amplify the abilities of able-bodied humans, often for military purposes, however Yugoslavia was intent on developing assistive technologies for physically challenged persons. Even though the differences in the proposed use, these two fields face many of the same challenges and constraints, particularly those related to interfacing closely and portability to a human operator. In general, the term "exoskeleton" is used to describe a device that augments the performance of an able-bodied wearer. Occasionally, still, the term "exoskeleton" is also used to describe certain assistive devices, particularly when they encompass the majority of the lower limbs. [4].

Proc. of the Intl. Conf. on Progress in Additive Manufacturing
Edited by Chua Chee Kai, Yeong Wai Yee, Tan Ming Jen and Liu Erjia

ISBN: 978-981-09-0446-3 :: doi:10.3850/978-981-09-0446-3_130

In general one-third of surviving patients from myopathies do not regain independent walking ability and those ambulatory, walk in a typical asymmetric manner. Rehabilitation therapies are critical to recovery, and therefore vast research is ongoing in this field. The rehabilitation process toward retrieval of meaningful mobility can be divided into three phases : (a) the bedbound patient is equipped into the chair as soon as possible, (b) improvement of gait (i.e., training of free walking if possible) restoration of gait, and (c) Traditional rehabilitation therapies are very labor intensive especially for gait rehabilitation, frequently requiring more than three therapists together to assist manually, the legs and torso of the patient to perform physical activity. This point executes a huge economic burden to any country's health care system thus controlling its clinical acceptance. All these factors stimulate innovation in the domain of rehabilitation [5] in such a way that it becomes more affordable and available for more patients and for a longer period of time. Robotics for rehabilitation treatment is an emerging field which is expected to grow as a solution to automate training. Robotic rehabilitation can (i) replace the physical training effort of a therapist, allowing more intensive repetitive motions (ii) delivering therapy at a reasonable cost, and (iii) assess quantitatively the level of motor recovery by measuring force and movement patterns.

Incorporating the use of exoskeletal robotics in treating myopathy patients who possess motor function disorders is pertinent in making successful in the medical field and whose motor functionality has been compromised by recovery process. Neurological injuries like myopathies or muscular disorder cannot be fully recovered by physical therapists. The important aspect of future technology will be a continual development of combination of biomedical and mechanical technology [6].Sarah Webster et al. (2013) [7] designed and fabricated an Assistive Device for Emma Lavelle. She was diagnosed with arthrogryposis multiplex congenita (AMC), a non-progressive condition that causes stiff joints and very underdeveloped muscles. Emma was born with her legs folded up by her ears and her shoulders turned in. Emma was introduced to the Wilmington Robotic Exoskeleton (WREX), Wilmington Robotic Exoskeleton (WREX), an assistive device made of hinged metal bars and resistance bands. They preferred an Additive Manufacturing process to fabricate a WREX device, because it is easy to build complex human shapes with good finishes. This paper focused on customized exoskeleton for lowerlimb rehabilitation by using Bio CAD modeling with additive manufacturing technology.

KNEE JOINT KINETICS AND KINEMATICS

Powered exoskeleton design is achieved due to the kinetics and kinematics of the knee joint. The data initiating from winter (1991) [8], averaged over 19 unimpaired adults, walking over ground with a natural cadence (105 steps/minute) and a slow cadence (87 steps/minute). The average walking speeds at these cadences were 4:8 km/h and 3:6 km/h respectively (Figure1). Joint angle, moment of force, instantaneous power and their corresponding standard deviation curves are plotted against percentage of stride. The moment of force and instantaneous power are normalized with respect to body mass. The two major functions of the knee are providing limb stability during stance and a large mobility (about 60-70°) during swing in order to achieve sufficient clearance of the foot with the ground. The knee is slightly flexed prior to initial contact. Power absorption takes place as the knee flexes while counteracting gravity. From mid to terminal stance the knee is in single support phase and extended, while the body is progressed over the stationary foot. The knee joint moment grows negatively. During pre-swing the limb is being pushed off, while the body weight is transferred to the other limb. A knee flexion occurs prior to toe-off and this is continued during initial swing. Since this knee flexion occurs on average under a small extension moment

