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Design of customized additive manufactured exoskeleton for functional rehabilitation in patients with myopathies

P. Balamurugan, C.Bala Manikandan, B. Dhinesh

Department of Mechanical Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamilnadu, India

Abstract

Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. In this paper proposes a benefits of additive manufacturing (AM) within prosthetic device manufacturing, especially for the customization of exoskeleton for Muscular Disorder patients. This work starts with patient's CT scan data of lower limb in DICOM format is exported into MIMICS software to stack 2D scan data into 3D model. Then 3D models are imported in to 3matic software, to modeling a Top and Bottom braces with suitable scaling factor, and create 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 is valued as 1.65mm.The clinical gait analysis data's were evaluated and determined, a 100 kg system, the torque required for knee extension during stair climbing was 140 Nm and 50 Nm during walking. The weight of the leg exoskeleton suit will be reduced by using ABS material, for part fabrication and Pneumatic Muscle Actuator (PMA) will be adopted for actuating a knee exoskeleton. 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.

1. Introduction

In 1960s, research groups in United States and Yugoslavia itself began the 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 the latter 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].
This paper focuses on lower-limb rehabilitation, because one-third of surviving patients from myopathies do not regain independent walking ability and those ambulatory, walk in a typical asymmetric manner [5]. There are many research is ongoing on the field of Rehabilitation therapies. The rehabilitation process toward retrieval a meaningful mobility can be divided into three phases [5]: (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.

Corresponding author: P.Balamurugan
Email Id: Mechbala2009@gmail.com

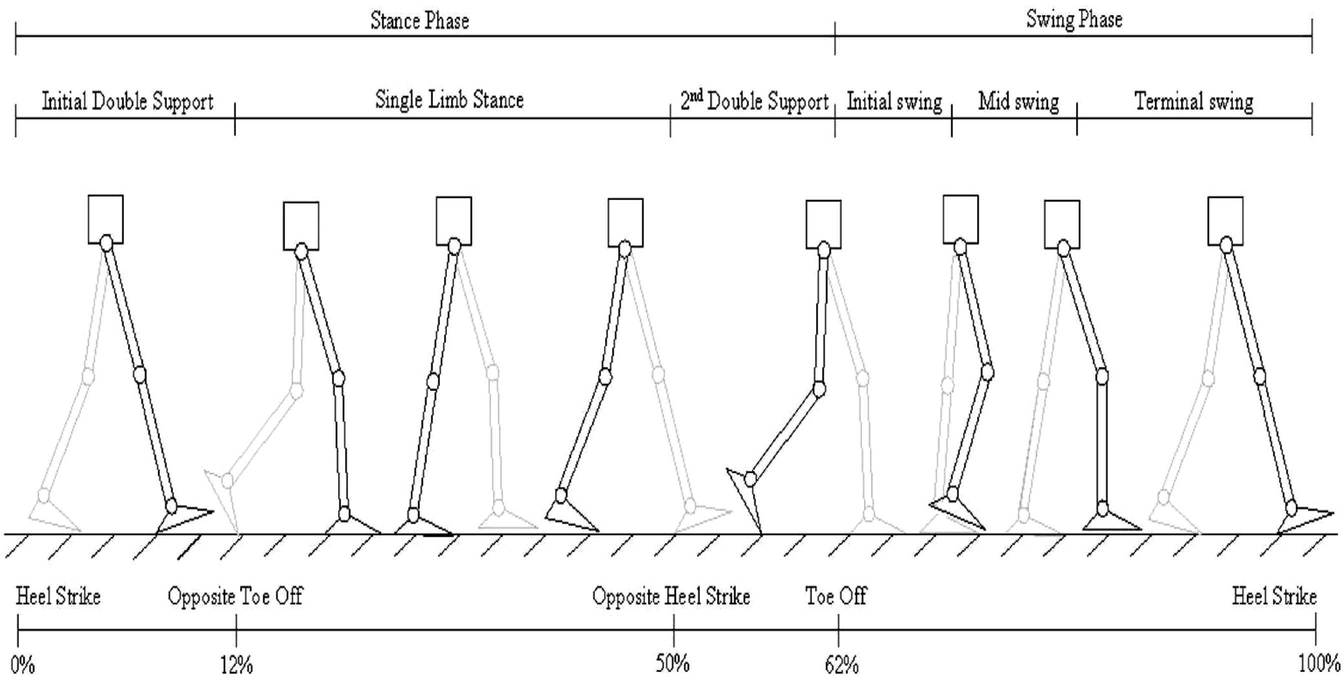
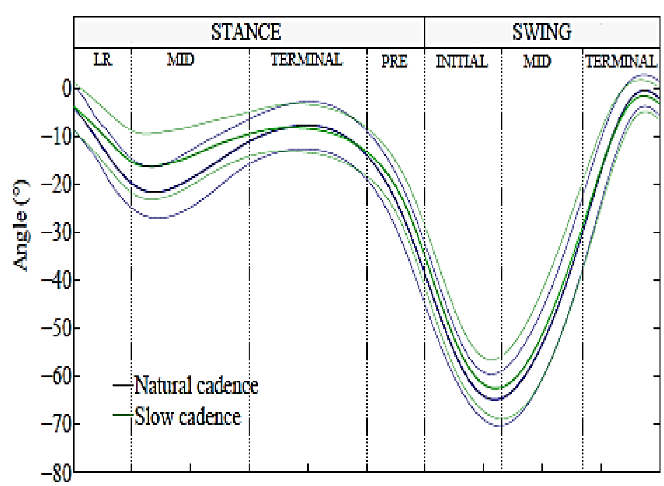


