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EXOSKELETON ROBOT MANIPULATOR FOR GAIT REFRAINMENT

Aann Smita Abraham[1], N. Arunai Nambiraj[1] and P. Vivekananda Shanmugan[2]
[1]School of Advanced Sciences, VIT University, Vellore, India
[2]School of Mechanical and Building Sciences, VIT University, Vellore, India
E-Mail: aannsmita@gmail.com

ABSTRACT

Design and implementation of a low cost gait refrain ment device which helps in the mobility of the MS (multiple sclerosis) patients is discussed in this paper. Walking impairment is one of the most ubiquitous features of Multiple Sclerosis. There is an increasing trend in using robots for medical purposes especially in neuro rehabilitation. There are some commercial exercise machines used for such rehabilitation purposes. However, these machines have limited use because of their insufficient freedom of movement and lack of flexibility. This paper introduces an exoskeleton robot manipulator for gait assistance for Multiple Sclerosis patients. This exoskeleton is capable of supporting the bodyweight of the patient partially. It takes the EMG signals of the patient to generate the control signals and deliver it to the actuator. The exoskeleton proved to be of much help to the MS patients in walking as the patient with relapsing remitting Multiple Sclerosis disease can control it like their normal leg.

Keywords: exoskeleton, gait analysis, multiple sclerosis, servo control.

1. INTRODUCTION

Multiple Sclerosis (MS) is a chronic inflammatory, demyelinating disease of the central nervous system (CNS). It mainly affects young adults between the ages of 20-50, and is often referred to as the “great crippler of young adults”. Walking impairment is one of the most ubiquitous features of MS and is a sentinel characteristic of the later or advanced stages of the disease. Studies suggest that half the people with relapsing-remitting MS will need some assistance for walking within 15 years of the diagnosis of disease. Multiple Sclerosis (MS) affects approximately 1 per 1000 persons around the world in a week. The majority comes between the ages of 20 and 50 years, and women are more often affected than men. Over the course of MS, there are further neurodegenerative processes that are presumably characterized by insufficient support of nerve growth factors within the CNS.

This paper describes design and implementation of a gait refrainment device which helps in the mobility of the MS patients with much ease. The exoskeleton robot manipulator is for gait position assistance for MS patients. The servo operated robotic manipulator helps the MS patients while walking by providing assistance by properly placing their leg. The patient can walk on various terrains using this exoskeleton.

2. DESIGN OF ROBOTIC MANIPULATOR

The robotic manipulator used for the exoskeleton has three joints and three links. According to the Denavit-Hartenberg Conventions the Links are numbered as link 0, link 1, link 2 and the joints are numbered as joint 1, joint 2, and joint 3. In application specific perspective joint 1, 2, 3 are named as hip joint, knee joint and ankle joint respectively. All the joints are of revolute type. A revolute joint is like a hinge and allows a relative rotation about a single axis. So the Denavit-Hartenberg parameters (D-H parameters), link twist (α_i) which is zero, link length (r_i) which is constant, link offset (d_i) which is considered as infinity, and joint angle (θ_i) which is the only variable parameter are the main considerations of this design. Link 0 is considered as fixed. The foot of the leg is termed as the end effector. An end effector is the link which experiences the final position change due to the relative motion of the links. Any robotic manipulator design is done on the basis of forward and inverse kinematics [1]. The forward kinematics is concerned with the relationship between the individual joints of the robot manipulator and the position and orientation of the end effector.

Inverse kinematics is concerned with the inverse problem of finding the joint variables in terms of the end-effector position and orientation, and it is in general more difficult than the forward kinematics problem. Therefore, we need to develop efficient and systematic techniques that exploit particular kinematic structure of the manipulator. Whereas the forward kinematics problem always has a unique solution that can be obtained simply by evaluating the forward equations but the inverse kinematics problem may or may not have a solution [1]. Even if a solution exists, it may not be unique. Furthermore, because these forward kinematic equations are in general complicated nonlinear functions of the joint variables, the solutions may be difficult to obtain even when they exist. In solving the inverse kinematics problem we are most interested in finding a closed form solution of the equations rather than a numerical solution. Finding a closed form solution means finding an explicit relationship:

$$q_k = f_k(h11, \dots, h34),\ k = 1, \dots, n.$$

Closed form solutions are preferable for two reasons. First, in certain applications, such as tracking a welding seam whose location is provided by a vision system, the inverse kinematic equations must be solved at a rapid rate say every 20 milliseconds and having closed form expressions rather than an iterative search is practical necessary. Second, the kinematic equations in general have multiple solutions. Having closed form solutions allows one to develop rules for choosing a particular solution among several of such available. Since the inverse kinematics gives infinite number of solutions; here we use the forward kinematics. Here the GAIT graph (angle vs time) of all the joints involved in the GAIT is found, and it is then fed to the three servo motors (i.e., at the hip, knee and the ankle).

