Soft Robo Exo-Suit for Paraplegics

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Abstract - Our vision of this paper is empowered by adding independency to the individuals with physical disabilities focused on inability to walk due to spinal cord injury. In this paper, we will have a deeper look into soft cable driven exosuit that will enable muscles of an injured individuals like paraplegic patients to walk. The main aim of this project is to provide stimulation to the paretic limb by placing electrodes and the soft roboexo-suit is designed to provide assistance to the paretic limb. Traditional exoskeletons have rigid frame, whereas soft exosuits can be worn just like cloth, yet it can generate action potential between muscles at a magnitude ranging from 18% – 30% which is generated by human body naturally during walking. Stepper motor is designed to control the Bowden cables connected to suit near ankle which is controlled by a microcontoller. Sensors like gyroscope and accelerometer are used to track the moments generated by the suit. Worn part of exosuit is extremely light that minimizes the suit's unintentional interference with the body's natural biomechanics and wearer's joints are unconstrained by external rigid structures, which is an added advantage. This soft roboexo-suit is economical than the traditional exoskeleton, wheel chair and the recumbent tricycle. It also has a broad applicability for assisting healthy individuals. The principle of the design is deeply discussed on how soft suit transfers force to the body. A significant parameter of the design is the consolidated effective stiffness of the suit and its interface. Subject experiences assistive torque during walking whose results are highlighted and effective stiffness of the exosuit are characterized.

Keywords:exosuit, functional electrical stimulation, actuator, sensor, electrodes.

I. INTRODUCTION

Robotic exoskeletons have been developed for a large number of applications, with the goal of assisting or enhancing human activities. For the lower extremity, devices have been developed to apply assistive torques to the biological joints to augment healthy individuals or assist those with disabilities to walk. The inability to walk is arguably one of the most notable impairments that individuals experience after spinal cord injury (SCI)[1]. Besides leading to physical complications such as skin breakdown, muscle atrophy, reduced cardiorespiratory capacity, and pain, being unable to walk also affects psychological well-being and can increase the risk of depression and reduce quality of life. For these reasons, recovery of walking consistently ranks among the top priorities related to mobility for individuals with SCI. Unfortunately, a large proportion of these individuals with complete or incomplete injury have limited, if any, recovery of walking function and are thus limited to a wheelchair for their mobility. Even with the use of conventional bracing for ambulation, individuals with SCI must expend high levels of energy to achieve modest, non-functional gait speeds, dependent on their level of injury. Recent developments in gait orthoses have produced the powered robotic exoskeleton, a rechargeable bionic device worn over the lower extremities with motorized joints that can provide externally-powered gait independent of a treadmill system. Compared to treadmill-based gait orthoses such as the Lokomat (Hocoma, Switzerland) and LOPES (University of Twente, Netherlands), these powered robotic exoskeletons are compact, lightweight, and portable[2].

This new technology has been designed as an assistive device to provide individuals with complete paralysis the ability to stand and walk independently over-ground in a natural, full weight-bearing, reciprocal pattern. They can also be used in the rehabilitation setting as a training tool to improve stepping and weight-shifting for ambulatory individuals with SCI[3]. Various designs have been developed, several of which are commercially available and are in the process of being approved for use at home and in the community. As with any form of gait rehabilitation, walking with a powered exoskeleton requires specialized training and practice. As a newly developed technology, the current evidence base surrounding the use of powered robotic exoskeletons in SCI rehabilitation consists of a number of studies, but the majority are case studies (single-subject reports) or single-intervention trials with a small number of participants[4].

A recent systematic review found that energy consumption was reduced when walking with powered orthoses compared to conventional orthoses in paraplegic SCI. To our knowledge, no systematic reviews have specifically determined the gait speed attained by non-ambulatory individuals with SCI while using a powered robotic exoskeleton to walk[5]. We defined non-ambulatory individuals with SCI as those who do not walk regularly, independently, with or without gait aids or bracing. Gait speed is an important indicator and will contribute to the utility of the device; very slow speeds may regulate the device to uses solely for exercise, while faster speeds may enable community ambulation. The primary objective of this project was to examine the evidence on the ability of powered robotic exoskeletons to provide gait, specifically focusing on gait speed, in individuals with SCI by performing a systematic review of relevant clinical studies. Before acquiring a powered robotic exoskeleton, clinicians and users alike should have an understanding of the feasibility of powered exoskeleton use. Thus, secondary objectives were to summarize the (1) screening process for determining suitability for an exoskeleton and the (2) training process to habituate an individual with SCI to walk with an exoskeleton[6].

