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Simulation of Control for Reduced Dof Lower Limb Exoskeleton Robot using Cad Design

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ABSTRACT: These years, there has been continuous development in the research of exoskeleton robot for many purposes like augmentation, physical assistance and rehabilitation therapy. Basedon statistics, aging population with weakened limbs and people with lower limb disabilities are always increasing. Many therapists are required to perform physiotherapy for walking rehabilitation. Exoskeleton robot research contributes in helping those people to regain normal walking ability. In this research, a lower limb exoskeleton robot for rehabilitation is proposed. Developing the exoskeleton structure and control is challenging in assisting patient to initiate locomotion and walk while providing additional power to the motion. The objective of this research is to design a lower limb exoskeleton robot structure with using mechanical engineering CAD software. Then to investigate the tracking response performed by the exoskeleton to given input to its control system. The research started with the lower limb exoskeleton robot CAD drawing. The CAD design is simulated and its dynamic response is studied. This research finding will improve the studies on the effect of the lower limb exoskeleton robot on rehabilitation therapy. Developing a simple and effective lower limb exoskeleton model can significantly contribute to the advancement of the rehabilitation therapy and health industrial needs.

KEYWORDS: Lower Limb Exoskeleton; CAD; Sim Mechanics; Exoskeleton Control Simulation.

1. INTRODUCTION

Exoskeleton robot is a powered wearable robotic suit which is worn on the whole or any parts of the human body in to augment, assist or restore human limb function. Over the years, researchers have been trying to develop exoskeleton which can help human to perform tasks beyond his limit or restore human disabilities with the help of the exoskeleton.

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Researches in recent years have shown the advancements in the development of lower limb exoskeleton robot for many purposes such as in load carrying, walking trajectory [1], walking endurance, walking assistance [2] and rehabilitation therapy.

BLEEX is the first energetically autonomous lower limb exoskeleton developed by Zoss, Kazerooni and Chu[3] from the University College of Berkeley. Designed anthropomorphically to be worn on human lower body part, it is capable of carrying heavy payload while the wearer can endure walking for long distance at the same time. The intelligent control system is provided by human while the exoskeleton actuators provide most of the strength necessary for walking, forms the overall concept of this lower limb exoskeleton. Researches on some walking assistance have been reviewed by Lovrenovic and Doumit[4]. According to them, HULC developed by Ekso Bionics and the Berkeley Robotics is a hydraulic powered exoskeleton enabling soldiers to walk longer while carrying payloads.

Some researches on robotic rehabilitation devices include Zoss, Kazerooni and Chu [3] BLEEX (Berkeley Exoskeleton), Kawamoto, Lee, Kanbe and Sankai [5] HAL-3 (Hybrid Assistive Leg), Pratt, Krupp, Morse and Collins [6] Roboknee, Walsh, Endo and Herr[7] quasi-passive exoskeleton and Rewalk by Zeilig et al.[8]. The device works to provide flexion and extension torques at hip joint to walk over extended periods of time with minimal fatigue while carrying heavy loads according to Bogue [9]. Ikeuchi et al. [10] from Honda created the bodyweight support assist, a powered exoskeleton that works to reduce user’s felt weight during walking. In 2014, a group of Honda researches created Honda Stride Management Assist to boost user’s hip motion during walking. These exoskeletons assist and strengthen human performance. Their movements are detected by EMG, force or position sensors. BLEEX and HAL-5 can carry extra payload besides their own weight while Rewalk is the only currently FDA-listed motorized exoskeleton available to aid paraplegics to regain their upright mobility.

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During application, the wearer and the exoskeleton have mechanical connections at the torso and the feet; beside having compliant or periodic contact elsewhere. The structure design can be fit or adjustable following human anthropometry. The structure must be light when the model is developed for elder people. One of the essential objectives in the design is to allow the joint angles of robot to be accommodate the force and motion of human joints as much as possible and good safety were discussed by Sen [11] and Yu et al. [12]. There are various human walking movements which involve lower limbs such as the pelvis, thigh, leg and foot according to Bo [13], which linked to the hip, knee and ankle joints. According to Y Miao et al. [14] there are four different types of movement with different modes to find the particular action state for walking, running, jumping and squatting.

In designing the structure, some of the exoskeleton CAD designs are drawn using Solidwork by Li et al.[15] with SimMechanics simulation, and Shaari, Isa and Jun[16] and Autodesk Inventor by Olinski, Lewandowski and Gronowicz[17] but are not simulated in SimMechanics while other researchers utilized the CAD designs simulation in SimMechanics for examples the laboratory truck crane by Cekus[18] and 6-DoFs (degrees of freedom) robot manipulator by Fedák, Ďurovský and Üveges [19]. Those designs are compared in Table 1. There are not many lower limb exoskeleton CAD designs which are simulated in SimMechanics and this study aims to simulate the CAD design of a lower limb exoskeleton created [20] in Autodesk Inventor. In this research, simulating the dynamics of a lower limb exoskeleton robot CAD design for paraplegic rehabilitation is proposed.