Figure. 1. Human walking gait through one cycle, beginning and ending at heel strike. Percentages showing contact events are given at their approximate location in the cycle [8]

All these factors stimulate innovation in the domain of rehabilitation [5] in such way it becomes more affordable and available for more patients and for a longer period of time. Robotic rehabilitation can (i) replace the physical training effort of a therapist, allowing more intensive repetitive motions and delivering therapy at a reasonable cost, and (ii) 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 or 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 [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 are preferred an Additive process to fabricate a WREX device, because easy to build complex human shapes with particular finishes. The aluminum and steel device was a lifesaver for Emma, which helped her to pick up objects and lift her arms toward her mouth for the first time. But the supporting structures were heavy for little Emma, so as an alternative, printed structure with light weight ABS material was designed.

The knee DOF was actuated, while the hip and ankle joint was designed to be passive. Data from clinical gait analysis [9] 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. Pneumatic Muscle Actuators were selected such that the maximum torque was met, which allows for the operator to be raised or lowered from a seated position.



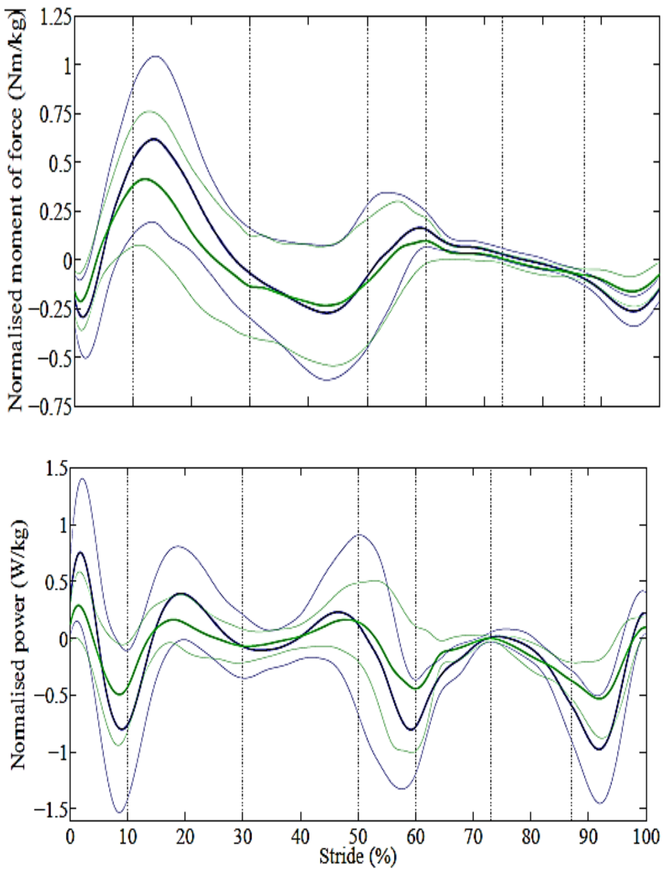


Figure 2. Averaged gait analysis data of the human knee joint: angle, normalized moment of force and normalized power with [-σ, +σ] confidence bounds as a function of stride percentage at natural (blue) and slow (green) cadence [10].

The Bio CAD Modeling software (Mimics & 3 Matic software) used for the design of exoskeleton suit for the patients with muscular disorders. The structure of exoskeleton was developed by reverse engineering techniques. Anotomy of Human lower limb is very complicated shape. So 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. Slice thickness is 1mm. Minimum slice thickness can lead to higher accuracy of solid model and avoid reconstructing a slices. After that slices of the DICOM data are imported to MIMICS software. All the slices are stacked together and converted in to solid model by using 2D segmentation and 3D region growing techniques. Initially creating a mask for Thresholding operation, it has been used to increase a density of soft tissue (muscles) and hard tissue (Bone).

