DETECTION OF GAIT EVENTS USING A VIBRATORY GYROSCOPE

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ABSTRACT

The replacement of force sensitive resistors (FSRs) with a single vibratory gyroscope has been examined for use within a drop foot correction system. The sensor is small and lightweight enough to be easily attached to the shoe, and may be used (currently with an IBM compatible PC) to detect four gait events: heel contact, foot flat, heel rise and toe off. The cost of the gyroscopic sensor is comparable to that of two FSRs, but it is expected that the lifetime will be greater. To date the system has been used to reliably detect these events in the gait of eight able bodied subjects verified using either a force platform or two FSRs. The system has also been used successfully to detect the gait events in eight hemiplegic subjects. A portable version of the system is to be developed which may be used with the University of Surrey's Compustim 10B two channel gait assist stimulator.

INTRODUCTION

The correction of foot-drop using FES has now become a successful and routinely practiced treatment for several hundred patients in the UK [1]. One reason for this achievement is the simplicity of the apparatus required for the detection of gait events and the stimulation of one (or two) muscle group(s). Despite the success of the treatment, however, the operation of such systems can be impeded by the force sensitive resistors (FSRs) that are mounted inside the shoe and used to trigger the stimulation. Variations in both gait style and footwear, and deterioration of the FSRs themselves can all lead to an occasional failure to provide stimulation at the appropriate time.

In order to address this problem, other researchers have investigated the use of other sensors, such as goniometers [2], inclinometers [3], and accelerometers [4]. In every case, the sensor has been involved with some aspect of the shank (ankle angle, shank angle or shank acceleration) from which information regarding foot contact with the ground can only be implied. Combinations of these sensors with FSRs have also been examined [5], resulting in high measurement accuracy but a requirement for more than one sensor.

The use of a vibratory gyroscope in combination with these types of sensors has also been considered, [5], [6], but it is likely that a realistic replacement sensor would require a level of simplicity comparable to that of just one FSR. The use of a single gyroscope sensor system is described here, which, when attached to a small microcontroller unit, will offer the detection of heel contact, foot flat, heel rise and toe off. Since the sensor is mounted on the foot, the angular rate information acquired is a more direct indicator of foot contact with the ground (the ankle angle varies according to the inclination of both the foot *and* the shank). When compared to the information provided by FSRs, which is essentially of a binary nature, the gyroscope has the advantage that it could predict a gait event –and therefore begin, end, ramp up or ramp down stimulation- before its occurrence. This is because the time window within which the sensor software thresholds may be varied is far wider than that of the FSR. It is possible that the sensor will offer improved reliability, especially since there will be little or no deterioration during the sensor's lifetime (which is often the cause of inappropriate stimulation timing when using FSRs). The sensor may also prove to be more appropriate for staircase use. It is believed that the cost of the gyroscope sensor system will be slightly higher than that of two FSRs, but the lifetime of the sensor is expected to be greater.

METHODS

A vibratory gyroscope sensor, the muRata ENC-05E, is to be connected to the University of Surrey's Compustim 10B two channel gait assist stimulator [7] via a small microcontroller unit (the system could also be used with other stimulators that have been designed for use with binary footswitch data). The vibratory gyroscope sensor and its supporting components are small enough to be housed within a package of dimensions 8 x 15 x 25mm. The microcontroller unit will be designed to be attached to the Compustim unit, or included within the sensor package. The sensor is mounted on the foot, just above the metatarsals, and the Compustim unit will be worn about the waist.

The current Compustim clinical software has been designed to operate with sensors whose output may be divided into two states (the detection of each state is used for controlling stimulation). Since the gyroscope sensor produces a voltage that is continuously proportional to the angular rate measured, the microcontroller unit is required to run software which will detect heel and toe contact with the ground, and output a suitable signal for the stimulator unit. Software, written in 'C', has been developed on an IBM compatible PC for this purpose. Figure 1 shows a block diagram of the proposed system.

