Bench and in vivo testing of sensors for triggered open loop control of RF Bion® micro-stimulators in upper limb rehabilitation following stroke

Notley SV[1], Burridge JH[1], Turk R[1]

[1]University of Southampton UK
svn@soton.ac.uk

Abstract

The radio frequency Bion® (RFB) device is an injectable microstimulator that has been developed by the Alfred Mann Foundation. A control unit, capable of receiving inputs from external devices, is used to control the stimulation profiles. As part of a preliminary study using RFB micro-stimulators for re-education of upper limb function following stroke an automatic, responsive control system will be developed.

Three controlling devices are considered. The first is an EMG activation trigger that senses intention to reach. Initial results with a healthy volunteer and subject with stroke show that the anterior deltoid had good modulation during initial reaching movements. The second is a touch/release device that is based on a force sensitive mat. Results are presented showing the rate of false positives and false negatives. The third device is an off-the-shelf electro-goniometer that will be used to measure the elbow angle. This was bench-tested with the 2MHz electromagnetic coil and no discernable differences can be seen between the coil on and coil off environments.

1. INTRODUCTION

The paper forms part of a larger body of work investigating the efficacy of an implanted microstimulator; the Radio Frequency Bion® (RFB) developed by the Alfred Mann Foundation. Once implanted, the RFB receives power as well as stimulation commands (data) via an inductive link from an external, body worn, RF coil, which is connected to a Control Unit (CU). The CU is capable of receiving a number of inputs from external devices to control the sequence of stimulation profiles delivered by the RFB devices.

Three control devices are considered in this work: (1) An activation trigger based on electromyographic (EMG) recordings, (2) A touch/release sensor, and (3) An angle sensor.

2. METHODS

2.1. EMG Activation Trigger

The project requires that a trigger be available to the CU that is able to sense the subject's *intention* to reach and grasp an object. A natural candidate for such a trigger would be to detect a signal from a muscle normally active during the *initial* movement of a reaching and grasping task. Four muscles were considered; Upper Trapezius, Anterior Deltoid, Pectoralis Major, and Rhomboids. The candidate muscle groups were investigated to assess their modulation with intention to reach, modulation with non-associated tasks, and artefact contamination.

EMG recordings were made on both a healthy volunteer and a stroke subject. EMG recordings were made using the Noraxon wireless EMG system (Noraxon U.S.A. Inc, Arizona, USA).

In each of the following cases the subject was seated at a table. The intention to reach was investigated by having each subject rest their hand on the edge of the table. A small object was placed on the table approximately 12 inches distant from the table edge. The subject was asked to make an initial movement to reach as if intending to pick the object up. This process was repeated seven times.

Two non-associated tasks were investigated. The first was moving the hand from the lap to chest height. In practice this may be a necessary movement to position the hand such that it is ready to reach. The second non-associated task was to move the 'non-affected' arm whilst the 'affected' arm remained stationary in the lap. In the case of the healthy volunteer, 'affected' arm applies to the arm being used to reach.

2.2. Touch/Release Trigger

The project requires that a device be available that is capable of providing a trigger when either the subject has touched an object or has placed an object down for release. A necessary criterion to be met is that the device be compatible, without modification, with everyday objects and not interfere with a subject’s tactile sense. A device has been developed, based on a force sensitive mat that is capable of detecting small forces applied to objects placed on its surface.

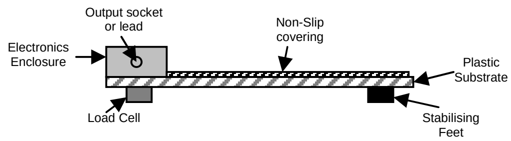

Figure 1 The Touch/Release Sensor

The resultant signal is differentiated, smoothed and rectified to provide a positive moving transient relating to small forces on the mat.

The device was tested using three wooden blocks designated small, medium and large. The mat was placed on a table 12 inches distant from the table edge. Two healthy volunteers, seated at the table, were asked to perform reaching tasks to either pick up the specified object or place it back down on the mat. Each object was picked up and place down five times. Between each reaching task the table was ‘banged’ five times.

2.3 Elbow Angle Sensor

The BION implants are powered and controlled by two RF coils worn on the forearm and upper arm. The Measurand S720 electro-goniometer (Measurand Inc, New Brunswick, Canada) was chosen as the elbow angle sensor as it is specifically designed to operate in the presence of strong electro-magnetic field environments.

The electro-goniometer was bench tested using the CODA motion tracking system. A manual goniometer was mounted to a table with CODA markers placed along the length of its arms. The electro-goniometer was mounted on the manual goniometer aligned with the centre of rotation.

The manual goniometer was moved through a range of -90 degrees to +90 degrees. The voltage from the electro-goniometer was recorded and time aligned with the angle calculated by the CODA system.

3. RESULTS

3.1 EMG Activation Trigger

Figure 2 shows the EMG signals for the four muscles investigated. For this task the Upper Trapezius muscle initially showed good modulation but then remained active during resting phases. The Anterior Deltoid showed good modulation between the resting and active phases of the movements. The Pectoralis Major and Rhomboids also showed modulation between the resting and active phases but had significant contamination due to the heart beat.