Exosuits offer a number of benefits as compared to traditional exoskeletons. The suits themselves, composed primarily of fabrics, can be significantly lighter than anexoskeleton frame or linkage system, leading to very low inertias and lower cost of transporting the suit mass. Since the suit does not contain a rigid frame, it also provides minimal restrictions to the wearer's natural kinematics, avoiding problems relating to joint misalignment. Further, control for the system can be less precise as the inherent compliance in the system can make it more forgiving. Finally, the suit can alsoprovide torques on multiple joints simultaneously but having it span multiple joints, which may assist with reducing the total number of actuators[7].

II. LITERATURE REVIEW

The main goal is to establish stimulation in the paretic limb via electrodes and to collect datas with the help of sensors. Luke M Mooney discuss the ability to carry substantial loads is required by many professions, including many that may experience cognitive deficits associated with the extreme physical demands. In their study, the design and testing of an autonomous leg exoskeleton is presented[8]. The aim of the device is to reduce the energetic cost of loaded walking. In addition, we present the Augmentation Factor, a general framework of exoskeletal performance that unifies our results with the varying abilities of previously developed exoskeletons. We developed an autonomous battery powered exoskeleton that is capable of providing substantial levels of positive mechanical power to the ankle during the push-off region of stance phase. We measured the metabolic energy consumption of seven subjects walking on a level treadmill at 1.5 m/s, while wearing a 23 kg vest. In the design of leg exoskeletons, the results of this study highlight the importance of minimizing exoskeletal power dissipation and added limb mass, while providing substantial positive power during the walking gait cycle[9].

III. NON-INVASIVE FES

Functional electrical stimulation (FES) is a form of orthotic/therapeutic treatment that applies transcutaneous electrical current to initiate contractions in muscles, and is commonly used for individuals with spinal-cord injuries (SCIs) or stroke[10]. FES has been used to facilitate upper and lower extremity mobility, improve respiratory function, restore bowel and bladder function, restore male sexual function, and to treat and help prevent secondary complications such as muscle atrophy, spasticity, pressure ulcers, deep venous thrombosis, contractures, and bone demineralization. For FES, a controlled electrical stimulus is applied to motor units/nerves to elicit a muscle contraction in an attempt to restore functional movements of a paralyzed musculoskeletal system[11].

Several FES stimulators with microprocessor or microcontroller have been developed to improve lower and upper limb functions in subjects after SCI or stroke. Most of the proposed systems have a more or less fixed design and lack of an open architecture[12]. As new technologies were developed, in this project we use Arduino Uno as microcontroller which provides stimulation to the muscles via electrodes placed on the paretic limb. Arduino Uno is based on ATmega 328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller[13].

DATASHEET OF ARDUINO UNO

Microcontroller	ATmega328
Operating Voltage	5V
InputVoltage (recommended)	7-9V
InputVoltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O	40 mA

Pin	
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) (0.5 KB used by bootloader)
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

DISTRIBUTED MULTIPAD ELECTRODES

Core of the multi-pad control hardware is an Arduino Uno. The microcontroller communicates over SPI with a port expander (MAX7301) which switches reed relays. Each relay is connected in series with one electrode, which allows passing the stimulation current to a desired electrode by closing the normally open relay. The system supports up to 16 active electrodes. To control the system, a keypad and two buttons are used. A display allows the user to navigate through different stimulation protocols. Power supply is currently achieved over the USB-port of the Arduino Uno. An external battery can be used to power the system. Up to four sensors are supported at the moment. Optionally, a computer can be connected via USB to control the system and to visualize sensor values more precisely, however, is not necessary for normal operation. The conductive electrode surface is made of electroless nickel immersion gold, which is a good conductor and suitable for transcutaneous applications without permanent skin contact[14].

DETECTING GAIT EVENTS

Stroke significantly affects thousands of individuals annually, leading to considerable physical impairment and functional disability. Gait is one of the most important activities of daily living affected in stroke survivors. The interaction between user and exoskeleton is very important for users comfort and safety in a wearable robotic device. Also, when sensors have to be physically placed on human limbs, several issues, specially related to safety, comfort, reliability and donning/doffing process need to be expected and appropriately dealt with[15].

