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NEURO-MUSCULAR JUNCTION BLOCK STIMULATOR SIMULATOR

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Abstract

Improved technology and higher fidelity are making medical simulations increasingly popular. A simulated peripheral nerve stimulator and thumb actuator has been developed for use with the SimMan Universal Patient Simulator. This device incorporates a handheld control box, a McKibben pneumatic muscle and articulated thumb, and a remote software interface for the simulation facilitator. The system simulates the action of a peripheral nerve stimulator on the ulnar nerve, and the effects of neuromuscular junction blocking agents on the thumb motion.

Key words: simulation, SimMan, McKibben artificial muscle, PNS

Introduction

Industries such as aviation, the military, and nuclear power generation have used simulations very effectively for years. Simulation training allows the student to experience adverse or rare situations that require a high degree of familiarization to recognize and respond to. It is just these features of rarity and/or poor outcome that make it essential for the person responding to the situation to be experienced in its management, and at the same time unlikely to have seen this situation in reality without years of practice. Medical simulations are becoming more and more common as the technologies improve, and the industry recognizes the benefits.

The simulation unit at the Flinders University School of Medicine has been established to provide a wide range of learning opportunities through the use of a variety of simulators. These simulators range from highly specific task trainers to extremely realistic simulation of a whole patient using two Universal Patient Simulators (SimMan) from Laerdal.

During a surgical procedure, a number of different medications are administered to patients to achieve the goals of sedation, paralysis, amnesia and analgesia. Each of these goals are accomplished with different medications that act independently, and with variation between patients. Monitoring of the action of these drugs is essential to allow the use of minimal doses to achieve the full effect. Overdose of neuromuscular blocking medication has been known to cause prolonged paralysis, up to 2 days, or continual muscle weakness.[1] Level of paralysis is measured through the use of peripheral nerve stimulators. Nerve impulses travel to muscles via a synapse at the neuromuscular junction. Various drugs are available that can block these impulses as they cross the synapse.

Electrical stimulus of a peripheral nerve causes a muscular contraction. As the degree of neruo-muscular block increases, the muscular reaction to the electrical stimulus decreases until it disappears entirely. Visual or tactile observation of the response to the stimulation gives the clinician an indication of the degree of neuromuscular block.

The Flinders Simulation Lab routinely conducts operating theatre simulations. To enhance the experience for the participants, it was requested that a peripheral nerve stimulator and associated thumb actuator be developed and integrated with the SimMan Universal Patient Simulator[2].

The device described in this paper incorporates a handheld control box which is roughly equivalent to the Peripheral Nerve Stimulator (PNS) used in the operating theatre, and an actuator that has been integrated into the manikin's right arm. The electrical connection between the control box and the arm is via two connection points on the arm that are roughly equivalent to the electrode points over the ulnar nerve. In addition, power, compressed air, and a data link back to the control computer are provided via connections in the manikin's torso.

System Features & Design

Features needed for simulated NMJB Stimulator

Peripheral nerve stimulators have several modes of action that correspond to generating a muscular response under different levels of neuromuscular block. [3] Each of these modes has been incorporated into this simulator.

• Single Pulse

The single pulse forms the basis for all the other pulse types. It is a square pulse of 195 µs duration, with a current of 0-70ma. This pulse can be used singly, or repeated at 1 Hz. It is typically used to determine the current setting that elicits maximum muscular response before a blocking agent is administered.

• Train of Four

This pulse pattern is four single pulses at 500ms intervals. It is used at moderate block levels. With nondepolarizing agents, subsequent pulses will tend to decrease in magnitude. The ratio of the magnitude of the fourth contraction to the first contraction gives a good indication of neuromuscular block.

• Double Burst

The double burst is 2 or 3 single pulses at 50 Hz, a 750 mS rest, and another burst of 2 or 3 single pulses at 50 Hz. The muscular response is seen and felt as two flexions. The ratio of the second flexion to the first flexion is equivalent to the TOF ratio. The double burst is preferred at light paralysis levels. It seems that the middle two pulses in the TOF can often make determining the TOF ratio difficult.