Table 1: Comparison of some CADs designed in Solidwork and Autodesk Inventor, and Sim Mechanics simulation

Researchers	**Solidwork**	**Autodesk Inventor**	**Sim Mechanics Simulation**
Li et al. [15]	10-DoFs Lower limb exoskeleton		ZMP location calculation
Shaari, Isa and Jun [16]	6-DOFs Lower limb exoskeleton		Not used
Olinski, Lewandowski and Gronowicz [17]		Ankle joint module	Not used
Cekus [18]	Laboratory truck crane and forest crane		Animation and motion trajectories
Fedák, Ďurovský and Üveges [19]	6-DoFs robot manipulator		Motion trajectories, kinematics and dynamics analysis

To accomplish this aim, this paper contributes by highlighting the opportunity in integrating the advantages of CAD design [21] and Matlab simulation environment without performing any mathematical modelling and fabricating CAD design into actual prototype. Through this integration, the CAD design together with its developed control system can be simulated so that its response [22] can be analyzed without any cost of fabricating the actual structure or prototype.

2. METHODOLOGY

Firstly, the CAD drawing of the lower limb exoskeleton model is designed using Autodesk Inventor software to meet some design requirements. The metals material in the design are Aluminium alloy 6063 hollow rod with density of 2.69/cm^3 for the links and Aluminium alloy 1100-H14 with density of 2.8/cm^3 for the joints and foot plates. The lower limb exoskeleton structure must be able to be worn by patient with safety and stability. The range of motion of each joint should match the range of motion of human joints and the structure should be easy to put on and take off. The exoskeleton drawing is designed at reduced 6-DoFs movement in sagittal plane with 3-DoFs in each leg for hip, knee and ankle joints, left and right legs. The 6-DoFs are the minimum requirement for the robot to move forward, similar to human while normal human walking gait required 12-DoFs.

The CAD in Autodesk Inventor is exported to SimMechanics First Generation in Matlab version R2015a. The SimMechanics is a part of Simscape Toolbox under Matlab Simulink. By option, the CAD can also be exported to SimMechanics Second Generation but in this study, the former is used. Once exported, an xml physical modelling file is created by Autodesk Inventor in the same directory of the CAD files. At this point, the xml file cannot be read by Matlab command unless mech_import instruction is entered at Matlab command.

The stl stereolithography files which contain parts geometric information from the original Autodesk Inventor ipt part files are created automatically by Matlab when running the xml file. This opens a Simulink block diagram as shown in Figure 1

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which be saved as a Simulink slx file. In the block diagram, every part is connected to rootpart via Six-DoFs blockWhen the block diagram is simulated, Matlab utilized the stl files to visualize the mechanical model as originally drawn in Autodesk Inventor. Before simulating the block diagram, it must be ensured that the stl external graphic files is stored in the path which is recognized and accessible by Matlab. It is important to add the path in the Matlab command so that the stl files which hold the original drawing and design information from the CAD software can be read by Matlab.

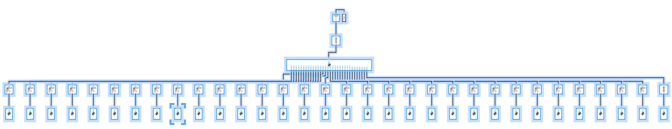

Figure 1: Overall view of Sim Mechanics block diagram before modification.

The block diagram in Figure 1 must be rearranged to resemble the exoskeleton design with right leg and left leg being attached to center hip. After rearrangement, all joints between every body block need to be modified and changed to either weld block or revolute block. The SimMechanics block diagramis modified by rearranging the blocks so that the block diagram shape resembles the shape of the lower limb exoskeleton. As the exoskeleton is designed to have DoFs only in sagittal plane, all joints have only revolute movement to form extension or flexion. The overall view of the SimMechanics block diagram new arrangement is shown in Figure 2.

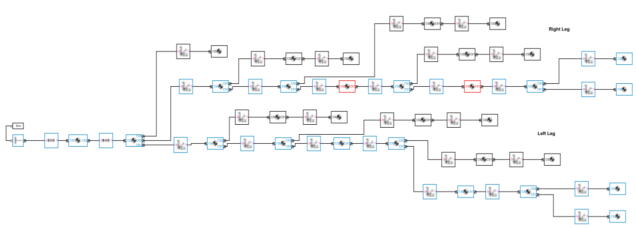

Figure 2: After rearrangement and modification with only joints connected to Six-DoFs block.

The exoskeleton has been designed with 6-DoFs with every joint only having 1-DoF. To have DoFs in sagittal plane only, the Six-DoFs block is changed to revolute block. After changing to revolute block, the joint actuator and joint sensor blocks are connected to it. The joint actuator functions as actuator to actuate each joint and it receives the input from external source while the joint sensor reads the joint output in terms of angle, velocity and torque. The process flow to simulate an exoskeleton CAD design follows the sequence as stipulated in Figure 3.