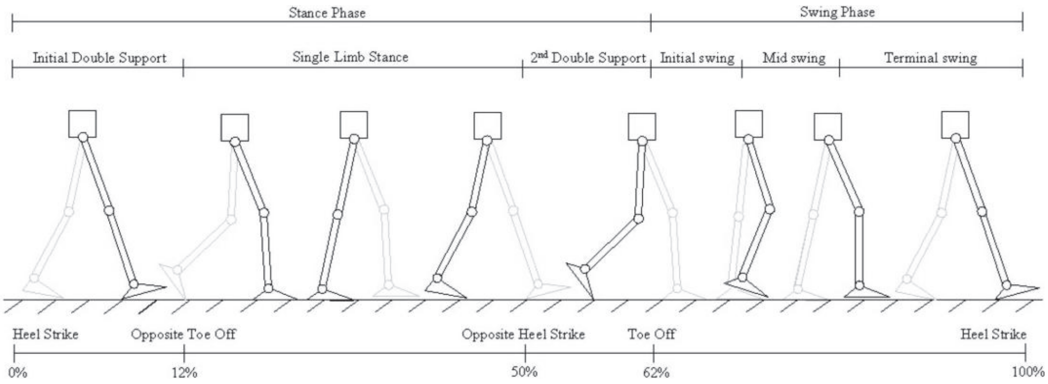
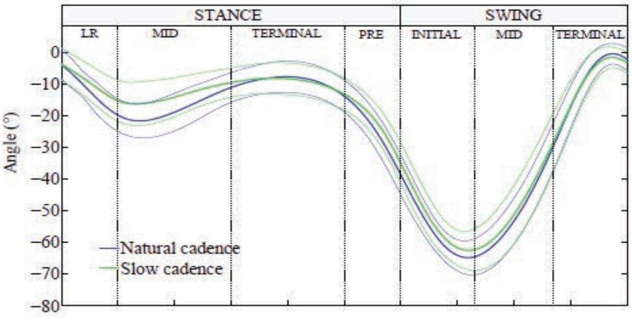


Figure. 1. Human walking gait through one cycle, beginning and ending at heel strike. Percentages showing contact events are given at their approximate location in the cycle [8]

power is absorbed. From the onset of initial swing (toe-off) on the knee joint moment is close to zero. Maximum flexion is reached and from mid-swing, the knee is extended to timely reach a quasi-stretched leg configuration prior to the next initial contact. Maximum extension occurs slightly before initial contact of the next stride and is accompanied by a small flexion moment resulting in power absorption. It is important to note that the joint moments are the net result of all internal forces. In the absence of any voluntary muscle force, also called passive elastic joint moment is observed due to tendons and ligaments. The influence is considerable near full extension of the knee (up to about -10Nm) and at large flexion angles (up to about 5Nm at 90°) [9]. The interpreting gait analysis data are giving guidelines for the design and control of a powered exoskeleton (Figure 2).

The knee DOF were actuated, while the hip and ankle joint was designed to be passive. Data from clinical gait analysis were evaluated to determine the joint torques for the actuated DOF. For a 100 kg system, the torque required for knee extension during stair climbing was 140 Nm and 50 Nm during walking [9]. Based on these analysis, muscle energy activity has been identified at walking condition and Degree of freedom (flexion and extension) of knee joint has been considered for modeling an exoskeleton.