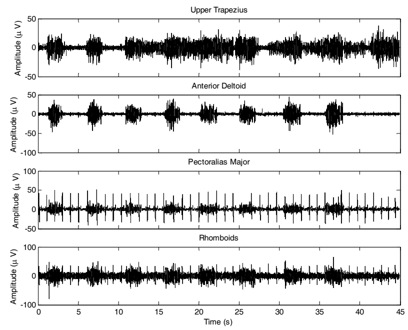

Figure 2 EMG during initial movements of reaching (Healthy Volunteer)

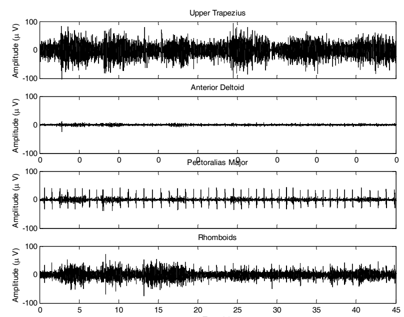

Figure 3 EMG recorded when moving the hand from the lap (healthy volunteer)

Figure 3 shows in this case that the Upper Trapezius and Rhomboids showed significant activation during the task. The Pectoralis Major showed some activation and significant heart beat artefact contamination. The Anterior Deltoid indicated minimal activation without any significant heart beat artefact.

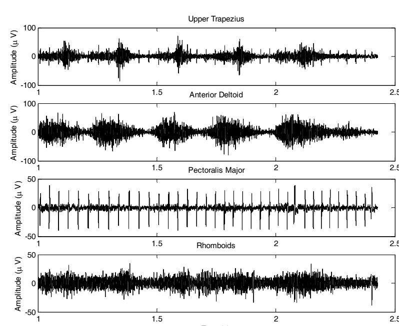

Figure 4 EMG during initial movements of reaching (Hemiplegic Subject)

Figure 4 demonstrates that there is modulation of the Anterior Deltoid, however, it should be noted that the subject had to make a more exaggerated movement forward than the healthy Volunteer.

In the case of moving the 'non-affected' arm no activation of the muscle is the desirable result. During testing of this task, the Upper Trapezius showed significant activation and the Pectoralis Major showed minimal activation but was affected by a heart beat artefact. The Anterior Deltoid showed minimal activation during the task with no significant artefact contamination.

3.2 Touch/Release Sensor

Figure 5 shows the results of the testing with two healthy volunteers as described in section 2.2. The signals were processed using a simple threshold detection algorithm. The figure shows the percentage of false positives and false negatives as a function of the threshold level.

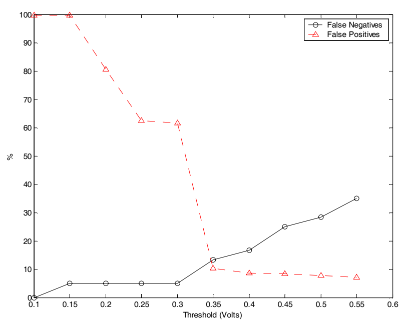

Figure 5 Rate of False Positives and False Negatives

The figure indicates that there is a trade off in the threshold value that minimises the rate of false negatives and the rate of false positives. However, it should be noted that the rate of five artefacts to one grasping/releasing action is inflated. A much lower rate of artefact contamination is expected in practice and thus a rate of false negatives and false positives both below 10% should be achievable.

3.3 Angle Sensor

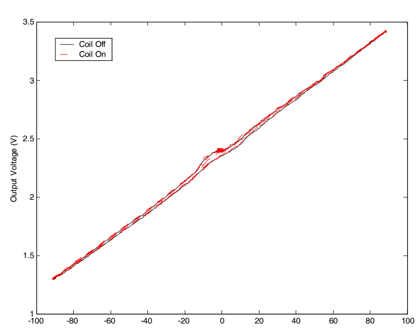

Figure 6 Output voltage as a function of the angle calculated by the CODA system.

Figure 6 shows the results of bench testing the Measurand 720 electro-goniometer. The solid line shows the relationship between the output voltage and the angle without the RF coil. The dotted lines show the relationship with the RF coil on. It can be seen that there is no discernable difference between the two. The plot demonstrates good repeatability in both environments.

4. DISCUSSION AND CONCLUSIONS

The results of the EMG investigation demonstrated that the Anterior Deltoid may be a suitable candidate muscle for use as an initiation trigger. The muscle showed good modulation during the initial movements of a reaching task and no activation during other unrelated tasks. The muscle is also free from heart beat artefacts.

The results of the bench testing of the touch/release sensor showed that an optimal threshold value may be found that minimises the number of false positives and false negatives.

Testing of the Measurand electro-goniometer showed that the device was operational in close vicinity to the RF coils.

Further testing of these sensors will be carried out in a formal study involving 12 healthy volunteers.

References

[1] Hart RL, Kilgore KL, Peckham PH, A Comparison between Control Methods for Implanted FES Hand-Grasp Systems, *IEEE Trans. on Rehabilitation Eng.*, vol. 6, no. 2, pp. 208-218, 1998.

[2] Hermens HJ, Freriks B, Disselhorst-Klug C, Development of recommendations for SEMG sensors and sensor placement procedures, Rau G, *J. of Electromyography and Kinesiolog*, vol. 10, pp. 361-374, 2000.

[3] Sinkjaer T, Haugland M, Inmann A, Hansen M, Nielsen KD, Biopotentials as command and feedback signals in functional electrical stimulation systems, *Medical Engineering and Physics*, vol. 25, pp. 29-40, 2003.

[4] Johnson MW, Peckham PH, *IEEE Trans. on Biomedical Engineering*, vol. 37, no. 9, pp. 876-885, 1990.

Acknowledgements

We would like to acknowledge the Alfred Mann Foundation for its support.