Issues Surrounding the Design of an EMG Triggered Upper Limb Stimulator

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Abstract

An EMG triggered upper limb stimulator would be of benefit to significant number of patients. However the design of such a device presented a number of technical difficulties that needed to be overcome. Collecting and conditioning the EMG signal amidst the noise generated by stimulation; Establishing suitable control algorithms to provide stable smooth operation; Deciding upon user controls and displays that are simple to use and impart information not confusion; Devising a way to generate two distinct voltages on the output antenna less than 1ms apart. This paper details the solutions adopted along with the background to the decision.

1. Introduction

In Britain each year there are approximately 100,000 people who suffer their first stroke.[1] Of all acute stroke patients starting rehabilitation, about half will have a marked impairment of function of one arm of which only about 14 % will regain useful function.[2.] The low recovery is due to a reduction in the ability to selectively activate wrist extensor muscles while their action is dominated by excessive activity in wrist, finger and thumb flexors. In practice this means that if a hand can be placed around an object, while it can be grasped, it can not be easily released. Unfortunately the effort associated with making the grasp can lead to increased muscular tone in the flexor muscles exasperating the difficulty in opening the hand. The lack of wrist extension while making a grasp results in a weak grip and a hand position that is less than functional.

This group a patients may be helped by use of a Functional Electrical Stimulation (FES) Orthosis capable of maintaining wrist extension while assisting hand opening. One approach is to measure residual EMG activity that is present in extensor muscle groups (this activity is due to weak voluntary muscle movement generated by the patient, but of insufficient strength to overcome the flexor muscle tone). Several studies have shown that this activity can be used to trigger an electrical stimulation device. This has chiefly been done for therapeutic device using electrical stimulation as the "reward" in a biofeedback system, where it has been shown to be more successful in improving activates of daily living than conventional electrical stimulation exercises[3, 4, 5.] Work in Salisbury attempted to use this technique orthoticaly with stroke patients to open the hand[6]. It was demonstrated that the system could be used for task such as using a door handle or picking up household objects. These orthotic devices used two sets surface or skin electrodes, one for measuring the EMG and the other for introducing the stimulation into the body. The device described in this paper also uses surface electrodes for collecting the EMG signal, but has an output stage that drives an implanted receiver to deliver the stimulation. The implant has two channels to enable individual control over wrist extension and hand opening. The design required three functional modes of stimulator operation as well as a basic exercise routine. The first functional mode is a fixed duration of stimulation, initiated by a burst of EMG from voluntary muscle activity. After the predetermined time has elapsed, stimulation automatically ends. The second mode is similar but the EMG is used to both start and stop the stimulation. The final functional mode is a proportional EMG modulated output, in this mode changes in the EMG signal are related to the size of the stimulation pulse giving the patient control over the degree of stimulation required for the task in hand.

1.1 EMG signals

Analysis of EMG measurements taken at the surface of the skin, has show that typically the amplitude of the signal can range from 0 to 10 mV (peak-to-peak) or 0 to 1.5 mV (rms). The usable energy of the signal is limited to the 0 to 500 Hz frequency range, with the dominant energy being in the 50-150 Hz range[7].

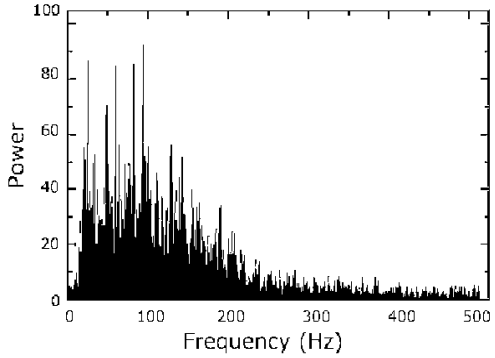

Figure 1 - *Frequency spectrum of a typical EMG signal detected during a constant force isometric contraction at 50% of voluntary maximum.*

1.2 Implant

The implant used is a two-channel device made up of induction coils and tuning circuits. The two coils are tuned to respond to 1MHz and 2Mhz respectively.

When an external coil is located on the surface of the skin directly above the implant, and excited with each of these frequencies in turn, an output is produced from the implant that is used to directly excite the nerves supplying the target muscle groups.

2. Stimulator Design

The design of the stimulator was based around a Microchip PIC processor (Figure 2). The chosen processor incorporates an analogue to digital converter and supports the Serial Peripheral Interface (SPI) bus protocol. The user interface consists of an LCD display with three digital input buttons (Up, Down & Enter), these are used to navigate through a series of menu screens where options can be chosen and parameters set. The unit also has one analogue control for setting the EMG threshold level.

2.1 Measuring EMG

The EMG signal detected at the skin needs to amplified and conditioned before it is able to be feed into the analogue to digital converter (ADC) of the PIC microprocessor. Initial amplification is done using an Instrumentation Op Amp (MAX4196 Maxim Integrated Products, USA). Because the stimulator is using variations in the EMG signal to control the magnitude of the output stimulation it is necessary to sample the EMG between stimulation pulses. Normally the significantly higher voltage of the stimulation compared to the EMG signal would drive the amplifier deeply into saturation; the time to recover from this would seriously limit the amount of useful signal that could be measured. The solution is to use an Instrumentation amp with a shutdown function, the amp is then switched off during the stimulation and on again afterwards. The next stage is to condition the signal with 10 – 500Hz band pass filter before rectifying, extra gain is also introduced at this stage before being feed into the ADC as a varying between the split rail 2.5V and 5V maximum. The user interface analogue control on the unit is used to set the threshold at which EMG is measured, and can be set above any noise on the signal. In practise it is set up with the limb at rest by adjusting the control until a continuous EMG signal is registered and then turn it back until it just goes off. Once the device has been set up in this way a signal proportional to the effort exerted by the muscle will then be registered as soon as the limb is moved.

