Gait Event Detection Using Intramuscular Electromyography to Trigger Functional Electrical Stimulation in the Child with Cerebral Palsy

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Abstract

Under investigation is whether intramuscular (IM) electromyography can be used to trigger functional electrical stimulation (FES) to improve ambulation for the child with cerebral palsy (CP). In this study, bifilar percutaneous intramuscular (IM) recording electrodes were implanted bilaterally into a quadriceps muscle of a child with CP. Following implantation, 5 walking trials consisting of 2-4 steps were conducted during which gait events and IM EMG data were collected simultaneously. Based on the data from the first trial, a fuzzy inference system (FIS) was developed to determine 5 gait events for one leg from the 2 IM EMG signals and their derivatives. The FIS was evaluated using the remaining 4 trials. For 4 of 5 gait events detected, the average error between the actual and predicted events was 3% of the gait cycle or less suggesting that it may be feasible to accurately detect gait events using IM EMG signals.

Introduction/Background

In order to coordinate the stimulation of specific weak or paralyzed lower extremity muscles to provide or improve upright mobility, a reliable, accurate and clinically reasonable method of detecting critical gait events is required. Thus gait event detection has received considerable attention using various signal sources including foot switches [1], tilt sensors [2], accelerometers [3], and sensory nerve activity [4] among others, employing various state control techniques. Gait event detection using electromyography (EMG) signals from voluntarily controlled muscles has received less attention presumably since FES research has focussed on mobility for individuals with complete thoracic spinal injuries for whom lower limb control is completely absent. Graupe [5] used surface EMG signals from upper trunk muscles to predict intended lower extremity movements for reciprocal walking or postural corrections for static standing.

At our institution we are investigating functional electrical stimulation (FES) as a means of improving walking ability for the child with cerebral palsy (CP) [6]. For this population, voluntary lower extremity muscle activity is present so that EMG triggering of stimulation during gait is conceivable. The EMG signal is attractive for gait event detection for several reasons. The lower extremity muscle activity occurs in a repeatable way with respect to the gait cycle. The target population has numerous potential sources of EMG activity. The technology exists to use completely implanted recording electrodes with an implanted stimulator [7] so that the sensor system itself could be easily implanted in the future avoiding sensor maintenance and donning. Finally, if unique EMG signatures can be extracted for other walking conditions such as on non-level surfaces, steps or ramps then EMG control could be extended to these situations as well.

The goal of this study was to determine the feasibility of using electromyographic (EMG) signals from voluntarily controlled lower extremity muscles to detect gait events (transitions between gait phases) using a fuzzy inference system (FIS). The long-term goal is to eventually trigger stimulation of ill-timed or weak lower extremity muscles in the child with CP based on a real time EMG-based FIS system.

Methods

EMG Recording Electrode Implantation

One 14 year old female with spastic diplegia, CP was implanted with bifilar percutaneous intramuscular recording electrodes to the left Rectus Femoris and right Vastus Medialis using a needle insertion procedure. The electrodes' leads were pathed under the skin to an exit point on the proximal inner thigh for connection to the amplification circuitry.

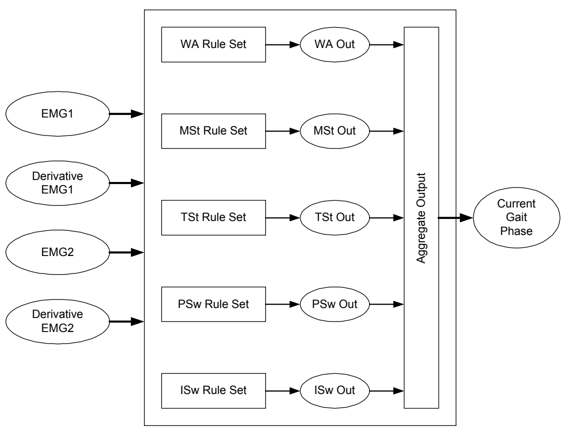
EMG Signal Processing

Motion Lab System's MA-310 EMG pre-amplifiers were used. These pre-amplifiers have a gain of 20 and a bandwidth from DC to 2kHz (-3-dB). These amplified signals were connected to a patient worn backpack unit that provided anti-alias filtering (f_c=350Hz) and bandwidth filtering from 20 to 2,000 Hz. The pack provides an amplitude turn dial that was adjusted to give maximum amplitude during gait without causing the ADC to saturate (rails are +/- 2.5VDC). The EMG signals were then sampled at 1,200-Hz, full wave rectified and low pass filtered using a 2nd order Butterworth filter with a cutoff frequency of 1Hz. The resultant signal is a linear envelope that served as the input to the fuzzy inference system.

