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POWERED LOWER LIMB EXOSKELETON

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ABSTRACT

Robotic exoskeletons have been built for augmenting *human performance, assisting with disabilities, studying human physiology, and re-training motor deficiencies. They have wide range of applications, from improving the muscular capabilities of soldiers in rough terrains to aiding therapists in the rehabilitation of patients who have suffered from neurological conditions in particular to stroke or spinal cord injury. This work presents the methodology of fabrication of a robotic powered lower limb exoskeleton to assist patients with at least one degree of freedom to the knee. This device provides an accurate movement for the displacement of legs with precision and accuracy as an ordinary individual does without any gyroscopic effect usually found in existing devices.*

INDEX TERMS – *Robotic exoskeletons, Lower limb, stroke, spinal cord injury.*

INTRODUCTION

Stroke is the loss of brain function due to disruption in blood supply to and from the brain. Without blood to transfer oxygen and nutrients, brain neurons quickly begin to die (Sims, N.R., Muyderman, & H. (2010). When this occurs, the affected person usually has one or more limbs paralyzed in one side of the body because the contra lateral affected area on the brain can no longer function. When the lower limbs are affected and unable to perform, usually rehabilitation treatment is undertaken to restore gait function and regain the ability to walk self-sufficiently. Over the years and with the improvements in medical technology, a number of individual rehabilitation treatment approaches have been proposed, researched and applied to the concerned patients to improve their overall walking ability (Hollands et al., 2012).

The rehabilitation process to regain lost movements is more effective during the initial months after the stroke onset and it depends a lot on the particular individual. At this stage, intervention programs could be introduced to retrain the capability to produce strong movements and functional actions of limbs while performing activities of daily living. However, the most important task to be retrained as claimed by patients who suffered a stroke, is the option to walk again, in order to return to a normal life as soon as possible (Ditunno et al., 2006). Task oriented and highly repetitive practice is recognized as an intervention for the restoration of the gait function. Recently, in an effort to improve the recovery process in the after case of a stroke, many autonomous robotic platforms have been developed (Dollar, A.M., Herr, & H., 2008). Also, a significant amount of work has been done to validate the efficiency of robotic rehabilitation compared with manual physiotherapy in patients who suffered from a stroke. Robotic rehabilitation is an ongoing research field that tries to comprehend the recovery process, methods implemented and improve it by applying robotics devices. This rehabilitation process aims to develop therapies using robots or robotic devices that can be completely or partially automated as therapy aid devices (Krebs et al., 2004). The robotic equipment for gait training are divided mainly into two groups: end effectors and powered exoskeletons. The first group of devices, end-effectors, simulates the stance and swing phase during gait cycles, while the patient's feet are placed on footplates. The second group, powered exoskeletons, are more technologically advanced devices. An exoskeleton, from Greek "exo" = outer + "skeletos" = skeleton, is an external structure that supports and protects an animal's body, in contrast to the internal skeleton of, for example, a human. Powered exoskeletons are wearable robots attached to subject's limbs, in order to replace or enhance their movements. They should be compliant with the user's movements and deliver at least part of the power necessary to accomplish the movements (Mehrholz, J., Pohl, & M., 2012).

LITERATURE REVIEW

Early Exoskeletons

The earliest mention of such a parallel exoskeleton is a set of United States patents granted in 1890 to Nicholas Yagn. His invention comprises long leaf springs operating in parallel to the legs, and was intended to augment the running abilities of the Russian Army. Although Yagn's mechanism was designed to augment running, there is no record that the device was ever built and successfully demonstrated.

The first true exoskeleton in the sense of being a mobile machine integrated with human movements was co-developed by General Electric and the United States military in the 1960s. The suit was named HARDIMAN. Powered by hydraulics and electricity, the suit allowed the wearer to amplify their strength by a factor of 25, so that lifting 25 pounds was as easy as lifting one pound without the suit. A feature dubbed force feedback enabled the wearer to feel the forces and objects being manipulated.

