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THE NEURA-FEAT POWERED EXOSKELETON; DESIGN AND CONTROL

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ABSTRACT

Currently between 250,000 and 500,000 people globally suffer a life-changing spinal cord injury (SCI) each year increasing both the morbidity and mortality of those afflicted [1]. The design of robotic exoskeletons to support, protect and enable movement of disabled individuals have been developed for the past 35 years [2]. However, the successful design of a human like exoskeleton which act smoothly based on the person brian orders without external inputs still is a challenge. This paper presents the design of the Neuro-Feat exoskeleton which uses the brain signals through a brain computer interface to control the exoskeleton actions. The goal of this project is to help SCI people with a reliable, helpful and affordable exoskeleton help them in tackling daily life challenges without relying on others. The design requirements and the challenges for Neura-Feat evaluation comply with the regulations of the Cybathlon competition on 2020 in Zurich.

INTRODUCTION

The number of people in the United States with an ambulatory related disability ranges from 11.2% (West Virginia) to 4.2% (Utah)[3]. Canadians on average by comparison range from 4.3% to 44.5% physically disabled depending on the age demographic, with 12.5% of men and 14.9% of women being afflicted with some sort of mental or physical disability on average a majority of which is related to dulled senses or reduced ambulation [4]. People afflicted with this condition are 2-5 times more likely to die prematurely as compared to those without a spinal cord injury; additionally those afflicted suffer from a range of debilitating and deadly secondary conditions that negatively impact their health such as deep vein thrombosis, urinary tract infections, muscle spasms, osteoporosis, pressure ulcers, chronic pain and respiratory complications[1]. These conditions additionally put a lot of strain on the healthcare systems economically increasing the costs of healthcare and decreasing the accessibility.A majority of these problems could be alleviated by an intelligent machine which can be worn that amplifies the user's sensory capabilities as well as enhances mobility and dexterity.

Exoskeletons are external skeletons that support, protect and enable movement of physically disabled individuals. However, exoskeletons demonstrated limitations with regards to controls such as those used by rewalk which rely on stilts and predominantly physical and electromyography (EMG) based sensors that read what the user's upper body is attempting to do in order to control the body; additional restrictions are cost, as most walkers can be prohibitively expensive to everyday potential users of the technology [4, 5]. The exoskeleton over-all is designed as an actively controlled suit with hip adduction/abduction, rotation and raising the knee being capabilities of the hips.

This project designed a lower limb exoskeleton that will aid with mobility to individuals with paraplegia and other mobility related conditions that adversely affect their ability to control and move their lower body. This endeavour is being driven by the effort on the part of faculty and students alike who are part of the University of Prince Edward Island (UPEI) Society known as +1 Cybernetics.

The exoskeleton was named Neura-Feat; the precursory word "neura" comes from the fact that the inputs are based on the user's neural network being read by the headset and additional sensors. The acronym "feat" comes from its double entendre with the word feet, as the walker itself is designed to augment the lower capabilities of the body. The term "feat" additionally means "an achievement that requires great courage, skill, or strength" [definition from google dictionary] which reflects what the user is doing everytime they defy their fate by choosing to walk through working in harmony with an external technology. The acronym stands for "Freedom Enhancing Augmentative Technology" emphasizing its primary purpose which is to liberate the user from whatever mobility related limitation ails them.

DESIGN

Design Requirements

The design requirements follow the regulations of the Cybathlon competition on 2020 in Zurich [6]. The maximum walking speed of the exoskeleton is 1.42 m/s which is determined as an average speed of a healthy individual. However, this maximum speed can be decreased in the exoskeleton settings to comply with safety regulations especially in first trials.

Neura-Feat's function has been designed to tackle the challenges related to the daily life activities experienced by those with ambulatory limiting conditions. The weight restriction for the Cybathlon and the minimum standard for our walker is 75 kg [6]. For optimal functionality the goal for the neura-feat walker is to set the maximum weight restriction for 35 kg; this goal can be achieved through the use of lightweight metals and 3D printed plastic parts.