2.2 Software Solutions

The EMG signal is sampled at a frequency not less than 1kHz for 32ms. This period is referred to as a sampling window. The results of the ADC are integrated for each sampling window and stored. The stored value from each successive sampling window is compared to the previous to decide if the patients voluntary effort has increased, decreased or stayed unchanged. If the EMG has increased the stimulation will be increased proportionally up to a pre-set maximum in response to the demand. Recursive digital filtering is used to control the rate of response and provide immunity to spikes. When the EMG has reduced, a different filtering algorithm is used to ensure a fast turn off response. The software has been designed to allow easy setting of all variables to ensure maximum flexibility when experimenting.

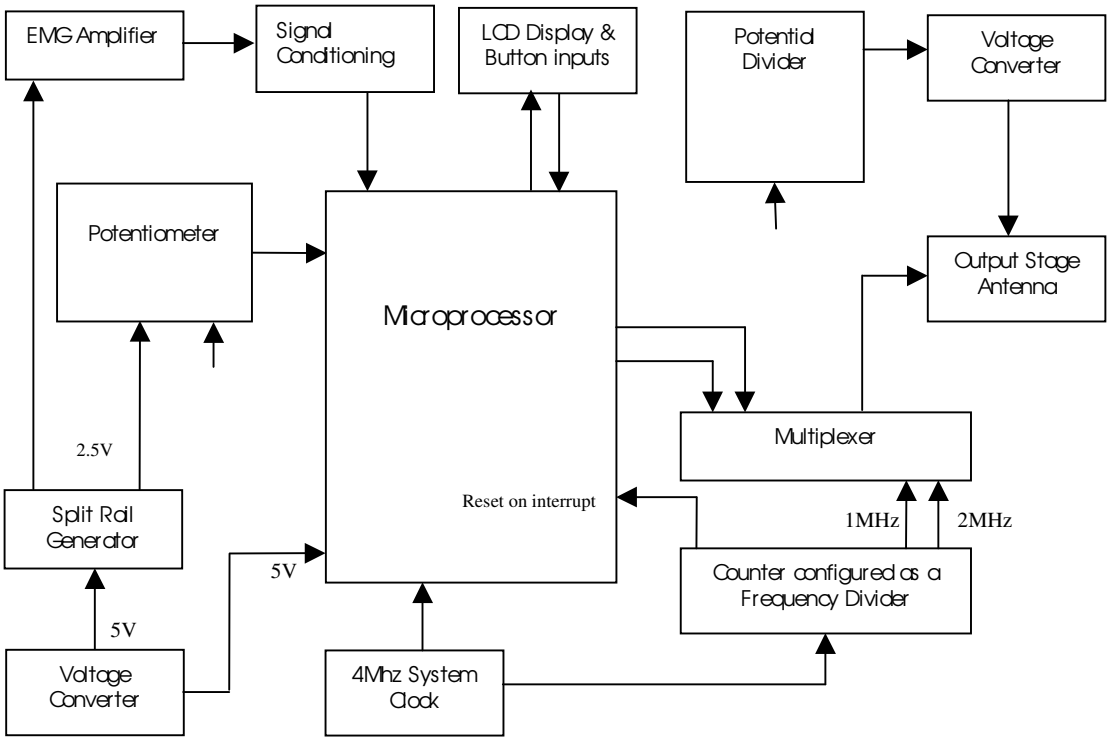

Figure 2 – *Block diagram of stimulator design, safety features include reset on counter overflow and safe limit pre-set on controls*

2.3 Producing the Stimulation

Two parameters can be varied to change the characteristics of the stimulation pulse. The duration is altered by changing the pulse-width, and the intensity by setting the amplitude of the output waveform. The stimulator uses a counter configured as a frequency divider to produce the 2MHz and 1MHz frequencies from the 4MHz clock, that are required to excite the implant coils. A safety feature of this arrangement is that should a software error occur, the processor would be reset following counter overflow, preventing the risk of continuous stimulation. A multiplexer switches the required frequency to the output antenna for the duration of the pulse-width for each channel in turn. Control of the amplitude that is induced in the implant is achieved by varying the voltage switched across the output antenna. A complication here is that each channel may require a different voltage, so a way is needed to rapidly change this voltage between stimulation pulses. It is also important that the channel 1 and channel 2 pulses are as close together as possible so that sufficient time is available for collecting the EMG signal. The solution adopted was to control the feedback circuit of a DC to DC converter. The speed of response of this arrangement was found to more than adequate for this application.

3. Closing Comments

The aim of this project was to design an EMG triggered stimulator for use with an implant in the arm. The work to date suggests that this is a both possible and practical undertaking. The equipment has been designed to enable easy alteration of all of the operating variables to maximise its potential during the next phase of testing with patients.

Of interest have been some of the incidental ideas that the design process has sparked off, for example. For ease of software development the prototype stimulator built, was given a surface electrode output stage as well as one for the implants antenna. Such a device using only surface stimulation could have marked benefits for stroke rehabilitation patients, where the positive feedback of movement following voluntary effort on a fully mobile wearable device could speed up recovery. Also, a small packaged EMG triggered drop foot stimulator worn on the leg now seems practical.

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