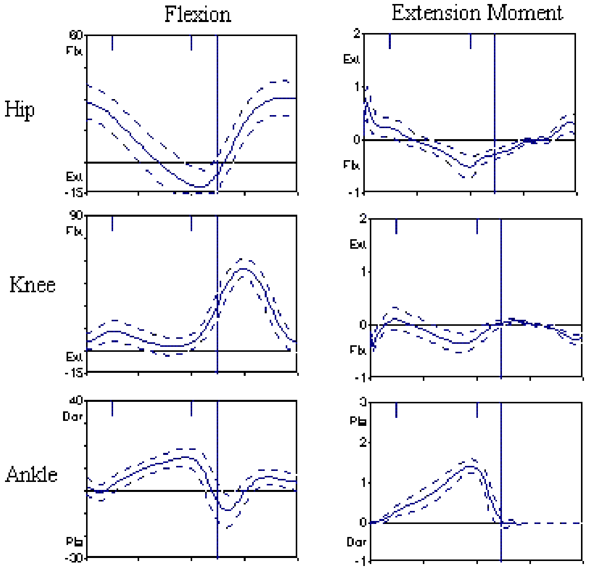

Figure-1. Gait analysis data (angle vs time graph).

3. ACTUATORS AND CONTROL

Servo motors are a type of electromechanical actuators that do not rotate continuously like dc/ac or stepper motors; rather they used to position and hold some object. They are used where continuous rotation is not required so they are not used to drive wheels (unless a servo is modified). In contrast they are used where something is needed to move to a particular position and then stopped and hold there for a preloaded time. They are DC motors with position and velocity control feedback. The control signal required for controlling this type of servo motor is PWM signal with 20 milliseconds period (T = 20 ms) and pulse length varies between 0.6 to 2.4 milliseconds (0.6 ms $\leq t_H$ 2.4 ms). The servo motors rotate from 0 to 180 degree. Angular position of the servo motor axle depends proportionally linear to the pulse length (t_H) parameter of the PWM signal fed to it. Since the final complete design shall have 6 DOF (degrees of freedom), it means that 6 independent PWM signals will be needed to control 6 servo motors independently each other.

Here the manipulator basically consists of six servo motors- three for each leg which are controlled through a microcontroller. Positioning the leg basically requires controlling hip joint, knee joint and ankle joint. For that we place servo motors at hip, knee and ankle. Before deciding which servo motor type to be used on the specific joint the required capacity of torque must be calculated [1, 2]. For this calculation there are four parameters about the concerned joint that must be determined by Total load weight estimate (W), Length /distance estimate from the joint axle to the loads center of mass (l), Movement angle for the coverage of the joint axle (αmin $\leq\alpha\leq\alpha$max), Safety factor percentage (sf). S(safety factor represents any unpredictable additional load on the joint operation). The required torque capacity of the concerned joint can then be calculated as follows:

$$t = (1+sf) * W * l * \max(\sin\alpha) \qquad (1)$$

The function max (sinα) lies within the range $\alpha_{min} \leq\alpha\leq\alpha_{max}$. Besides of the torque capacity requirement, servo motor dimension and weight also became two factors of consideration in servo motor type selection.

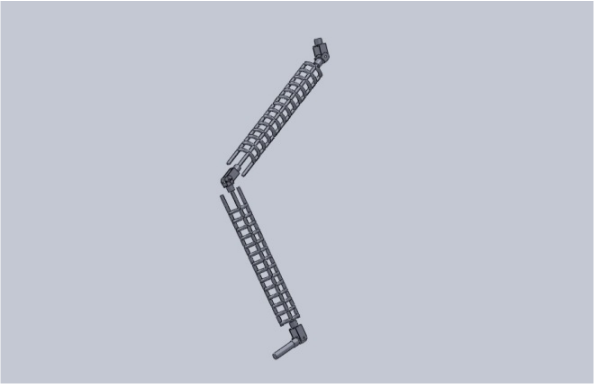

Figure-2. The mechanical design of the exoskeleton for left leg.