There are some tasks that have been designed to evaluate the Neura-Feat's functions including: sitting, standing, slalom between objects, ascending/descending a ramp, opening doors, walking on rough terrain, walking on a tilted path, and ascending/descending stairs [6].

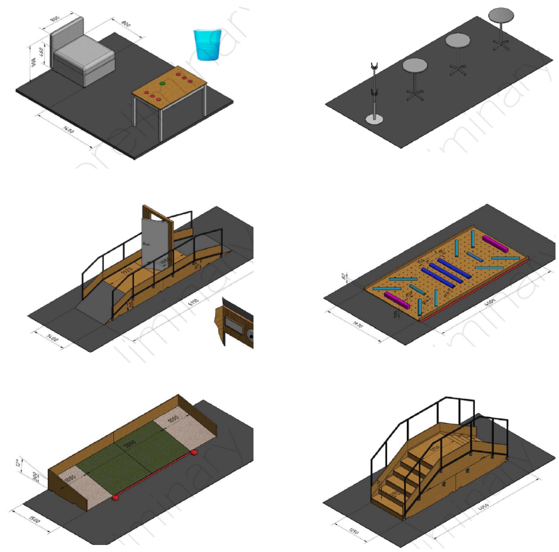

Figure 1. Challenges for Neura-Feat [6]

Table 1.Design Criteria

Design Parameter	Value
Maximum Speed	1.42 m/s
Neura-Feat Weight	<35 kg
Pilot Weight	<80 kg
Pilot Height	150 cm – 190 cm
Pilot hip width	35 cm – 50 cm

Table 2. Joints degree of freedom, range of motion, and actuation type

Joint	Range Degree	Powered
Hip Abduction / Adduction	30 / 20	Yes
Hip Flexion / Extension	90 / 20	Yes
Hip Rotation	40 / 20	Yes
Knee Flexion / Extension	150 / 5	Yes
Knee Abduction / Adduction	0/0	-
Knee Rotation	0/0	-
Ankle dorsiflexion / plantarflexion	20 / 20	Yes
Ankle Inversion / Eversion	10/10	Yes
Ankle Rotation	40 / 20	No

The purpose of Neura-Feat is helping Spinal Cord Injury (SCI) persons to tackle the mentioned challenges by using crutches. However in the next phase of the project we will develop a Neura-Feat version that could be used without any external help. The design criteria of Neura-Feat is summarized in table 1. The maximum required torque is considered as

100 Nm and the actuators are selected based on this required torque [7, 8].

The degree of freedom, the range of movements, and the passive and active actuation type of each joint DOF is illustrated in Table 2.

Actuators

Neura-Feat uses five identical actuators for knee and hip active control. Each actuator consists of a DC brushless motor and harmonic drive gear reduction system. For ankle dorsiflexion / plantarflexion control, a linear actuation system consisting of a ballscrew and a DC brushless motor beside of a spiral series spring and a joint encoder have been used. For ankle inversion/eversion active control, a rotational actuation system using a solid shaft servo motor has been designed and implemented, figure 2.