The MIT Bio Mechatronics Group built an elastic exoskeleton. However, its intended application was not for running augmentation, but for lowering the metabolic demands of continuous hopping. The exoskeleton comprises fiberglass leaf springs that span the entire leg, and is capable of transferring body weight directly to the ground during the stance period. Without accounting for the added weight of each exoskeleton, wearing the exoskeleton reduced net metabolic power for continuous hopping by an average of 24% compared to normal hopping. Since the biomechanics of hopping are similar to that of running, it seems plausible that the effects of wearing an exoskeleton during hopping could predict the biomechanical and metabolic effects of wearing an exoskeleton during running and those substantial energetic advantages might be achieved while running.

Recent Developments

Parallel-limb exoskeletons have also been advanced to augment the load-carrying capacity of humans. This type of leg exoskeleton could benefit people who engage in load carrying by increasing load capacity, lessening the likelihood of leg or back injury, improving metabolic locomotors economy, and/or reducing the perceived level of difficulty. The Berkeley Lower Extremity Exoskeleton (BLEEX) was developed by Professor Kazerooni. One of the distinguishing features of this exoskeleton is that it is energetically autonomous, or carries its own power source. Indeed, its developers claim it as the first "load-bearing and energetically autonomous" exoskeleton (Adam Zoss, H. Kazerooni, Andrew Chu, 2005). BLEEX features three degrees of freedom (DOF) at the hip, one at the knee, and three at the ankle. Of these, four are actuated: hip flexion/ extension, hip abduction/adduction, knee flexion/extension, and ankle flexion/extension. The kinematics and actuation requirements of the exoskeleton were designed by assuming behavior similar to that of a 75 kg human and utilizing clinical gait analysis data.

At the University of Tsukuba in Japan, Professor Yoshiyuki Sankai and his team have been developing an exoskeleton concept that is targeted for both performance augmenting and rehabilitative purpose (Kawamoto,

H., Sankai, & Y., 2005). The HAL system does not transfer a load to the ground surface, but simply augments joint torques at the hip, knee, and ankle. The leg structure of the full-body HAL-5 exoskeleton powers the flexion/ extension joints at the hip and knee via a DC motor with harmonic drive placed directly on the joints. The HAL-5 system utilizes a number of sensing modalities for control: skin-surface EMG electrodes placed below the hip and above the knee on both the anterior (front) and posterior (back) sides of the wearer's body, potentiometers for joint angle measurement, ground reaction force sensors, a gyroscope and accelerometer mounted on the backpack for torso posture estimation. The total weight of the full-body device is 21 kg. The ability of HAL to improve performance by increasing the user's capacity to lift and press large loads has been demonstrated. An operator wearing HAL can lift up to 40 kg more than they can manage unaided.

Other exoskeletons like HULC (Human Universal Load Carrier) developed by Lockheed Martin, ReWalk Developed by Acro Medical Technologies, etc. are present now. However, as their description is more or less similar to the ones discussed above and we shall not go into their details further. For recent progress made in this field the reader is referred to (Bortole, 2013)

METHODOLOGY

Introduction

As detailed in the previous section, Exoskeletons were first used by the American soldiers for the military purposes and after that, with improvement in technology it was designed for the people with disabilities. Now also technology is being developed to make this as a complete aid to disabled persons.

But the cost of the equipment is very high and which restricts its access to large section of society. With that limitation in mind we designed this for the people who are having disabilities and which can be afforded by all classes of people.

Design Aspects

In this section the design aspects and what all considerations we put while designing the exoskeleton are explained.

Manufacturing Aspects

Based on the data collected and research, we started the design of exoskeletons.

We designed the device with the help of CAD software's such as Solid Works and CREO. The next part of project was divided into three main stages/phases in the manufacturing side, which were;

1. Mechanical design
2. Electrical design
3. Computer programming

Mechanical and Electrical Design

The major components involved in the design and the fabrication of the assistive limb are as follows.

- Motor,
- Battery,
- Cam mechanism,
- Bearing with bearing cap,
- Spur gear,
- ON/OFF switch.
- Microcontroller ATMEGA 16
- Accelerometer ADXL335
- Relay Board-Single pole double throw.

PROCEDURE & WORKING PRINCIPLE

The experiential setup consists of a leg frame in which the thigh frame and the bottom leg frame are pin jointed so that they can be folded and expanded as a normal leg. Then using double crank mechanism, the thigh part is made to reciprocate so that the walking motion can be achieved.

