ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Design and fabrication of powered wireless control lower limb exoskeleton for rehabilitation process

Rithin George Skaria, M.R.Stalin John*, and V.P.R.Sivakumar
Dept. of Mechanical Engineering, SRM College of Physiotherapy, SRM University, Chennai, India
***Corresponding author: E-Mail: mrstalinjohn@gmail.com**

ABSTRACT

The paper describes about design of an exoskeleton and control method for the human leg. It requires knowledge about the joint torque due to gravity. The proposed method helps a person to perform stand and sit. The exoskeleton movement can be controlled using a wireless device. The Bluetooth installed in exoskeleton is paired with the smart phone of the user. The existing lower limb exoskeleton is bulky and complicated in design which has more limitation in real time application. The negative reviews created a need for a system which is compact, less complex, ease of control and economic which can provide more flexibility than existing ones. The demand for user-friendly and less complex system enhances its application in the field of the rehabilitation process. The proposed leg exoskeleton is manufactured based on research experience in driven manipulators and design of rehabilitative regimes. This motor driven system will help in movement of links attached to control exoskeleton movements. This project describes the control and the design parameters of the exoskeleton.

KEY WORDS: Leg, exoskeleton, lower limb, wearable, wireless control.

INTRODUCTION

The human body has significant relation with joint movements in upper or lower limb such as reaching, walking or doing daily activities. Nowadays, many causes make the people get losing the joint movement, e.g. geriatric disorders, trauma, sports injuries, spinal cord injuries, and strokes. Rehabilitation treatments are the primary program for people with the disabilities. After world war, only 4.9% of the world's population was over the age of 65. Today, almost 20% is over 65, and this figure is predicted to exceed 35% in next fifty years. The high increase in population growth imposes attention of medical science in health risk associated with aging. The continuous war and safety threats create the need of robotic assistance. The sudden decrease in death and injury rate shows the influence made by the modern technology in regaining human lives. For example, about 20% less injured and death casualties are reported in Iraq compared to that of World War II. At present, the injured survivors are provided with permanent assistance for the rest of their lives. In these areas, the power-assisted exoskeleton robotic system is needed for the rehabilitation process. The rehabilitation process is to restore the patient's physical, mental and actuation natural capabilities lost due to accident, illness, or disease when in contact with different circumstances. The typical habilitation for a lower limb is divided into three types, which are active, passive and active assistive mode. Active mode increases or maintains the joint function by providing proper resistance to the body muscles to increase endurance and strength. For passive mode, patients cannot participate completely in the rehabilitation process, and zero percentage effort is required from them. The exoskeleton suit will drive Patient's lower limb.

Gabriel (2012), proposed a method of the lower-limb exoskeleton, based on the function to control leg-swing motion, without the use of control parameters, the exoskeleton mechanism was difficult to apply its motion along the joints. The lack of scrutiny on exoskeleton reduces the freedom of leg swing leads to shorter step during walking, which forces the user to apply more energy to the movement. The continuous energy consumption increases the lower frequency movement. The proposed controller provides a feedback loop to overcome the drawback, and it uses low pass filtered angular acceleration. This simulates the low frequency range in negative inertia. The present controller provides two beneficial effects: performing network per swing cycle and gradual increase in frequency of lower limbs. The mounted exoskeleton that has knee flexion and expansion was tested continuously with the enhanced controller. The testing is performed by, first with an unassisted exoskeleton and using exoskeleton. The output shows frequency of leg swing and angular velocity mean are reduced consistently. Baijun (2012), presented finite element analysis and light weight designing of the lower extremity exoskeleton of a gait rehabilitation training robot. For developing and assembling the entire machine structure of the lower extremity exoskeleton PRO/E is used. The lower extremity exoskeleton of finite element model is built using ANSYS Workbench. The intensity and rigidity of link material of lower limb exoskeleton are taken and studied. The integral stiffness characteristic is obtained by knowing the bulk structure rigidity of lower extremity exoskeleton. From the model analysis, the design of lower extremity exoskeleton and initial ten natural frequencies are noted, which provide important model parameters, and it removes the chance of resonance. The output results show that the exoskeleton has enough space to improve and optimize its structure. The connection drive block is adjusted in according to the looseness. The designed exoskeleton cause laterality due to its non-compact model structure, to overcome this negativity, forward the optimization scheme is introduced which makes the model more compact. Under the condition of meeting the request for the intensity, rigidity, vibration characteristics, and rehabilitation training the system makes it a lightweight design of the lower extremity exoskeleton. Surachai (2012), the studies about the injuries in lower limb come under urgent priority in the design of exoskeleton. This rehabilitation considers joint movement of leg actuation. The knee, joint capsule, muscle, ligament and tendon actuation are considered while designing exoskeleton. In this paper, the structure design and the possible motions of each joint simulation are introduced. Some of the exoskeleton proposed by NASA on each leg they created a correspondent spring hardness varies on knee part of exoskeleton. The current NASA spacesuit matches with the proposed method. The space suit's leg acts as spring for the movement where there is zero gravity in space.

An exoskeleton with impedance control combined with functional electric stimulation (FES) is control strategy for exoskeleton designed by Yixiong (2014). The dynamic compliance of the Leg is to accomplice the training task in patient's rehabilitation effort. During the training process, the FES is applied with muscles which are similar to the patient. The FES property is selected to extract the electromyography signals using the neural network which should be proportional to the active torque using back propagation method, this kind of positive feedback device enhances patient to accomplish the desired motion.