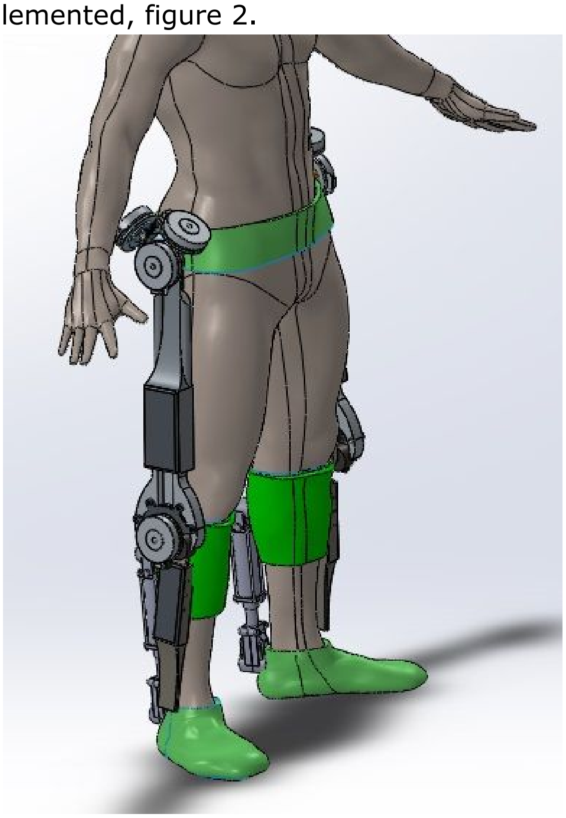

Figure 2. Neura-Feat

Neura-Feat Human Attachment

Neura-Feat is attached to the body in several locations. It is connected to the body in thigh, shank, foot, torso, and pelvis. Cuff type braces are used to connect the exoskeleton to the body. The foot and pelvis connections are tight to prevent the exoskeleton detachment.

Control

The Neura-Feat Walker will be controlled through a series of inputs received through interfacing with the pilot's central nervous system. These commands will be interpreted, and the intended output will be executed by an onboard central processing unit.

Brain Computer Interface

Interfacing with the pilot's nervous system will be done using several methods. An electroencephalogram, or EEG, of the pilot will be monitored measuring voltage fluctuations through multiple sites on the user's scalp. These fluctuations, or neural oscillations, will be monitored for patterns that we will use as one of our input sources. Additionally, an electromyograph, or EMG, will be conducted on several muscle groups measuring the voltage generated by the muscle cells for additional control inputs. Both the EEG as well as the EMG will be consolidated with the Cyton and Daisy Biosensing (8-16 channel) board from OpenBCI [9]. OpenBCI is an open source brain-computer interfacing company providing hardware as well as software and baseline data through Github. The board we will be using, allows for 8-16 channels to use for inputs and data comparison options to be more specific [9].

Processing

After consolidating the data, the wave patterns gathered from the 8-16 channels will be analyzed looking for pre-designated patterns. These patterns will be initiated by practiced thoughts and muscle activation combinations. Once recognized the suit will begin the assigned action to that input, for instance the through of moving forward in addition to squeezing the left bicep could be used to initiate moving through a forward gate cycle.

The Neura-Feat walker additionally utilizes OpenBCI's 3D printable neural headset to make a cost effective control system that uses both EEG (electro-encephalography) as well as EMG additionally with stilts, creating a seamless control system that gradually adapts itself to the user based on their neural patterns. The long-term goal of the research being conducted with respect to this project is to develop an algorithm that recognizes and engages in particular forms of ambulation based on what the user is thinking allowing the internal artificial intelligence (AI) to develop a library or internal memory of unique signals based on the user.

This library will act like a neural engram, allowing for the AI contained within the walker to develop meanings behind what specific patterns of neural signals mean allowing for the AI to cut down on the time it takes to respond to the user. This occurs similarly to the auto-correct function on a cellular device in that the more the user uses types in specific words the faster the phone's AI becomes at predicting what words the user is attempting to type, even if only a couple letters have read. This premise is identical to how Neura-Feat except for movement, mimicking both how our own neural system processes information as well as how AI and Deep Neural Nets currently work.

Another unique capability of Neura-Feat is that the ankles utilize active control based off of two prosthetic ankles, one designed by the military and the other known as the iWalk BiOM [10, 11]. The active ankle piston design allows the user to easily perform more complex movement than they might otherwise be able to handle; based on biomimicry it is based off of the calf's natural musculature, particularly the medial and lateral heads of the gastrocnemius as well as the Soleus and Achilles tendon.

CONCLUSION

In this paper, Neura-Feat a powered exoskeleton for person with SCI was introduced and the design considerations were elaborated. Neura-Feat has been designed to enable persons with SCI to tackle the challenges related to the daily life activities. Neura-Feat design requirements followed the regulations of the Cybathlon competition on 2020 in Zurich. Furthermore, the brain computer interface of Neura-Feat as a beneficial system for controlling the exoskeleton was developed in details. Neura-Feat will be fully developed for the Cybathlon competition in 2020, where will be tested and optimized for the SCI athlete.

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