Data Collection for FIS Model Development

Using a Vicon motion analysis system, the raw amplified intramuscular EMG signals (bandpass filtered) were collected synchronously with 3 dimensional motions of the knee and ankle using a limited marker set. Five separate trials of 2-4 steps each were collected on the same day. Sagittal plane kinematic data were used to establish the transitions between five gait phases for each leg: weight acceptance (WA), mid-stance (MSt), terminal stance (TSt), pre swing (PSw) and initial swing (ISw). The definitions established by Perry were used [8]. The raw EMG signals as described here were processed as described earlier before passing into the fuzzy inference system model.

Figure 1: Fuzzy Inference System Model Using the Matlab Fuzzy Logic Toolbox (Mathworks, Inc.) [9].



A FIS model was developed using the processed EMG signals and their derivatives and actual gait event data from the first of the five walking trials. Five sets of rules were developed, one set for each gait event (See Figure 1). Rules for only one leg were developed in this initial study. Membership functions were limited to triangular and trapezoidal shapes and the Mamdani method was used to determine the output.

Results

Once the FIS model was established with the first walking trial, the remaining 4 trials of EMG data were applied to the model and the model output was compared to the occurrence of the actual gait events. Figure 2 shows an example of the FIS model output based on the input EMG data.

Figure 2: Example of FIS model output (solid line) versus the occurrence of the actual gait events (circles) for 1 of the 4 test trials (4 steps).

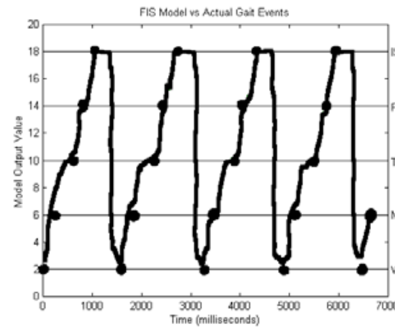
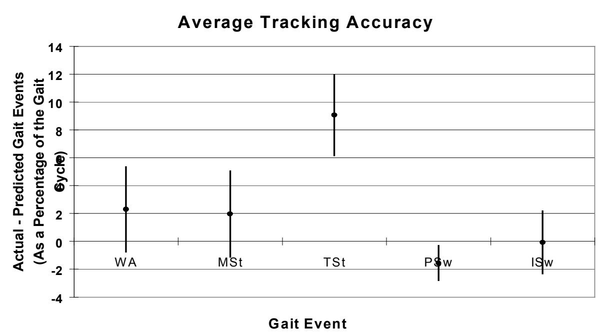


Figure 3 shows the average difference (+/-1 SD) between the actual and model-predicted gait events expressed as a percentage of the gait cycle over the 4 test trials (11 steps). For four of five events, the model followed the actual events to within 3 percent of the gait cycle or better. The difference between the predicted and actual transition to terminal stance was within 8.5% of the total gait cycle.

Figure 3: Average difference (and 1 standard deviation bar) between the actual and model-predicted gait events expressed as a percentage of the gait cycle for the 4 walking trials.



Discussion/Conclusions

These preliminary data sets suggest that it is feasible to accurately determine transitions between gait phases with 2 EMG signals and their derivatives using an FIS model. The model that was developed is amenable to eventual real-time embedded application as only simple triangular and trapezoidal functions were used for calculations. Real-time embedded application will likely need the Sugeno method of defuzzification because of its faster processing algorithm and performance equivalency to Mamdani [9].

One advantage to this EMG control technique is that the FIS model provides an estimate of the gait phase at each time sample (Figure 2). This could offer higher resolution state control of stimulation and provide stimulation in anticipation of events (i.e. stimulation parameters could be mapped to the FIS model output).

The terminal stance accuracy may have been affected by the difficulty in determining the actual event. In the future we will include rater crosschecking to validate actual terminal stance event times.

One critical aspect to EMG control for FES is to extract the EMG signal in the presence of the electrical artifact caused by the stimulation waveform. We have not yet evaluated in this initial study how the FIS control can perform with artifact present. However, other studies have shown that the linear envelope of the EMG signal can be successfully used for threshold detection control of upper extremity FES by sampling between stimulation pulses. [10,11]

Our plans are to integrate the FIS model into our stimulation system so that real time operation of the FIS can be tested. Also planned is an expansion of the FIS model to include events for early and terminal swing phases of gait.

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