• Tetany

Tetany is a continuous string of single pulses at 50 or 100 Hz. Tetany is used to "kick start" the muscle when deeply blocked. Repeated pulses at this rapid rate blend together to form a single prolonged contraction at a much higher force than a single pulse. Repeated stimulus is believed to facilitate acetylcholine mobilization and release in the neuromuscular junction. When used with non-depolarizing blocking agents, response to tetany also fades.

• Post Tetanic Count

PTC is a pulse pattern composed of 5 seconds of tetany at 50Hz followed by a 3 second rest, and then 10 to 20 single pulses at 1 Hz. The period of tetanus mobilizes acetylcholine in the neuromuscular junction, and facilitates subsequent muscular contraction. Counting the number of pulses felt after the tetany gives an indication of the level of very profound blocks.

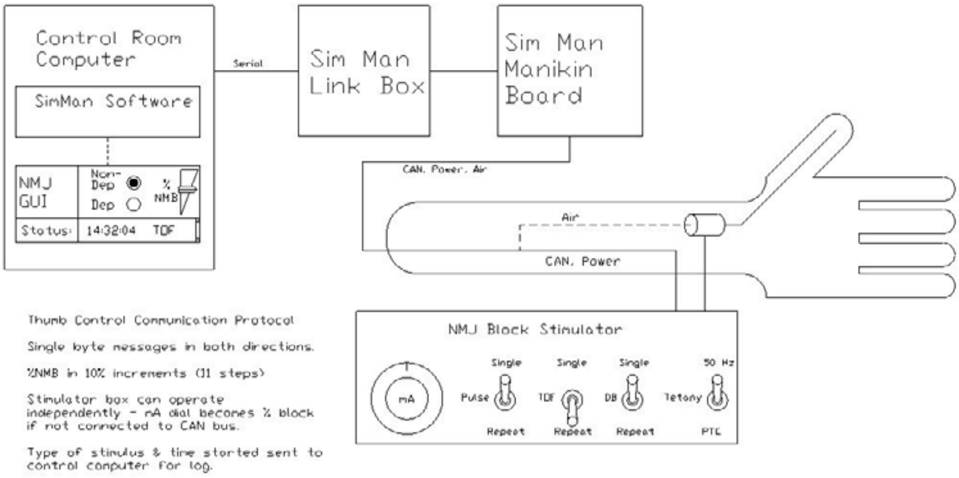

Figure 1. *System Design.*

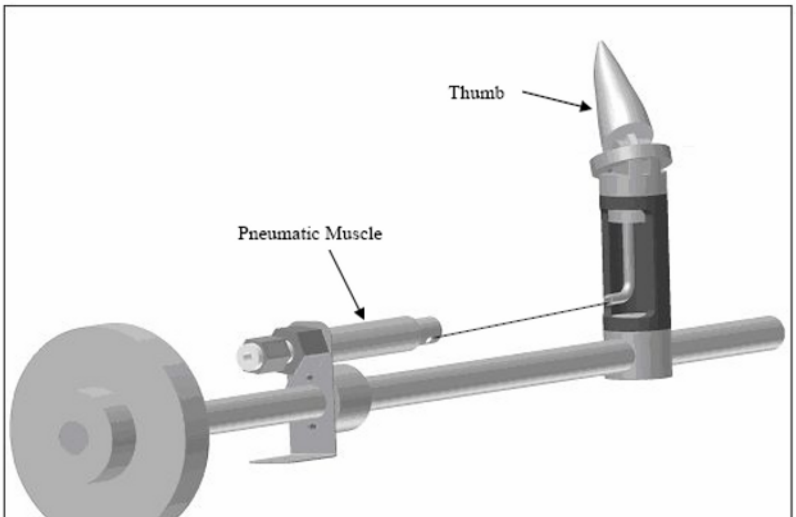

Figure 2: Actuator Mechanical Layout

Figures 4 and 5 show the thumb mechanism and the actuator/solenoid assembly before being installed in the arm.

