

Eight-Channel Stimulator for Paraplegic Cycling

M. Bijak⁽¹⁾, M. Reichel⁽¹⁾, C. Hofer⁽²⁾, M. Gföhler⁽³⁾, W. Mayr⁽¹⁾,
T. Eberharter⁽³⁾, T. Angeli⁽⁴⁾, P. Lugner⁽³⁾, L. Rinder⁽⁴⁾, H. Kern⁽²⁾

⁽¹⁾ Department of Biomedical Engineering and Physics, University of Vienna

⁽²⁾ Department of Physical Medicine and Rehabilitation, Wilhelminenspital

⁽³⁾ Department of Mechanics, Vienna University of Technology

⁽⁴⁾ Institute for Machine Elements and Machine Design, Vienna University of Technology
Vienna, Austria

E-mail: m.bijak@bmt.p.ac.at

Abstract - An eight-channel surface stimulation system, designed for paraplegic stepping was adapted for paraplegic cycling on a newly developed tricycle.

The stimulation system consists of two four-channel modules an Inter Integrated Bus (I2C) to RS232 interface for direct stimulator control and data exchange and a standard laptop computer.

A software package for personal computers with a comfortable graphical user interface allows evaluation and testing of complex stimulation patterns for cycling.

Mechanical properties of the tricycle were investigated first in a simulation process and then in vitro on a multiply adjustable test bed. Static and dynamic measurements of the pedal forces and drive torques applied to the crank help to optimise the tricycle layout and the stimulation sequences.

Standard hydrogel surface electrodes were applied to m. quadriceps, gluteus maximus, hamstrings and peroneal reflex.

A sensor reports the position and velocity of the crank to the laptop computer via RS232 port for calculation of velocity depending start and stop points for each stimulation channel.

Keywords: FES, paraplegia, multichannel, stimulator, tricycle, cycling

1. Introduction

Functional electrical stimulation (FES) for reactivation of lower extremities of paraplegic patients is subject to scientific research since the early sixties. Experiments with surface electrodes led 1982 in Vienna to the worldwide first implantation of a 16 channel stimulation system for lower extremities [8]. The four implanted patients were able to stand up, perform crutch supported walking and sit down. Also riding a special designed tricycle was possible [5].

But implantable technology did not replace surface stimulation systems. A rapid progress in microelectronics helped to miniaturise stimulators while surface electrodes became easier to handle and more reliable. Rehabilitation with surface electrodes is still in the focus of several scientific groups.

Twenty years of FES taught us not to overestimate the functionality of the technical devices we offer the patient [6]. We should not overlook that getting out most of a “leg pacemaker” will cost the patient lots of patience, efforts and time - comparable as much time as someone invests into his favourite hobby or into his seriously practised sportive activity. Therefore it must be our goal to provide as much functionality and “fun” to make the FES training enjoyable.

Cycling is a sport that involves lots of advantages. It can be done outside enjoying nature, has lots of social aspects and is an excellent training for the leg muscles and the circulation. In addition, compared to other means of locomotion, cycling converts the force applied to the pedals into motion with very high efficiency, an important fact for the locomotion of paraplegics.

Based on this thoughts we started an interdisciplinary project to develop a tricycle for FES-experienced paraplegics with the following requirements:

- Must be small and light enough to be transported in a car
- Should work as a wheelchair extension
- Must have sufficient stability in curves
- User should be able to get on and off without assistance
- Must have a small auxiliary motor – just in case

2. Material and Methods

Lots of publications describe the cycling behaviour of able-bodied individuals. Based on this research a cycling strategy for paraplegics has to be developed. Data retrieved from a special constructed multiply adjustable test bed helped to model and simulate paraplegic cycling. In vivo testing and the simulation outcome provided the necessary parameters for the mechanical construction. Especially a four bar linkage was constructed to create an optimised (non-circular) pedal path. In comparison to a circular pedal path higher efficiency of movement and a smaller hip angle for reduction of spasm probability are achieved [1; 2].