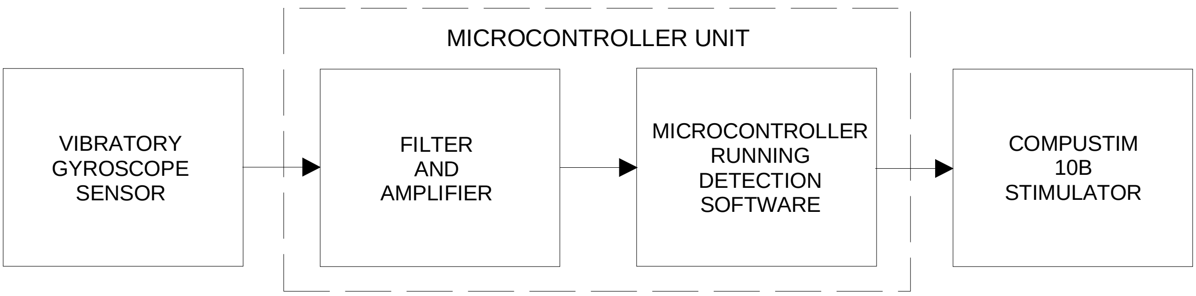

Figure 1 Block Diagram of The Gyroscope Drop Foot Correction Stimulation System

The detection software uses a rule based algorithm to determine the occurrence of gait events. Since the gyroscope sensor effectively measures the rate of tilt of the foot, a measurement of zero (or close to zero) within a gait cycle would indicate that the foot is in contact with the ground. A positive peak indicates the swing phase, and the following negative peak indicates the period between heel contact and foot flat. After a period of little or no movement, a second negative peak indicates heel rise before the cycle repeats itself. Figure 2 shows a typical plot of the angular velocity measured during normal gait (the measured voltage is proportional to the angular velocity).

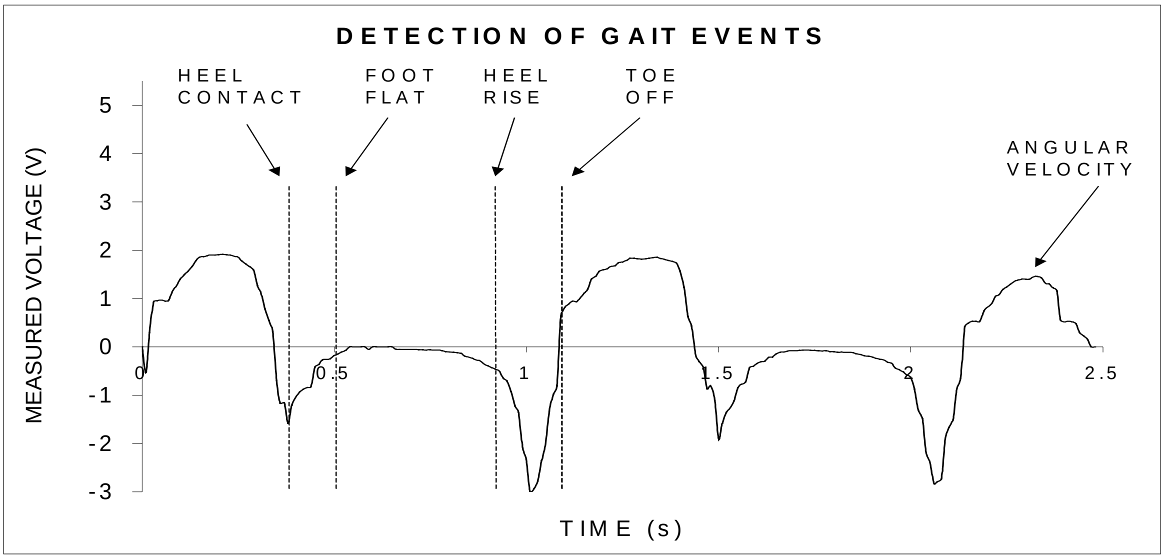

Figure 2 Angular Velocity Measured using the Gyroscopic Sensor (Normal Gait)

RESULTS

The gyroscope sensor system, using detection software running on a PC, has currently been shown to correctly detect gait events (heel contact, foot flat, heel rise and toe off) in the gait of eight able-bodied subjects, verified using a force platform or two FSRs. The same system has correctly detected the same events in the gait of eight hemiplegic subjects (seven had suffered strokes and one suffered from multiple sclerosis [MS]), verified using FSRs only. Figure 3 shows the computer prediction of gait events and footswitch data for pathological gait (stroke).