4. EMG EXTRACTION

The EMG signals from the lower limb muscles of the patient are obtained. EMG can be extracted either by using needle electrode or surface electrode. For the extraction of the EMG using the needle electrode the needle needs to be inserted to the muscle of the patient. Due to the practical difficulty of using needle electrode, we use surface electrode. Surface electrode or Gelled electrodes are used for extracting EMG signals from the patient's body. Gelled electrodes use an electrolytic gel as a chemical interface between the skin and the metallic part of the electrode [3]. Since the patient move during every locomotive action, the gelled electrodes proved to be safer than needle electrodes. It provides protection from getting hurt during rapid motions.

A. Muscle activation pattern

During the gait cycle of a human being, in each instant there is active participation of a groups of muscles. This gives the muscle activation pattern for the walking structure of human being. Anatomical Structures like Ipsilateral and contralateral erector spinae at lumbar site, gluteus medius, rectus femoris, medial hamstrings, lateral hamstrings (biceps femoris, long head), gastrocnemius (medial head), and tibialis anterior are the groups of muscles involved in this process.

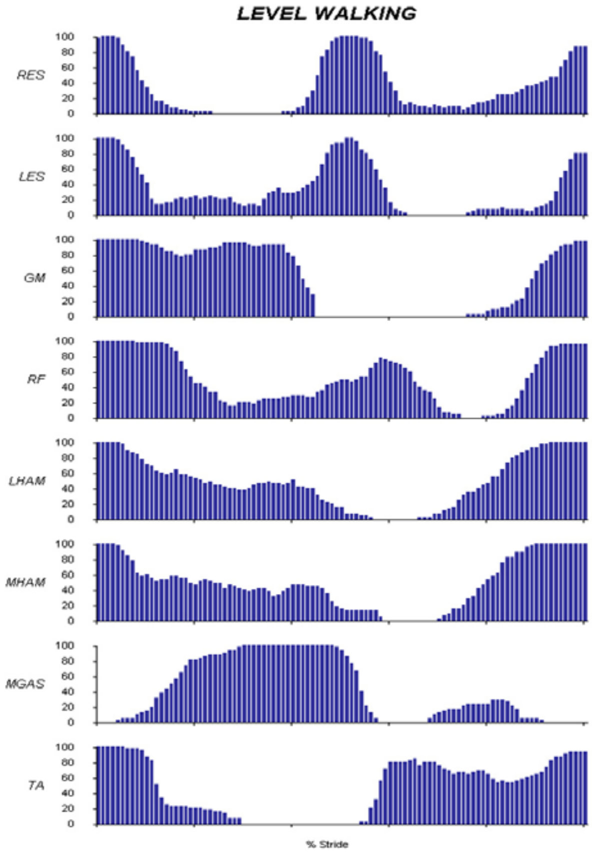

Figure-3. On-off muscle timing during level walking as a function of the percentage of the gait cycle.

For each muscle, the muscular activity is presented as percentage of subjects whose muscle is active at the specific percent of the stride considered. RES: right erector spinae, LES: left erector spinae, GM: gluteus medius, RF: rectus femoris, MHAM: medial hamstrings, LHAM: lateral hamstrings, MGAS: medial gastronomies, TA: tibialis anterior. Extracting these EMG signals and proper processing is required for the control of the actuators.

B. Data acquisition board (DAQ)

Data Acquisition board, DAQ is required for the EMG extraction. It acts as guide to create fast and accurate measurements with no programming using the DAQ assistance. It has a multithreaded streaming technology for 1,000 times performance improvements. It consists of Automatic timing, triggering, and synchronization routing to make advanced applications easy. It has software configuration of all digital input/output features without hardware switches. It has a single programming interface for analog I/O, digital I/O, counters on hundreds of multifunction DAQ hardware devices. The EMG signals can be processed inside DAQ to digital form. This digital data is then used for the ON/OFF control of the actuators.

5. CONCLUSION AND FUTURE RESEARCH

This exoskeleton can be very effective in the rehabilitation of multiple sclerosis patients. It can also be used to rehabilitate spinal cord injury (SCI) patients and other partially paralyzed patients. The future research includes making the device more efficient. The decrease in nerve conduction velocity has to be tackled effectively to increase the speed of response. Also, making it more cost effective can be helpful to a large population of multiple sclerosis patients.

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