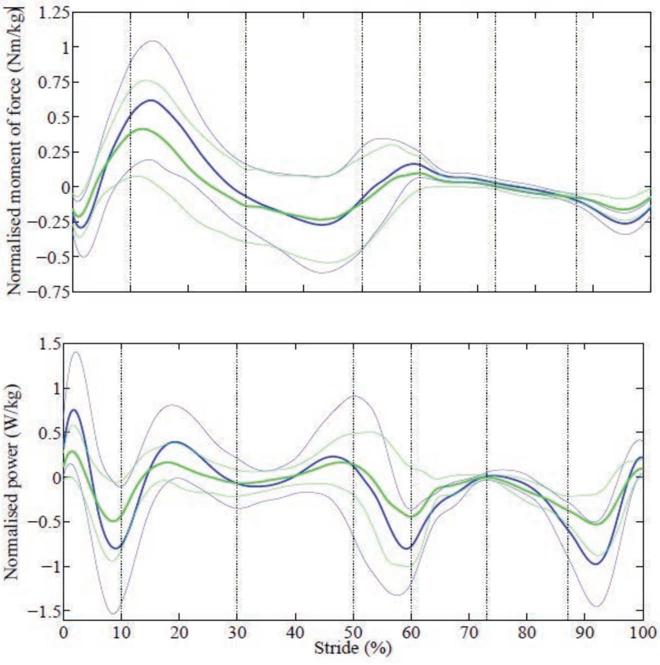


Figure 2. Averaged gait analysis data of the human knee joint: angle, normalized moment of force and normalized power with [-σ, +σ] confidence bounds as a function of stride percentage at natural (blue) and slow (green) cadence [10].

MODELING OF CUSTOMIZED EXOSKELETON STRUCTURE

The modeling of exoskeleton suit are carried out by using Bio CAD modeling software (Mimics & 3 Matic software)(Figure 3).Reverse engineering techniques are used for developing a structure of exoskeleton. Because the anotomy of Human lower limb is having a very complicated shape, the dimensions of the structures are obtained from the patients CT scan in DICOM format.Advanced 320 slices CT scanner is used for taking the image. Max. slice thickness for CT scan is 1mm, it can lead to higher accuracy of solid model and avoid reconstructing a slices.After that slices of the DICOM data were imported in to MIMICS software.The slices are stacked together and converted in to solid model by using 2D segmentation and 3D region growing techniques.To extract the soft tissue (muscles) from the hard tissue (bones), appropriate threshold value of muscles has been developed and used for modeling. Select a particular region (knee) of lowerlimb based on the requirement (no of slices) of corresponding dimensions.A mask has been generated for corresponding solid model. After that 3D digital model is imported in to 3 – Matic module for modeling a exoskeleton with connecting structures.Boolean operation is used to create a top and bottom brace structure with adequate provision for sensors placement. Then smoothening operation is performed on the edges and surfaces of braces for removing sharp corners. Figure 4 (a) shows the design model of knee exoskeleton. This model will be fabricated by AM techniques.

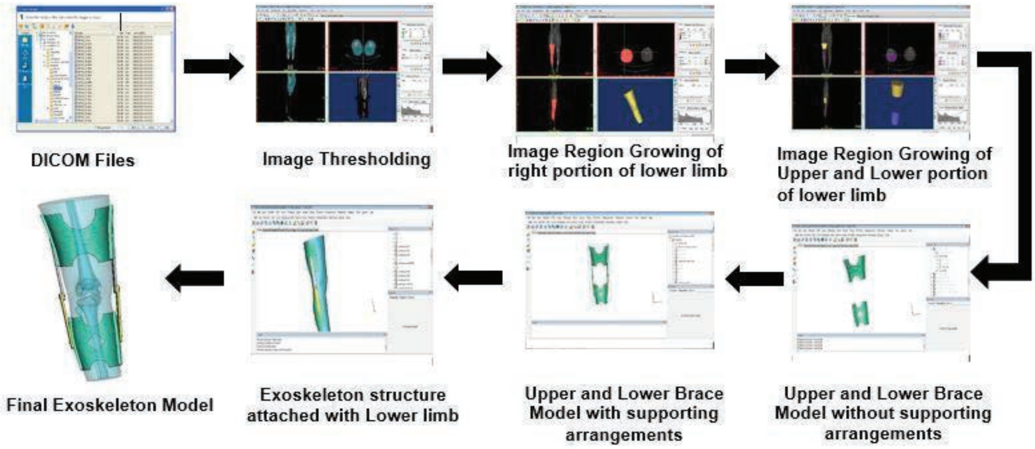


Figure 3. Modeling sequence of knee exoskeleton

Figure 4 a) 3D Model of Braces Integrated with connecting structure

Figure 4 b) Wall thickness analysis of braces integrated with connecting structure