Kinematic sensors are useful for monitoring joint angles in real-time, so control systems can have an estimate of the body's motion. This approach is especially important for using these systems outside of the laboratory in challenging environments and when performing activities of daily living[16]. Previous work on wearable sensors to measure human kinematics include compliant sensors such as nano tubes or silicon encapsulated in soft polymers, which require complex fabrication techniques, or inertial measurement units (IMUs). While extensive work has been done to properly measure human kinematics with IMUs, these systems require additional sensors or aggressive filtering techniques to avoid problems related to integration drift. In addition to joint kinematic measurements, we use several additional sensors in conjunction with our soft exosuits[17].

GYROSCOPE SENSOR

In this project, we connect a GY-521 module with a MPU 6050 chip 3 Axis Gyroscope and Accelerometer to Arduino board. This is an IMU sensor. IMU sensors are one of the most common types of sensors used today in all kinds of electronic gadgets. IMU sensors help us in getting the attitude of an object, attached to the sensor in three-dimensional space. These values are usually in angles to help us to determine its attitude. They are used in smart phones to detect their orientation or in wearable gadgets like the Fit Bit, which use IMU sensors to track movement. IMU sensors have a prolific number of applications. It is even considered to be an inexorable component in quad copters. Some of the sensors: ADXL 345 accelerometer, ITG 3200 gyroscope, Sparkfun 6 DOF IMU sensor board, MPU 6050. The accelerometers and gyroscopes are not as accurate alone as when they are combined[18].

IMU sensors usually consist of two or more parts. Listing them by priority, they are the accelerometer, gyroscope, magnetometer, and altimeter. MPU 6050 is reliable and accurate IMU sensor and it is significantly cheaper than the other sensors. The MPU 6050 is a 6 DOF (Degrees of Freedom) or a six-axis IMU sensor, which means that it gives six values as output. Three values from the accelerometer and three from the gyroscope. The MPU 6050 is a sensor based on MEMS (Micro Electro Mechanical Systems) technology. The MPU-6050 sensor contains a MEMS accelerometer and a MEMS gyro in a single chip. It is very accurate, as it contains 16-bits analog to digital conversion hardware for each channel. Therefore it captures the x, y, and z channel at the same time[19].

SPECIFICATIONS

- Chip: MPU-6050

- Power supply: 3.5V (But as there is a voltage regulator on the breakout board, you can use 5V directly)
- Communication mode: standard I2C (Inter-Integrated Circuit) protocol for communication.
- Chip built-in 16bit AD converter, 16bit data output
- Gyroscopes range: +/- 250 500 1000 2000 degree/sec
- Acceleration range: +/- 2g, +/- 4g, +/- 8g, +/- 16g

ORIENTATION OF AXES OF SENSITIVITY AND POLARITY OF ROTATION

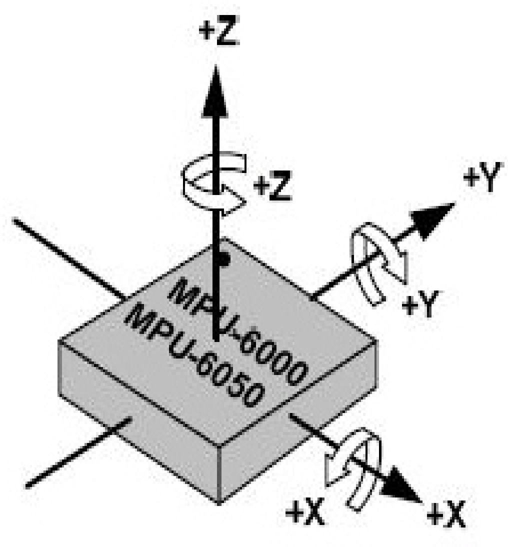

Fig.1 Polarity of rotation

LOW POWER ACTUATOR

The next key component of an exosuit is the power source and transmission. These need to be able to convey power to distal body segments while conforming to the body and not restricting its motion. Furthermore, the actuation scheme needs to be fast enough to move with the limb and displace the series compliance of the human body, the suit, and the interface between the human and the suit[20]. During human walking, positive power is generated by the muscles at the joints in short bursts. Thus, the actuators of an exosuit must be able to function with this timing and utilization as well. To determine the actuator specifications, the starting point is the biological moments and kinematics of the joints. From there, the series compliance of the suit-human system must also be considered. With the human tissue and suit displacing under applied forces, to achieve a given joint moment the actuators must move further than would be required if there was a rigid connection to the body[21].