Rehabilitation Robots: The rehabilitation history can be traced back to the development of efficient prosthesis; this prosthesis can be considered the backbone of rehabilitation in robotics. The prosthesis continued to develop from regular joints to the application of springs and releases.

The progress in the field of prosthesis until the end of 17th century when Pieter Verduyn developed the first non-locking below-knee prosthesis. This design later become the foundation for present joint and corset devices. The advancement in prostheses has always been pushed forward during the times of war. During the American Civil War, the number of casualties rose astronomically, forcing Americans to concentrate in the field of prostheses. The World War II, opened the eyes of US government to initiate rehabilitation for injured veterans. The lack of technology forced to do more researches. The government made a deal with military companies to carry on the research and to produce prosthetic equipment. This significant step taken leads to development and manufacture of modern rehabilitation devices. Today these devices meet the need of many people which makes their life more hopeful by providing weightless, compact, made of plastic, and other composite material in combination modern technologies.

In the 1960s, Rehabilitation Engineering officially started research in powered human exoskeleton devices. The research group finds its success in United States and Yugoslovia by accomplishing different goal. To extend interface between human and machine experts focus research on development of exoskeleton.

Exo-Skeleton: In robotics, an exoskeleton is a user wearable machine with joints links and actuators equivalent to those of the human body. The exoskeleton, as an external assistive device, is also an outer structural to direct the joints and links equivalent to the human body. The user wears the exoskeleton, and its actuators generate torques is applied on the human joints. In using the exoskeleton as an external human power generator, it produces power for task performance for the control signals for the exoskeleton. The exoskeleton becomes the part of human body and more force is produced by exoskeleton. The natural capabilities of human body and artificial capabilities of exoskeleton combine to offer abundant opportunities for exploring and developing an assistive technology for the future generation.

The technology related to exoskeleton classification and human power extension can be divided into upper extremity exoskeletons and lower extremity exoskeletons. The reason for this was twofold initially; one could envision a large number of applications either on lower or upper extremity exoskeleton in the future. The most important factor for the division is that these exoskeletons are in their initial stages, and furthermore research still needs to accomplish to ensure that the upper-extremity exoskeleton and lower extremity exoskeleton can work out independently before anyone can venture an attempt to integrate them.

Figure.1. Modeling Lower Limb Exoskeleton

Lower Extremity Exoskeletons: The physical therapy revolutionized due to the modern advancement in the field of robotics there has been more robotics devices committed to the mechanization. Robot-mediated therapy becomes significant in cases where the therapist's effort is intensive leading to many drawbacks, availability and in the worst case it leads to injury. Lower Extremity Exoskeletons is one of these robotic systems, and it is implemented for gait rehabilitation by using a treadmill training system. Lower Extremity Exoskeletons is intended to bid assistance in leg movements while maintaining sideway balance. In order achieve this patient's limbs are strapped to the exoskeleton to robot and patient move in parallel. Lower Extremity Exoskeletons contain two extreme control phases which will help patients during the rehabilitation training. The first phase is the patient in charge phase. The goal of this phase is to minimize the interaction forces between the patient and the robot. In this phase, the patient can actuate or move freely without obstruction from the robot, as a result the robot maintains full support. The second phase is the robot in charge phase, throughout this period, the exoskeleton will take complete control over the movement which the human is unable to perform. Under these typical situations, the exoskeleton will operate between these two functions depending on how much aid the patient needs. Lower Extremity Exoskeletons uses joint actuation during the full cycles, during this cycle the robots offer uniform controls along the movement. With this external monitor, the patient receives support where is necessary. The main aim of lower extremity exoskeleton is to support the patient when he needs assistance. This will lead to a more active effort from the patient's side. The tradeoff for a more active session will likely be a smaller overall distance during the therapy period. Lower Extremity Exoskeletons system was developed using a series of cables and motor these cables is used to transmit mechanical force or energy.

Figure.2. Demonstration of working model

Lower extremity exoskeletons, which are also known as support devices, can reproduce forces on a human leg. These forces different and usually smaller than the forces needed to carry out load. When a human uses lower extremity exoskeleton to move, the device abide the bulk weight by itself, while transferring to the user as a natural feedback a scaled-down value of actual weight.

The concept of using exoskeleton for lower limb rehabilitation has been intended keeping in mind the different parameters related to human body. The human-machine interface of the exoskeleton is needed to generate natural process of the device. To start motion in the exoskeleton, control strategies require operating both to move part of lower limb and to apply a force on the exoskeleton system. The systems not only have ability to provide repetitive functional movement training, but also it can provide more sensitive and objective oriented quantitative assessments of movements. The DOF of the human leg is an important aspect of design robot.

Denavit–Hartenberg Model: Prime focus of this paper is lower body of legged actuation. It has two three DOF legs namely 1 DOF for the hip joint, one each for the knee and ankle respectively. Each leg of biped robot can be representing as a kinematics chain of with 4 links and 3 revolute joints. The assigned local frames are {Xi, Yi, Zi} frames are attached according to names given as numbers. Assignment of frames is done according to convention known as DH-notation.

The first step was to determine the coordinate frames according to D–H convention for the lower limb. In order to allow universal base frame for both arms, the base coordinate system ($X_0Y_0Z_0$) was located in the body.

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