Table 1. Analysis statistics of Top and Bottom braces

Analysis Parameters	Max wall thickness of Top and Bottom Braces		
Minimum-Maximum	0.0000 – 10.0000 mm		
Type	Q1	Median	Q3
Analysis Statistics	4.0076mm	5.0533mm	6.0857mm
Mean – Standard Deviation	5.2293 ± 1.6960		

Wall thickness analysis to find out the thickness varation throughout the structure is performed on the Top and Bottom braces using 3 – Matic software..The analysis statistics is represented in Table 1 and analysis model is represented in Figure 4(b)

CONCLUSION

In this work, customized exoskeleton is targeting a specific pathology which will benefit patients with muscular disorders. A biomechanical analysis has been made in order to determine the common characteristics, so that the patient will benefit from the exoskeleton (weakness, balance control, Lowerlimb mobility control) [2]. It provides better conditions to develop a standard gait next to the physiological one. One important aspect of patient comfort may be achieved by using the reliable technique of Bio CAD modeling with additive manufacturing for the purpose of customization.

ACKNOWLEDGMENT

The authors would like to thank DST-NHHID for MIMICS, 3-MATIC softwares.

REFERENCES

[1] ASTM F2792-10.Standard Terminology for Additive Manufacturing Technologies, copyright ASTM International,100 Barr Harbor Drive, West Conshohocken, PA 19428. www.astm.org.

[2] Riener, R., Lunen burger, L., Jezernik, S., Anderschitz, M., Colombo, G., and Dietz, V. "Patient-cooperative strategies for robot-aided treadmill training: First experimental results", IEEE Transactions on Neural Systems and Rehabilitation Engineering 13(3):380-394, 2005.

[3] Heinlein, R. A. Starship Troopers. New York: Putnam, 1959

[4] Aaron M. D. & Hugh Herr, "Lower Extremity Exoskeletons and Active Orthoses: Challenges and State-of-the-Art", IEEE Transactions on Robotics, vol.24, No.1, February 2008

[5] Iñaki, D., Jorge, J.G. & Emilio, S., "Lower-Limb Robotic Rehabilitation: Literature Review and Challenges", Journal of Robotics, Volume 2011 (2011), Article ID 759764, 11 pages

[6] Gelderblom, G. J.,Wilt, M.D., Cremers, G., & Rensma, A., "Rehabilitation robotics in robotics for healthcare; a roadmap study for the European Commission", in Proceedings of the IEEE International Conference on Rehabilitation Robotics, (ICORR '09), pp. 834–838, Kyoto, Japan, June 2009

[7] Sarah, A., & Webster, "A custom 3D printed version of the Wilmington Robotic Exoskeleton (WREX) empowers little Emma to use her arms despite arthrogryposis", Additive Manufacturing: A custom solution for the medical industry, April 2013

[8] Riener, R., & Edrich, T., "Identification of passive elastic joint moments in the lower extremities", Journal of Biomechanics 32(5):539-544, 1999.

[9] Riener, R., Lunenburger, L., Jezernik, S., Anderschitz, M., Colombo, G., and Dietz, V. Patient-cooperative strategies for robot-aided treadmill training: First experimental results. IEEE Transactions on Neural Systems and Rehabilitation Engineering 13(3):380_394, 2005

[10] Winter, D., "The biomechanics and motor control of human gait: normal, elderly and pathological", University of Waterloo Press, second edition, 1991.