System Design

The block diagram of the system shows the interface with SimMan. Laerdal Medical–Norway kindly provided a CAN interface circuit board with a PIC 18F458 microcontroller, and an updated SimMan communications program that would recognize messages from the NMJB Simulator CAN node. A separate NMJB graphical user interface was written to run in parallel with the SimMan software. The SimMan Manikin board has spare CAN bus connectors, and air for the pneumatic actuator was "Tee'd" off the regulator box (not shown).

Hardware

There are two primary methods for implementing a simulator. The first method interfaces directly with actual medical signals or devices, interprets these signals, and responds in the desired fashion. The thumb in the METI Human Patient Simulator uses this approach, and a servo actuator.[4, 5] The second method uses simulated hardware and signals from end to end. This method is often simpler, but does not use actual clinical devices.

This may detract from the learning experience if the look, feel, and device operation are primary goals of the simulation. In this case, it was decided that the interface was simple enough (several switches and a knob), that a functionally equivalent replica of the hand piece was sufficient, and that the second approach would be used. Figure 2 shows the mechanical layout of the thumb actuator that sits in a hollow plastic "IV arm". A long rod sits in the little finger (at the right of the sketch), and extends up the arm to a large disk that interfaces with the arm in the biceps area. Mounted on this rod are the thumb post, and the actuator bracket. The thumb post crosses the palm, and extends through the hand where the thumb would sit. The thumb itself is articulated with a simple hinge and a spring for extension. A guide tube sits just below the thumb in front of the hinge, and directs the actuating tendon down into the arm and redirects it 90 degrees along the length of the arm to the pneumatic actuator. The actuator and air solenoid are mounted to the actuator bracket midway along the arm rod.

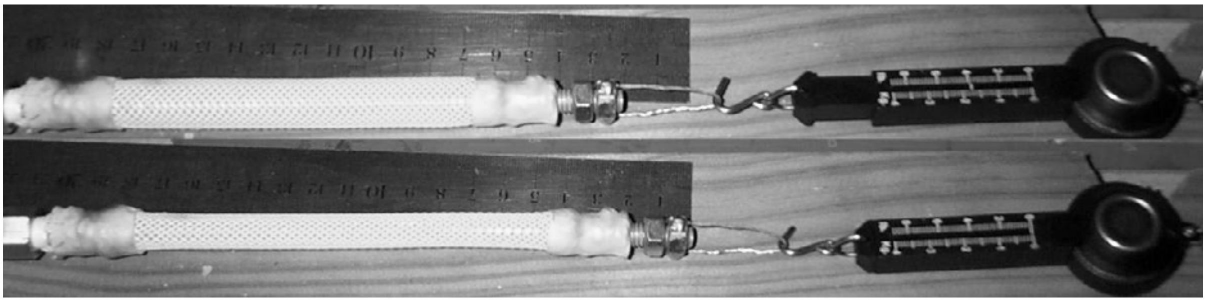

Figure 1. *Pneumatic Muscle Contraction.*

The pneumatic actuator is a McKibben pneumatic muscle.[6-8] It consists of a silicone tube surrounded by a double helical braid. It is sealed at one end, and filled with compressed air via the solenoid at the other end. As the compressed air pressurizes the tubing, it tends to expand. This expansion is translated into a linear shortening by the action of the helical braid. As can be seen in figure 3 of another test muscle (longer than the one used in the NMJB arm), it shortens approximately 20mm and exerts a pull of approximately 1.7 kg. The shortening length of 20mm was achieved with an actuator active length of approximately 140mm, or a ratio of 14%. This ratio is consistent for a given muscle diameter. The muscle length used in the NMJB arm was determined using this ratio and the stroke length needed by the thumb.