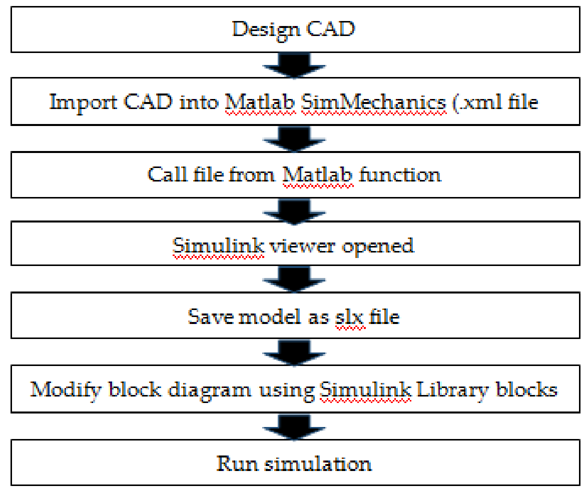

Figure 3: CAD simulation process methodology.

Figure 3: CAD simulation process methodology.

Running the simulation causes the block diagram to be compiled and displays the animated exoskeleton robot almost exactly as it is designed in the CAD software. Figure 4 shows the simulated CAD design as it appears in SimMechanics Visualization Window and t **Right leg** design in Autodesk Inventor. As the human walking gait to be imitated by the exoskeleton is periodic, it is enough at the point to use sinusoidal input for the simulation to begin with simulation. The block diagram in Figure 2 is further modified to include simple PID controllers and **Left leg** y for only the left leg of the exoskeleton as shown in Figure 4. It is tested with various sinusoidal inputs to the right and left legs hip, knee and ankle joints.

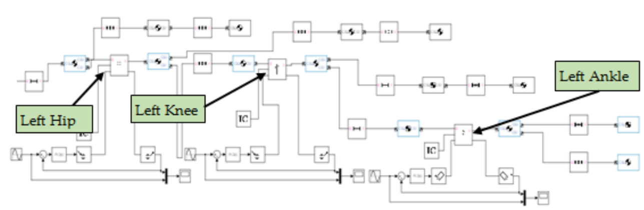

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Figure 4: Simulation of exoskeleton leg with simple PID controller and sinusoidal input to hip, knee and ankle joints (shown left leg).

3. RESULTS AND DISCUSSION

Figure 5a) and Figure 5b) show the exoskeleton design in different environments with the former in SimMechanics and the latter in Autodesk Inventor. By testing the sinusoidal input to all joints, the dynamics response from each joint can be visualized and the exoskeleton movement animated.

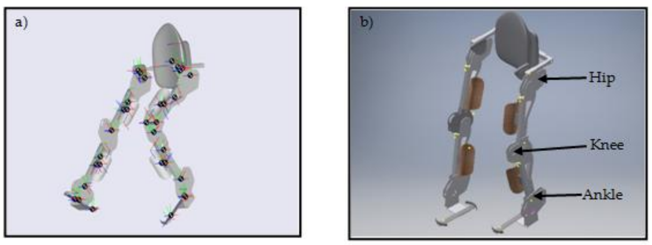

Figure 5: Exoskeleton Robot in a) SimMechanics simulation b) actual CAD design.

The responses are shown in Figure 6 where the green line outputs seem to have some tracking of the red line inputs.The results show that the exoskeleton structure in SimMechanics block diagram can be actuated at each joint while sensor can be added to give outputs in term of position angle, velocity and acceleration. Further analysis can be performed by designing different controllers utilizing the Simulink block and adding it to the block diagram.

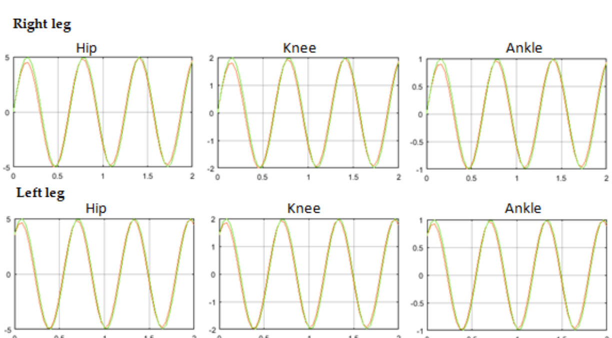

Figure 6: Response graphs of the exoskeleton robot joints that shows output to input tracking

4. CONCLUSION

The exoskeleton robot design which is drawn using Autodesk Inventor has been successfully exported from the CAD software to Matlab. Using SimMechanics, the design dynamics response can actually be simulated even before the fabrication of its prototype. This process skips any mathematical modelling and requires no mathematical equation. By modifying the resulting block diagram and running simulation, different control systems can be further developed while introducing various controllers which gives results of the prototype effectiveness before hardware and electronics are done. Further work can be done by including a human model wearing the exoskeleton with both the human model and the exoskeleton having different control systems. This is where the exoskeleton can be tested to assist the human model in his walking gait.

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