Drop Foot Stimulator with capability for programmable dynamic adjustment of stimulus intensity

Paul Breen, Gerard M. Lyons, Karol O'Donovan, Derek T. O'Keeffe, Thomas O'Halloran*

Biomedical Electronics Laboratory, Department of Electronic and Computer Engineering, University of Limerick, Ireland.

Introduction

The use of FES is well established; in 1961 Liberson et al [1] used a rectangular stimulation intensity envelope in an attempt to correct hemiplegic drop-foot. The intensity envelope is the signal describing how intensity varies during the gait cycle. For Liberson, intensity underwent a step function switch-on at heel-off and a step-function switch-off at heel contact. Thus the intensity envelope was rectangular in shape. Technology has evolved a great deal since then, as have the methods used to combat drop-foot [2]. Currently the most common intensity envelope in drop foot stimulators is trapezoidal in shape, with a ramp up period at the beginning of swing (to avoid a spastic reaction of the calf muscle) and a ramp down period during loading response to avoid foot-flap. This paper describes the development of an intelligent drop foot stimulator with the ability to programme a stimulation envelope of any shape and which adjusts the delivery of the stimulus to reflect walking speed changes by the subject. The system was developed by interfacing an existing clinically approved and commercial muscle stimulator, the NT2000 from Neurotech, with an Analog Devices micro-controller evaluation board (ADuC812S).

A Visual Basic interface was written to enable the intelligent stimulator to be configured graphically using a PC prior to fitting on the patient. The four major events in the gait cycle of interest are recognised via two, Force Sensitive Resistors (FSR) based foot-switches. Stance and swing phase durations are recorded each stride. The delivery of stimulus in a given stride is determined using the stride time from the previous cycle. The size, weight and portable nature of the evaluation board gives the possibility of a lightweight and non-cumbersome system. The graphical interface approach allows customized stimulation intensity profiles to be provided for each user.

Design

Using an existing electrical stimulator (NT2000), which includes a programming unit, stimulus pulse width and frequency, on/off time, ramp up/down time may be set. In normal circumstances the NT2000 can vary its intensity using an on-board digital-to-analogue converter (DAC), whose reference voltage determines the maximum stimulus amplitude. This is normally set at the maximum 5 Volts, however a modulating 0-5 Volts signal applied to the voltage reference pin of the NT2000 will allow for dynamic adjustment of the stimulus envelope.

In the developed system, the intensity-modulating signal is provided by a DAC output on the micro-controller board (ADUC812S). The value of the modulating signal is determined using a 1-D lookup table of 12-bit values stored in data RAM. The stored value used is based on the position of the user in the gait cycle. The micro-controller uses information from the previous gait-cycle to determine stimulus in the following cycle, based on the following algorithm:

Percentage of Current Gait Cycle Elapsed = (Current Gait Cycle Time/Adjusted Previous Stride Time)*100
Adjusted Previous Stride Time = Previous Stride time with a correction factor for acceleration/decceleration

The adjustment in the previous stride time is achieved using the two foot-switches. The trigger signal for the delivery of the stimulus envelope is the heel-off event. The times that toe-off, heel contact and toe contact were expected to occur are compared with the actual times and the stimulus envelope is appropriately adjusted in real-time.

If an event occurs before the expected time, the stimulation envelope is shifted backwards in time to reflect this and the envelope is scaled down in time. This is necessary as the gait event in question occurred before the expected time, and thus the stride time will probably be shorter than expected. If the event occurs after the expected time then the current stimulus intensity level is held constant until the event actually occurs.

This manipulation of the intensity envelope is achieved using a multiplier mechanism. If a person is accelerating or decelerating, successive strides will be shorter or longer, and the algorithm uses a multiplier mechanism to estimate a required stride time for the current stride.

Two FSR devices are configured in a simple voltage divider arrangement giving a clear change in voltage depending on the pressure on the sensors and these analogue voltage signals are input to one of the micro-controller's ADC.

The lookup table, which is specified by the clinician graphically using a PC-resident GUI, is sent from the PC over a serial link to the micro-controller UART connection. The user is always informed if the transmission of data was successful and a checksum and check-length is sent back to the interface and compared with those calculated locally prior to transmission. Details of stride times, split into times that each event occurred, may be uploaded and charted, and the results may be tabulated to display the longest, shortest and average stride times.

Results

The system has been fully bench tested to confirm performance to specification. The GUI in Figure 1 shows the stimulus graph (higher graph) that was applied to the system, the thresholds for the sensors, the completed lookup table and a typical chart of lengths of the several sections of the gait cycle (lower chart).

The system was also tested under gait conditions, with a healthy subject fitted with heel and toe switches which were input to the unit. An ambulatory data-logger (BM42 Biomedical Monitoring) recorded the stimulator control signal and the foot-switch signals to monitor the performance of the stimulus adjustment algorithm. Figure 2 shows the corresponding output of the system and includes the signals from both heel-switch and toe-switch.

Discussion

A working system for the delivery of a customised stimulus intensity envelope has been successfully developed. The developed system allows a very large number of stimulus intensity envelope shapes to be applied. The system has a novel algorithm for the adjustment of the delivered intensity envelope to reflect changes in walking speed as would occur during acceleration and deceleration. Preliminary testing of the system on a healthy subject is promising with the stimulus control signal being dynamically adjusted to reflect changes in walking speed. More comprehensive testing on healthy subjects will follow and finally testing of the system on a subject with hemiplegic drop foot will be carried out.