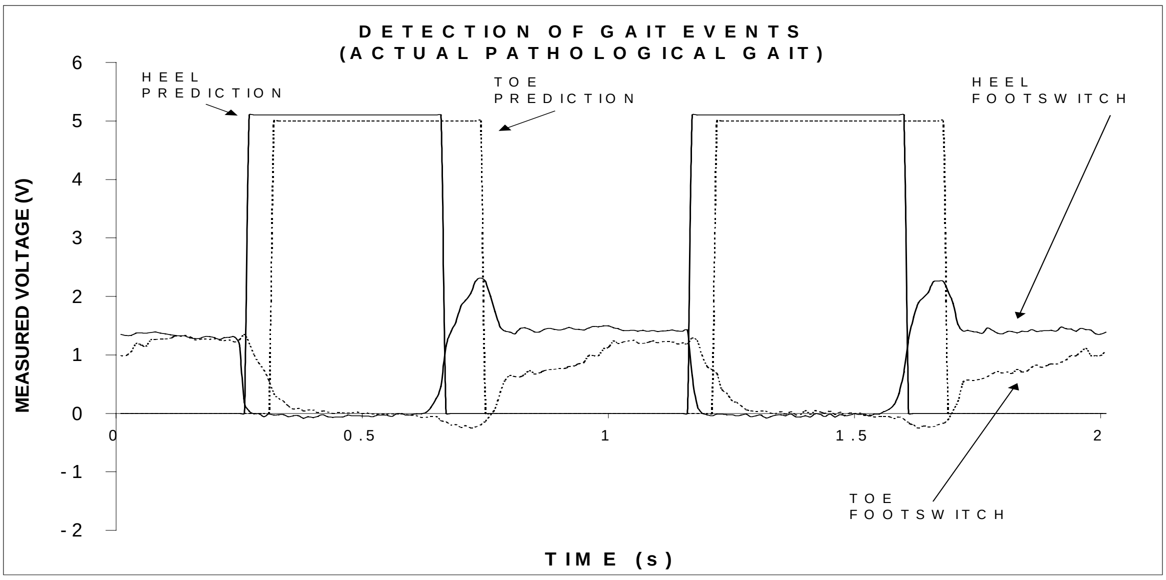

Figure 3 Footswitch Data and Computer Prediction of Gait Events (Pathological Gait –A High [5V] represents heel or toe in contact with the ground)

Event detection was also tested for in the gait of two incomplete spinal cord injured (SCI) subjects, both with hemiplegic drop foot. Reliable detection was not possible using the existing software, which was in both cases due to clonic activity of the ankle muscles leading to oscillations in the measured rate of tilt during the swing phase. However, it is believed that alternative software could be developed to address this problem.

DISCUSSION

It has been shown that the gyroscope sensor system has the potential to detect gait events in stroke (and possibly MS) hemiplegics. The system has currently used a PC for data collection and analysis, but there is obviously a requirement for portability. The next stage of development is to produce a microcontroller based device allowing the system to be tested over a greater length of time and also over different terrains. This will be followed by clinical tests with the Compustim 10B two channel gait assist stimulator

REFERENCES

1. Taylor P, Burridge J, Dunkerley A, Wood D, Norton J, Singleton C, Swain, I. *Long term Follow up of 160 Users of the Odstock Dropped Foot Stimulator.* Proceedings of 6th Vienna International Workshop on Functional Electrostimulation, pp 189-192, August 1998.
2. Peasgood W, Fry ME, Whitlock T, Bateman A, Jones RS. *An Inexpensive Optical Fibre Based Movement Sensor for use in Closed Loop FES Control.* Proceedings of 5th IPEM Clinical Functional Electrical Stimulation Meeting, 13-14 March 1997
3. Dai R, Stein RB, Andrews B. *Application of Tilt Sensors in Functional Electrical Stimulation.* IEEE Trans. Rehab. Eng., vol. 4, pp. 63-71, June 1996.
4. Willemsen AT, Bloemhof F, Boom HB. *Automatic Stance-Swing Phase Detection from Accelerometer Data for Peroneal Nerve Stimulation.* IEEE Trans. Biomed. Eng., vol. 37, pp. 1201-1208, December 1990.
5. Tong KY, Granat MH. *Using Neural Networks to Generate Optimum FES Gait Controllers.* Proceedings of 6th Vienna International Workshop on Functional Electrostimulation, pp 189-192, August 1998.
6. Popovic MR, Keller T, Ibrahim S, Bueren GV Morari, M. *Gait Identification and Recognition Sensor.* Proceedings of 6th Vienna International Workshop on Functional Electrostimulation, pp 189-192, August 1998.
7. Michael P, Ewins D. *A User Friendly FES System for the Rehabilitation of Hemiplegic Patients.* Proceedings of 5th Vienna International Workshop on Functional Electrostimulation, pp 115-118, August 1995.