Select a particular region (knee) of lower limb based on the requirement (in no of slices) of corresponding dimensions. Edit a mask whether draw it or erase the slices. Then generate a solid model for the corresponding mask. Measurements are taken using scaling options. After the solid model conversion, the 3Matic modeling software was used to modeling a structure of exoskeleton with supporting arrangements. Setting a scale factor 1:1 uniform thickness level. By using Boolean operation to form a top and bottom brace structure. Then smoothening operation is performed on the edges and surfaces of braces for removing a sharp corner. Select a fit plane and creates a suitable location for actuators and sensors placement. In both sides, supporting arrangement also created using CAD tool at corresponding plane.

Figure 3 shows the design model of knee exoskeleton. This model will be fabricated by AM techniques.

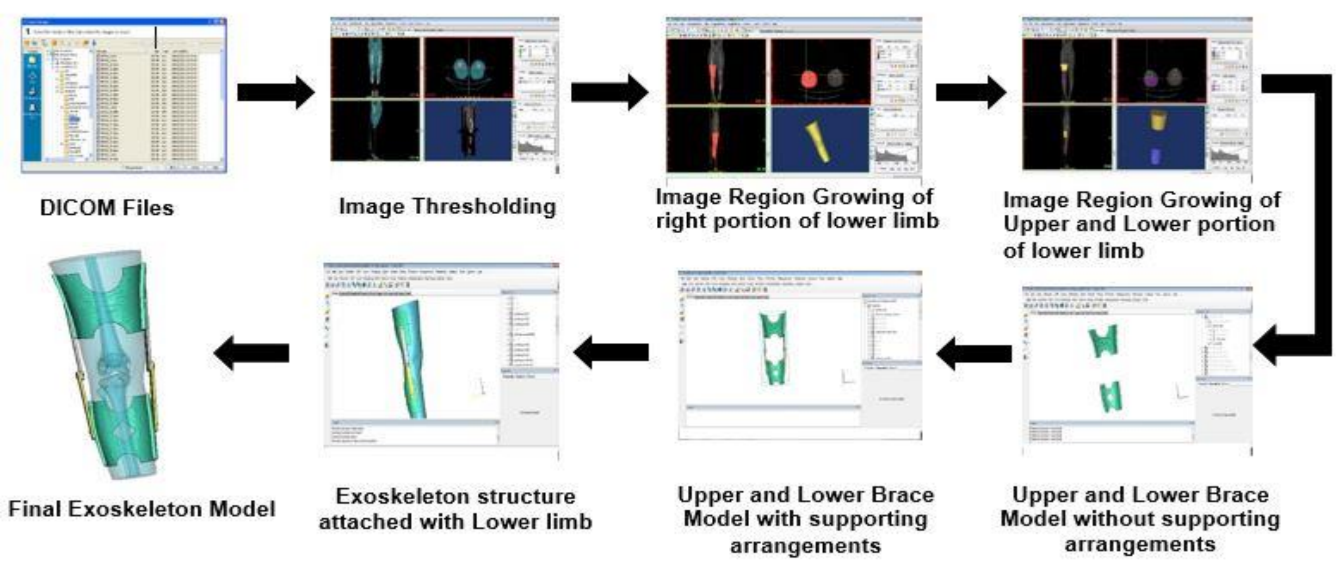
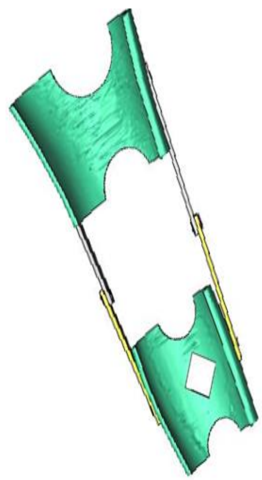
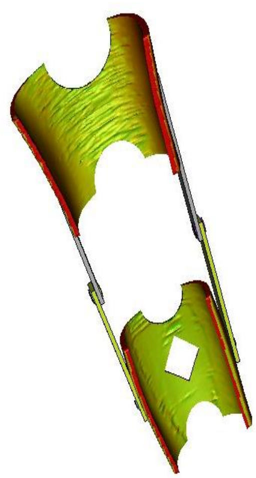


Figure 3. Design sequence of knee exoskeleton



(a)



(b)

Figure 4 (a) 3D Model of Braces Integrated with connecting structure (b) Wall thickness analysis of braces integrated with connecting structure

This process is possible with the application of 3-matic software. The brace thickness analysis for an exoskeleton is presented in figure. 4 and Table 1.

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		

2. Conclusion

In this work, patients with muscular disorders are benefitted with this customized exoskeleton. Regarding the patients, a biomechanical analysis has been made in order to determine the common characteristics that the patients will be benefitted from the exoskeleton (weakness, balance control, Lower limb mobility control). It's providing better conditions to develop a standard gait next to the physiological one. One of the important aspect of patient comfort has been achieved by using reliable technique of Bio CAD modeling with additive manufacturing for the purpose of customization. Advances in actuation technologies of Pneumatic muscle actuator gives benefit to the user during sitting and gait condition, and also it provides more strength.

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