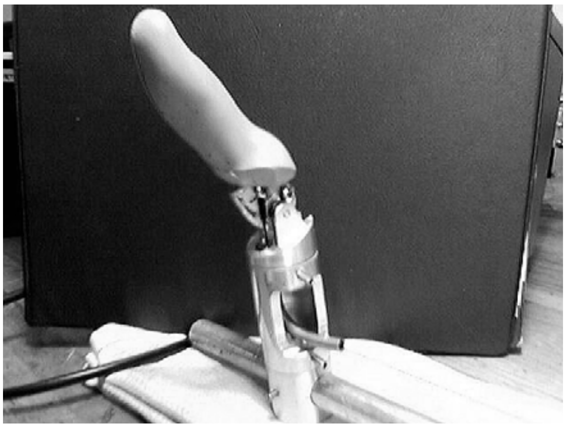

Figure 2. *Thumb Details.*

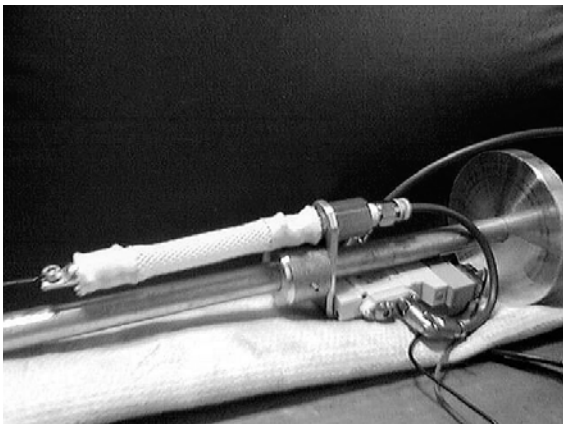

Figure 3. *Actuator Details.*

The control box incorporates all of the switches, interface electronics, and the Laerdal CAN board. The interface electronics uses two 74HCT147 10-4 line encoders tomap the 18 switches onto the 8 available I/O lines on the CAN interface board. The solenoid driver and protection diode are conveniently built into the CAN interface board. Figure 6 shows the layout of the front panel of the control box. The assembled arm and interface connectors are shown in figure 7. Another thin layer of artifical skin is placed over the entire arm. In addition to providing a cosmetic improvement, the skin also tends to dampen then thumb motion, requiring longer pulses. Two 3.5mm stereo ‘phono’ sockets are placed in the forearm in the approximate positions where the electrodes would be placed on a real patient. These two connectors provide 6 conductors between the arm and the control box. These signals consist of +12vdc, Ground, CAN +, CAN -, Solenoid+ and Solenoid -. The connectors are colored red and black, and require the user to connect them in the proper orientation (negative (black) distally). Reverse polarity protection is built into the control box to protect against incorrect connections.

Figure 4. *User Interface Panel.*

Software

There were two portions to the software development for this project. A windows program was written in Visual Basic to run on the control computer, and interfaced with the SimMan software via a TCP/IP socket. The SimMan software acted as a server and listened on a specific port for messages from the Thumb software. These messages were then passed onto the SimMan Link box, and then onto the CAN bus to eventually find the Thumb Control Box – the Stimulator Simulator. Messages from the Thumb Controller returned