Bipolar stepper motor is used as a actuator. Bipolar stepper motors always have 4 wires. Bipolar stepper motors have 2 coils. By driving the current in seperate directions through each of the coils, we can have a total of 4 different states:

- Coil A current flowing ‘left to right’.
- Coil A current flowing ‘right to left’.
- Coil B current flowing ‘left to right’.
- Coil B current flowing ‘right to left’.

Bipolar stepper motors require a dual H-bridge to drive them, one H-bridge for each coil. Bipolar motors offer increased torque compared to unipolar motors. Flyback diodes are required to prevent voltage spikes when the power to the coil is turned off and the stepper motor acts like a generator briefly (back-emf)[22].

PORTABLE WEARABLE ROBOT EXOSUIT

An exosuit consists of an integrated garment that includes attachment points to the body, a structured textile that transmits loads across the body, and actuated segments that can reducetheir relative length to provide controlled tensile forces in the suit. The suit creates moments around the joints as these forces are offset from the joint centers of rotation due to the tissue and bone structure surrounding the joints[23]. Exosuits offer a number of benefits as compared to traditional exoskeletons. The suits themselves, composed primarily of fabrics, can be significantly lighter than an exoskeleton frame or linkage system, leading to very low inertias and lower cost of transporting the suit mass[24]. Since the suit does not contain a rigid frame, it also provides minimal restrictions to the wearer's natural kinematics, avoiding problems relating to joint misalignment. Further, control for the system can be less precise as the inherent compliance in the system can make it more forgiving. Finally, the suit can also provide torques on multiple joints simultaneously but having it span multiple joints, which may assist with reducing the total number of actuators[25].

BLOCK DIAGRAM

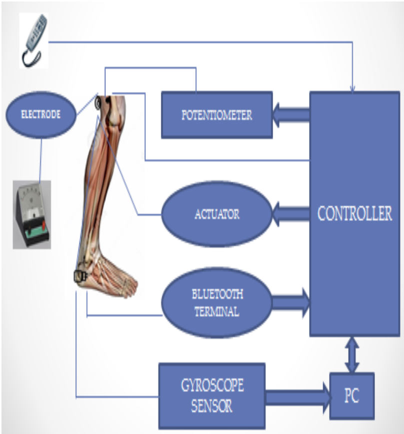

Fig.2 Block diagram

IV. EXPERIMENTS

A wireless remote is used to control the FES.Electrodes are placed on the paretic limb.Since we require 2mA we use a potentiometer or a voltage divider to reduce the output which is then delivered to the electrodes.After stimulation, the paretic limb starts to move with the help of actuator.The movement produced by the muscles is sensed by the gyroscope sensor. The datas collected are transmitted via bluetooth to the PC and to the controller.The collected datas are processed again by the controller.By using the wireless remote switch we can change the movement of direction of the leg[26].

V. CIRCUIT DIAGRAM

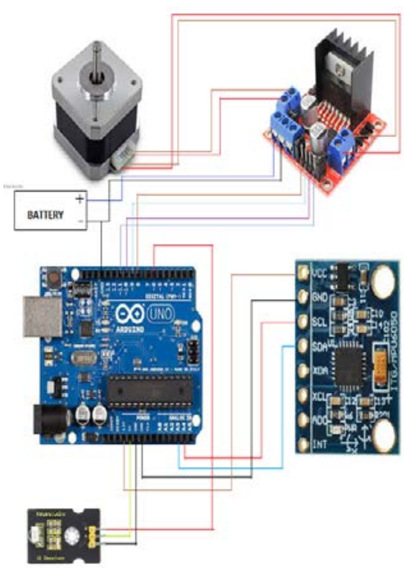

Fig.3 Circuit diagram

VI. RESULTS AND CONCLUSION

In this conclusion, the suit is extremely light, minimizing distal mass, and adds negligible inertia to the legs. The suit feels comfortable and does not cause chafing, even though it moves with the skin a small amount during actuation. The suit also does not constrain any of the degrees of freedom in the legs, and permits the wearer to move through their full range of motion. There are many areas for future improvement of the system. Measurements must be made of the suit's benefit, including metabolic and electromyography measurements.

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