Wireless Functional Electrical Stimulation (FES): Development of a Novel System for Cycling Applications

Bracher, Manuel J., Institute for Rehabilitation and Performance Technology, Bern University of Applied Sciences, Switzerland
manuel.bracher@bfh.ch

Hunt, Kenneth J., Institute for Rehabilitation and Performance Technology, Bern University of Applied Sciences, Switzerland
kenneth.hunt@bfh.ch

Introduction

The loss of voluntary function in limbs and other body parts, also known as paralysis, is caused by disease or injury to the neuromuscular system. A subset of such disorders results from injury or disease that affects the central nervous system. However, in an upper motor neurone lesion, the muscles themselves retain their ability to contract and produce force. By applying appropriate electrical fields to the lower motor neurones, action potentials are provoked artificially. Functional Electrical Stimulation (FES) is used to restore body functions such as walking, grasping, hearing, drop foot correction or cycling.

Mobile and dynamic applications, such as cycling or walking, require powerful, portable devices of small size, which allow the patient to move freely and without disruption by long wires. Most currently available devices for FES come in a bulky design and thus are restricted in portability.

The aim of this project was to develop a novel wireless controlled FES system, which provides functionality for cycling applications and fulfils output performance requirements for the activation of large human muscles.

Methods

The proposed FES system consists of three major sub-units. The first one is the coordination unit, which serves as a user interface and manages the overall process. It interacts wirelessly with up to 8 stimulation units, which form the second major sub-unit. Each stimulation unit generates modulated electrical pulses on four channels simultaneously. In cycling applications two stimulators are required – one per leg. A sensor system, including a data transmitter, is placed directly on a recumbent tricycle and forms the third sub-unit of the system. It logs sensor data from an encoder, throttle and emergency stop button, and sends it wirelessly to the stimulators. Depending on the pedal position, measured by the encoder, specific leg muscles are triggered phase-wise in order to obtain a cyclic motion of the legs. Using the throttle, the user can change the stimulation intensity via proportional adjustment of the pulse width. An emergency stop button enables the rider to stop the stimulation process immediately.

The hardware and software for the stimulators and the data transmitter, as well as the application code for the smartphone-based coordinator (Samsung Galaxy S5 running Android version 4.4.2), were fully developed in-house.

Different wireless technologies were investigated in order to set up an effective and low power network. ANT technology was selected due to its flexibility in network topologies. However, the hardware of all network nodes (Samsung Galaxy S5 and Nordic Semiconductor nRF51422) also supports Bluetooth Low Energy (BLE) and could therefore be used as an alternative with modified software.

Results

The whole system has been implemented and tested. The user interacts via a graphical user interface of a smartphone (Samsung Galaxy S5). Stimulation parameters can be set individually for each channel on each unit (current amplitude: 10-150 mA, pulse width: 15-500 µs, frequency: 5-100 Hz). The accuracy of stimulation pulse modulation is of the order of a few microseconds with regard to timing and 0.5 mA in amplitude. There are available two operation modes: test mode and cycling mode. In test mode, each stimulation channel is enabled and disabled manually. In contrast, when cycling mode is active, channels are activated dependent on the pedal position and the defined active angle range for each muscle group. Angle ranges can be adjusted for each patient individually. User can set stimulation pulse with via the throttle and stop stimulation immediately via the emergency stop button. Textile leg pockets allow installation of the stimulation units directly on a patient's legs in order to keep the distance to the surface electrodes as short as possible. Each stimulator has a size of 94x65x27 mm. Wireless range is approx. 30 m.

Conclusion

The aim of this work was to develop a wireless system which can be specifically used for FES cycling and generates stimulation pulses with sufficient intensity for the activation of large muscles.

Tests have shown that the specifications were met and performance requirements were fulfilled. Pulse modulation can be rated as very accurate in terms of timing and amplitude. The wireless range is sufficient for rehabilitation applications. Due to its aspect ratio, minimal wire length and ease of operation, this novel system has substantially improved functionality when compared to existing FES devices.