



A Review on Electromechanical Methods and Devices for Neural Rehabilitation



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Abstract

To help patients suffering disabilities caused by damage to neural system, engineers have developed new methods and devices. A recently emerging technique is called Functional Electrical Stimulation which is the application of electrical charge for stimulating damaged organ nerves and recover some muscular functions. In this paper, we aim to review the most recent developments in neural prostheses and their structures which have been designed and built to apply this technique to patients' nervous system.

Introduction

The nervous system of most quadrupeds consists of two main systems: The Central Nervous System including brain and spinal cord and the Peripheral Nervous System which is a large nervous system running through the body, controlling all voluntary and automatic body movements [1,2]. Disease like peripheral neuropathy [3], damage in spinal cord [4] and severe stroke to head can cause numbness, weakness, trouble with grasping items, problems with walking and balancing or severe debilitating disabilities. Some of these diseases and symptoms can be treated by medicines, physical therapies and surgery; however, in many cases, patients face permanent disabilities specially with those diseases related to brain and spinal cord injuries since these organs include a complex system of nerves and regeneration of those nerve cells after injury is impossible. To help patients with these sort of disabilities, engineers have proposed several electromechanical systems and methods such as designing and building neural prostheses to help patients restore some lost organs functions. In this article, we review recent developments of neural prostheses and their structures.

Neural Prostheses

Neural prostheses are a series of assistive devices which are designed and used for therapeutic electrical stimulation, reduce pain and even substitution of sensory or motor functions lost through damages caused by injury or a disease to the neural system to restore or rehabilitate normal bodily functions [5-9]. Many of these devices use a technique called functional electrical stimulation (FES) to stimulate peripheral nerves electrically using skin or implanted electrodes [10-15]. Although skin electrodes are safer and easier for patient to apply on body, a large current is needed for

stimulation of nerves. Implanted electrodes can be planted at proximity of target nerve to use smaller current for stimulation. These electrodes are more complex than ordinary surface electrodes and must be clinically safe and durable [16].

Although design, construction and use of neural prostheses with implantable electrodes and stimulators are complex, in recent years, using them in patients' bodies for various purposes have been grown. To produce these stimulators, technologies like construction of pacemakers may be used so that these devices can be remain in body for years and agitate target tissues nerves using electrical stimulations [16]. Example of these kinds of neural prostheses are dorsal column stimulator [17] and deep-brain stimulators [18-20] for release pain and reduce spasticity, phrenic nerve stimulator for respiration [21,22], sacral root stimulators for bladder control [23,24] and peroneal nerve stimulator for counter-acting hemiplegic foot drop [25,26].

Neural Prostheses Structures

Over recent decades, progresses have been achieved for rehabilitations and physical movements in paresis or paralyzed patients using FES technique [27]. Various optimized cycling mechanisms, stimulation strategy and stimulation patterns have been studied to rehabilitate lower-limbs of paralytics using FES to pedal stationary cycle [28-38]. Bellman et al. [39,40] designed an experimental set-up using a stationary cycle with an optical encoder and a sensor attached to the crank to measure cycling cadence and crank position, a current controlled stimulator to produce pulses to activate target muscles, a data acquisition hardware and software to analyze input data from sensors and calculate output command to be applied to

muscles and finally skin electrodes to deliver current to muscles. They proposed a switched system theory and a nonlinear model of a stationary FES-cyclingsystem to improve cycling cadence and performance.

Data acquisition system

Neural prostheses inducing FES usually have a data acquisition system to receive data from sensors and analytically determine the input command to muscles. This system is part of device stimulator and usually uses a controlling strategy to actively control the stimulation and induce proper charge to muscles to track the desired trajectory. For stationary FES systems, when the space limit is not crucial, usual data acquisition systems like computers or industrial or commercial stimulators like Compact RIO and Grass S8800 [41,42] can be used. For portable neural prostheses, the stimulator must be light and small and in many cases, wearable. Recently, with the advent of small and low-cost microcontroller platforms like Arduino microcontroller, wearable and carryable FES-based neural prostheses also have been designed and built [43,44]. Melo et al. [43] used Arduino MCU as their analytical modulus to develop a gait neuro-prosthesis. In their system, data received from Inertial measurement units and force sensitive resistors is analyzed and muscle stimulation command for drop foot correction is sent to an actuation modulus of the system.

Sensors

Sensors functionality in neural prostheses is sometimes detecting and tracking patient gait events and send the data for further analyses to device data acquisition system. For example, force sensing resistors are used under the shoe or sole to detect the time when foot heel touches the ground [45-47] or gyroscopes and accelerometers to measure velocities and accelerations of different patient's body parts to detect feet gait events such as initial contact, foot-flat start, toe-off and heel-off [48-57]. Maqbool et al. [58] used an inertial measurement unit (IMU) attached to the shank of amputees for detecting patient's gait event at real time. The IMU could measure the angular velocity and linear acceleration of the shank and these data was used by data acquisition system to detect gait with accuracy of 99.78% using a special algorithm.

Neural Prostheses Applications in Animals

Neural and spinal cord damages and diseases are also common in animals and can cause effects and symptoms like in humans. Dachshund, for instant, is a kind of dog which highly susceptible to spinal cord injuries because of its special physical body. This dog is famous for its short legs in comparison with its long body which makes dog more prone to breaks and damages to back of dog where the spinal cord located. If damages to spinal cord occurs, dog may lose its sense and movement abilities in its back leg. Sometimes dog loses its walking ability completely, however, in many cases, dog automatically moves its legs and even walk because of reflexes in muscles when dog toes touch the ground. Even in such cases, dog frequently falls since it has no sense in back muscles and ligaments and cannot control its body or balance its hip.

Rehabilitation treatments of these injuries in dogs is a challenge for Veterinarians. Taghavi et al. [59,60], invented a "balancing device" to correct the gait of these patient dogs. This device included an Arduino Uno microcontroller for gathering data from an IMU and functions as a stimulator to apply voltage to target muscles. The IMU attached on the hip of dog sends data about the hip balancing status by measuring angular velocities and accelerations. The amount of voltage and the duration of stimulation is based on different algorithm and strategies that are programmed and uploaded to microcontroller. These strategies were developed based on dog anatomy and gait analyses.

Conclusion

In this paper, we reviewed newly developed neural prostheses which deliver functional electrical stimulation to damaged nerves. We showed these devices include data acquisition systems and sensors to obtain sensing data, analyze stimulation command and provide enough charge which is delivered to target nerves using electrodes. Several different processors and microprocessors as well as electrical sensors can have applications in designing and building of such devices. We explained examples that shows these devices can help both humans and animals patients.

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