A motor is used for powering up the cam mechanism and the motor is actuated with the help of the battery. A toggle switch is provided on the frame in order switch ON and OFF the entire operation with ease. Hence when the button is pushed and the operation is switched ON, the supply from the battery reaches the motor thereby giving energy to the microcontroller. The suitable timings can be achieved by the programming part. The motor starts operating in the desired path.

First the motor in the knee part will be actuated. The motor rotates and delivers power to the link through a set of spur gears. The spur gears are used for the suitable speed reduction. This mechanism is used to convert the rotary motion to the reciprocating motion. and after a to and fro motion of the knee the ankle joint will be start moving. then after a time delay the second leg starts to move. due to lack of funds we couldn't manufacture the second part; instead of which we put an indicator LED will blink and shows the operation after that time cycle it start again. We had added an accelerometer for the gyroscopic detection. If there is any unbalance the accelerometer helps for that identification to the doctors as well as the patients. Another led is used for the detection of gyroscopic changes. Since this is a powered device battery level indicator LED is used to alert the patients in case of low charge.

RESULT & ANALYSIS

We have completed the manufcaturing part as per the design. The experiential setup consists of a leg frame in which the thigh frame and the bottom leg frame are pin jointed so that they can be folded and expanded as a normal leg. Then using double crank mechanism, the thigh part is made to reciprocate so that the walking motion can be achieved. A motor is used for powering up the cam mechanism and the motor is actuated with the help of the battery. A toggle switch is provided on the frame in order switch ON and OFF the entire operation with ease. Hence when the button is pushed and the operation is switched ON, the supply from the battery reaches the motor thereby giving source to the microcontroller. With the suitable timings given in the programming part the motor starts operating. First the motor in the knee part will be actuated. The motor rotates and delivers power to the link through a set of spur gears. The spur gears are used for the suitable speed reduction. This mechanism is used to convert the rotary motion to the reciprocating motion. and after a to and fro motion of the knee the ankle joint will be start moving, then after a time delay the second leg starts to move. due to lack of fund we didn't manufactured the second part instead of we put an indicator led will blink and shows the operation after that time cycle it start again. We had added accelerometer for the gyroscopic detection. If there is any unbalance the accelerometer helps for that identification to the doctors as well as the patients. Another led is used for the detection of gyroscopic changes. Since this is a powered device it's very difficult to know the battery level to the patients so for that again another led is used for this process to identify the battery level. After the whole process we had done the analysis for the best suited material. We did the analysis with epoxy, aluminum alloy. Of which epoxy is the best material.

ADVANTAGES

- Less number of moving parts.
- Highly reliable.
- The cost of the system is low.
- Maintenance is easy
- Parts are easily available in the market
- Construction is simple
- Easy to operate

DISADVANTAGES

- This device is designed to be used particularly for the leg handicapped.
- Constant power source is needed that should be both lightweight and cost effective.
- The battery must be checked and replaced periodically.

APPLICATIONS

These assistive limbs for handicapped have a wide range of applications like,

- Highly suitable for handicapped and physically disabled persons,
- Helpful for those who have problems in walking.
- It is highly suitable for aged persons for aiding them in their walking.
- It can be used for both physiotherapy and gait analysis.
- With the help of brain wave sensing mechanisms, a more autonomous and direct control of the device via the mind is possible.

CONCLUSION

We designed and fabricated a working prototype. It can be used for paraplegic and stroke patients who has at least a single degree of movement in their legs. The device is hardwired for now i.e. could be made on & off with a switch. Also we have programmed the movement functions of the device with the help of a microcontroller, to which other external sensing devices and indicators could be attached for increasing the flexibility and user-friendliness of the exoskeleton. Mild Steel was used for building the prototype, however we did the analysis for locally available better materials for fabrication. Analysis was done for materials like epoxy and aluminium alloys of which epoxy was better suited to our design.

In future, more research in this area can pave the way for more enhanced robotic therapy. Also with help of these devices augmentation of human muscle is possible, especially in people with disabilities or who are in old age.

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