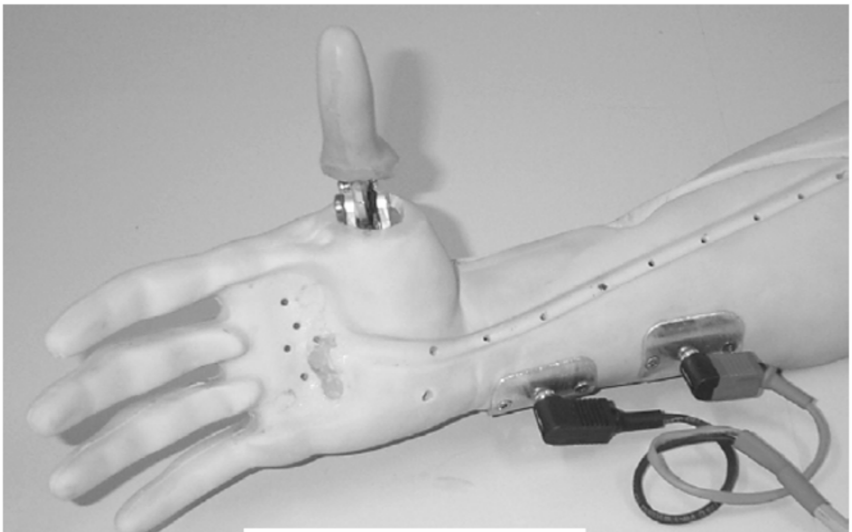

Figure 7: Electrode Connection

via the same path. Further commercial development would see this program integrated with the SimMan interface. Messages passed to the Thumb include whether the neuromuscular blocking drug currently being used is of the depolarizing, or non-depolarizing type, and the level of neuromuscular junction block from 0-100% in 10% steps. A GUI screenshot is shown in Figure 8. Messages passed back to the GUI include what type of pulse has been requested, and whenever the current setting changes. These messages are merely for the information of the facilitator in the control room, and do not influence the thumb operation. All messages are displayed in the "Thumb Activity" list box, and can be saved to a text file for later review.

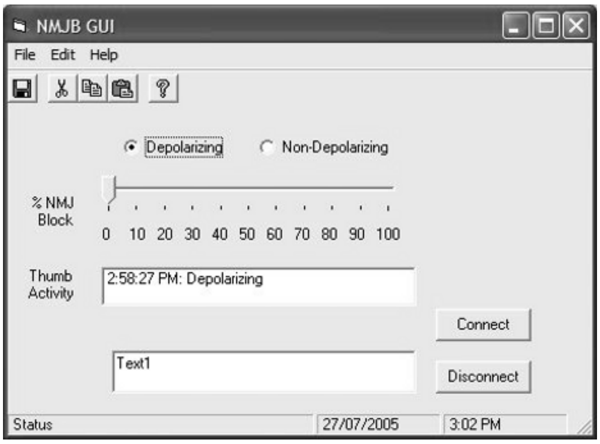

Figure 5. *User Interface.*

The Thumb Controller software was written in C for the PIC 18F458 microcontroller using Microchip's MPLab 7.0, and their C18 compiler. In addition, most of the CAN functionality was provided by a Microchip library.[9] A sample CAN application with some additional high level send/receive functions was provided by Laerdal.

The PIC program uses a timeout scheme to determine if the GUI is on-line. If no message is received from the GUI before the timeout, it is 'pinged' for a response. If there is still no response, it is assumed that the GUI is offline, and the interpretation of the selector knob on the hand piece is changed from "current" to "block", and the "current" is assumed to be a nominal value. Thus, if the NMJB simulator is used independently from SimMan, most of the functionality is still available. The primary function of the PIC program is to monitor the switches, and actuate the thumb accordingly. A series of lookup tables are used to determine the base time that the thumb should be flexed and then relaxed. These base times are modified according to the "current" and "block" values. The pneumatic solenoid is opened for this calculated duration. Very short pulses of 6-10 mS provide only the slightest movement of the thumb. Full flexion of the thumb is accomplished with a 25-30 mS pulse. However, the thumb can remain flexed indefinitely if desired. When the solenoid is closed, the air in the actuator is exhausted, and the thumb returns to its resting position.

Testing

The action of the thumb, and the operation of the simulated PNS control box was evaluated by several anesthetists from the Flinders Medical Centre. Adjustments were made to the supplied air pressure and the lookup tables in accordance with their feedback to provide the most realistic operation of the thumb under all operating conditions. Further use of this simulator is planned during routine "operating theatre" type simulations conducted in the simulation lab at the Flinders School of Medicine.

Conclusions

The goal of this project was to develop an actuated thumb and simulated peripheral nerve stimulator that integrate with SimMan. The project was completed over an 18 month period, “in my spare time”, on a very small budget. All parties involved are very pleased with the outcome. Due to the choice of a pneumatic actuator, some of the slow fade responses were impossible to simulate. In addition, the pneumatic “pop” of the solenoid is still audible, and may be a distraction to some users.

Acknowledgements

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