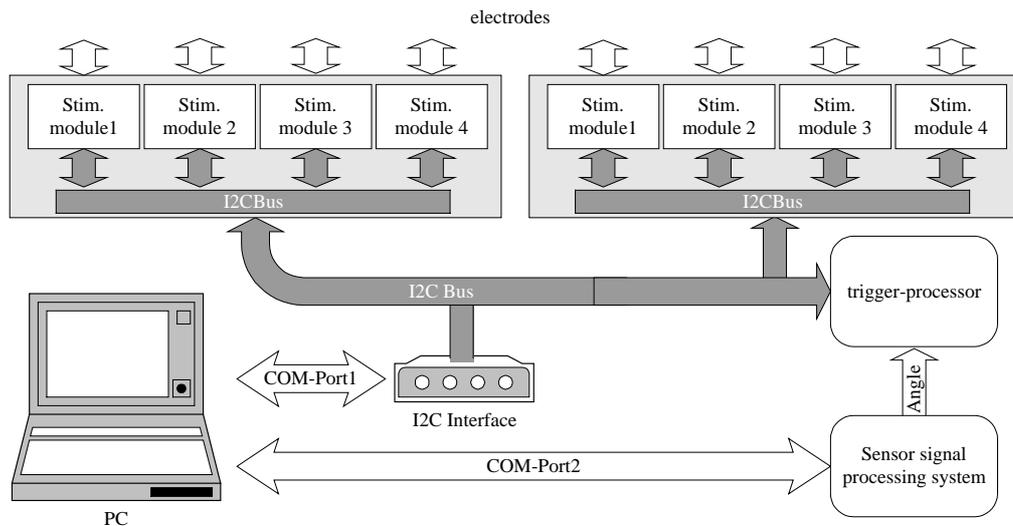


Fig. 1: Schematic of a stimulation system for paraplegic cycling

For first experiments two simple analog controlled three-channel stimulators were used. But to establish a more complex and optimised stimulation pattern a PC-controlled eight-channel stimulation system, originally designed for paraplegic stepping [3] and to prevent muscle atrophy for cosmonauts in low gravity surroundings [7], was adapted to the cycling task.

The eight-channel stimulation system (Fig. 1) consists of two four-channel stimulation modules. Each channel has its own microcontroller (PIC 16C72, Microchip, Chandler AZ, USA), transformer decoupled constant voltage output stage and stimulation current detection unit for electrode condition monitoring and can handle completely independent a stimulation sequence like shown in Fig. 2. which displays the positive envelope of the biphasic impulses. Three in time and amplitude individually adjustable sections (part1 to part 3) represent the burst. Continuous stimulation before and after the burst can be enabled or disabled as required. Each greyed region allows individual adjustment of stimulation frequency and pulse duration.

Each single channel can store two of the described stimulation bursts. Transmitting a short two-byte command does activation.

All eight channels are internally linked together via Inter-Integrated circuit (I2C) bus, a two wire serial bus, supported by the chosen microcontrollers.

Furthermore the stimulation system has to respond to various sensory input signals and must continuously adapt the stimulation pattern according to the cycling speed.

A standard Windows 9x based laptop computer was

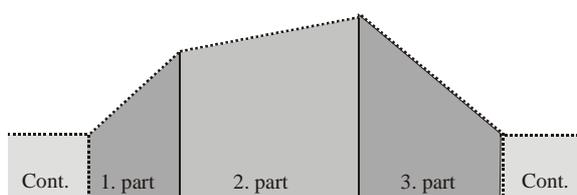


Fig. 2: Stimulation burst stored in each channel

used to achieve a proper stimulation management. This offers the possibility to create a clear user interface to keep track of the stimulation pattern optimisation. As programming platform Delphi (Inprise, Scotts Valley, CA, USA) was used. All data are stored in a database structure and can be managed and evaluated with standard software products.

Since Windows 9x is far away from a real time system all time critical tasks had to be transferred into peripheral hardware. An additional processor (PIC 16F876) monitors the crank-sensor activity and starts and stops the stimulation channels according to the pedal position. All trigger points can be programmed via I2C bus and altered during cycling if necessary. Upon request the trigger-processor can perform a complete stimulator shutdown.

A serial to I2C converter allows the PC to access the stimulation channels via standard RS232 port. Also, due to the lack of real time capabilities of Windows, the whole I2C management - like transmission retry if the bus is busy etc. is handled autonomous from the interface. If a job could not be executed (e.g. if the stimulator is not connected) an error information is passed to the PC. Based on the Borland Visual Component Library a component for communication with the stimulator was written. So the programmer who uses the stimulator must not take care of any communication protocols.

To avoid bus conflicts between the trigger-processor and the serial-I2C-interface I2C-multi-master mode had to be implemented in both devices.

An additional microprocessor system is directly attached to the tricycle and is responsible for the amplification and A/D conversion of ten sensory signals [4] and surveillance of safety limits. The actual values are transferred via RS232 to the laptop computer.

Eight hydrogel electrodes are attached to each leg and connected to four stimulation channel to activate m. quadriceps, gluteus maximus and the hamstrings and to elicit withdrawal reflex.



Fig. 3: T6 paraplegic on the tricycle relaxing between two trials

3. Results

The modified eight-channel system was applied first to able bodied subjects for testing and then adapted to two T6 paraplegic subjects (Fig. 3). After a warming up phase the carefully designed stimulation pattern was tested while the front wheel of the tricycle was put on a treadmill.

The whole stimulation system proofed to be suitable for the described application. The concept to use the functionality of a PC- based software application in combination with peripheral processors to handle the real time tasks proofed to be reliable for this FES application.

The flexibility of the chosen I2C protocol allowed unproblematic integration of the trigger processor into the system without changing the existing hardware. Due to the structure of the I2C protocol stations with different speeds can be connected together without influencing each other and busy (not responding) channels can be simply detect to repeat the communication requests later on. The implemented multi master mode worked reliable, bus collisions could be avoided.

The PC- based software allowed to test, setup and alter stimulation sequences in an easy way. Optimisation of the burst shape and the stimulation frequency led to smooth cycling movements.

The subjects could demonstrate cycling at flat floor and on a smooth uphill course.

4. Discussion

Paraplegic cycling with an eight channel PC-based stimulation system and a new developed tricycle was demonstrated. The huge variety of adjustable stimulation

parameters offered by the system helped to obtain smooth cycling movement though all the available possibilities are not fully exploited.

Furthermore autonomous (self learning) optimisation algorithms for maximum efficiency must be implemented for "out of the laboratory" use.

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