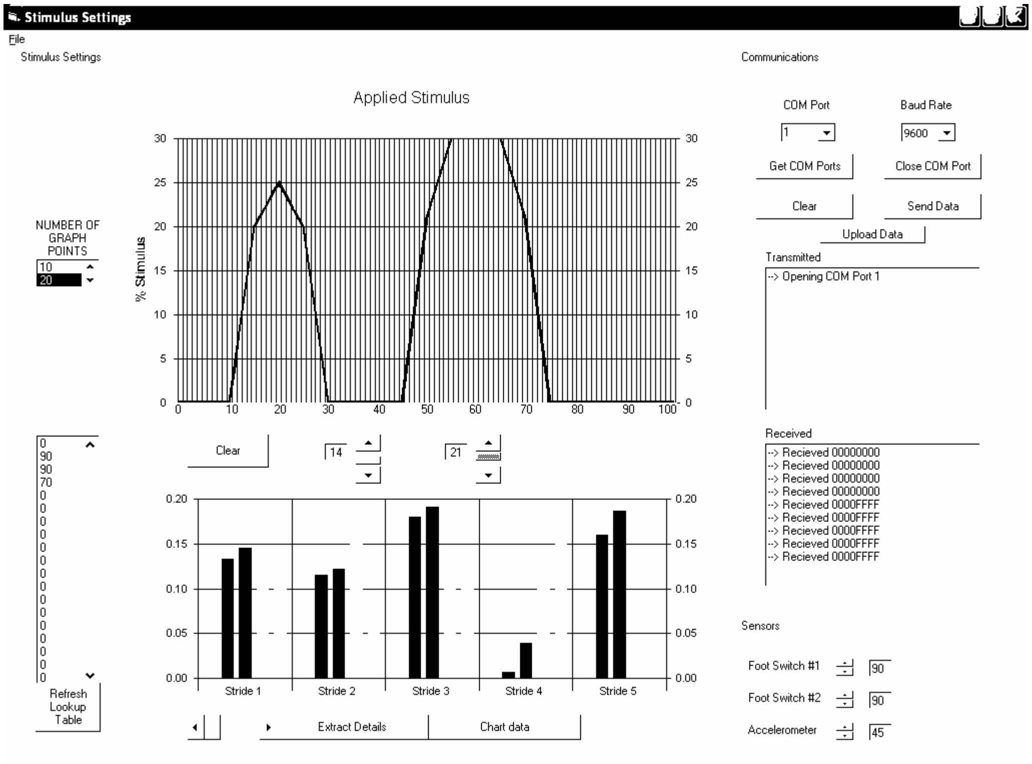

Figure 1

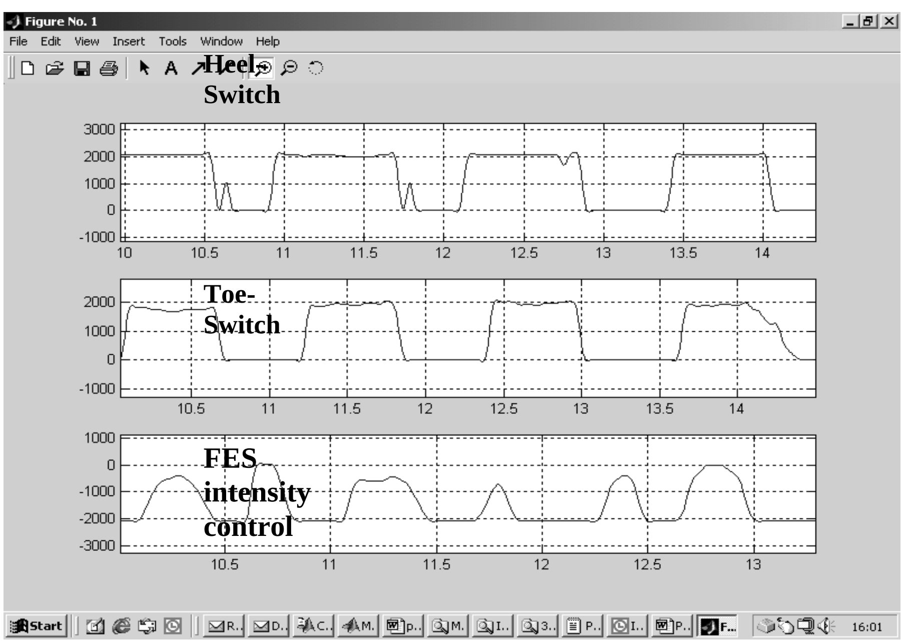

Figure 2

References

[1] Liberson, W.T., Holmquest, H.J., Scott, D. and Dow, M. Functional Electrotherapy in stimulation of the peroneal nerve sychronized with the swing phase of gait in hemiparetic patients. Arch. Phys. Med. Rehabil, 1961. 42:p 202-205.
[2] Lyons, G.M., Sinkjaer, T., Burridge, J.H. and Wilcox, D.J. A review of portable FES-Based Neural Orthosis for the correction of Drop Foot. IEEE Trans Neural Sys. and Rehab. Eng., 2002. 10(4): p. 260-279.
[3] Lyons, G.M., Wilcox, D.J., Lyons, D.J., Hilton, D., Evaluation of a Drop Foot Stimulator FES Intensity Envelope Matched to Tibialis Anterior Muscle Activity during Walking. IFESS 5th Annual Conference, 2000. p. 448-451.