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# Development of a Portable Actuated Orthotic Glove to Facilitate Gross Extension of the Digits for Therapeutic Training after Stroke

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*Abstract* – **An externally actuated glove, controlled by a microprocessor, is being developed to assist finger extension in stroke survivors. The goal of this device is to allow repeated practice of specific tasks for hand therapy in a home environment. The user can control the device by three different means: voice recognition, electromyography, or manual control. These inputs can be used either independently or in combination according to the needs of the user. Both position and force feedback are available for control and safety. Initial testing of the prototype has shown promising performance.**

## I. INTRODUCTION

Almost half of all stroke survivors will experience chronic hemiparesis [1, 2], especially involving the distal upper extremity. Finger extension is the motor function most likely to be impaired [3]. In fact, spontaneous finger flexion appears within a few weeks after the cerebrovascular accident and culminates in the stereotypical flexed finger posture [4]. Both hyperexcitability of the long flexors, *flexor digitorum superficialis* (FDS) and *flexor digitorum profundus* (FDP), and weakness of the extrinsic extensors are typically present.

In a recent study [4, 5] it was demonstrated that less than 30% of the severely impaired stroke subjects could create active isometric extension. In absolute terms, *metacarpalphalangeal* (MCP) extension torque was only 7% of the MCP flexion torque. This extension impairment limits the ability of the stroke survivor to properly position the hand for successful grasp and to appropriately release a grasped object.

While new therapy techniques such as constraint-induced movement (CIM) have led to improvement in hand function [6], many stroke survivors have insufficient hand movement to participate in these therapies. What CIM and other studies have shown is the importance of repetition in encouraging motor improvement following stroke.

Thus, a number of mechatronic devices have been developed recently to encourage repetitive practice of the hand [5, 7-12], including commercial products such as the Saeboflex (Saebo, Inc., Charlotte, NC) and the Hand Mentor (Kinetic Muscles Inc. Tempe, AZ). Very few devices, however, are both actuated and fully portable. Portability is important both in enabling the user to fully explore his/her environment and, ideally, in allowing the device to be used outside the clinic. In the United States, outpatient therapy typically consists of 3 one-hour sessions per week and this often ends after 6 months post-incident. A means to facilitate training in the home environment is needed.

Thus, a relatively low-cost actuated orthosis, controlled by a microcontroller, has been developed to help the user to facilitate gross extension of the digits for home-based hand therapy. The device is self-contained such that it is entirely worn by the user. To provide flexibility for the user, the device can be controlled by any of three input mechanisms: voice recognition, electromyography (EMG) or manual (button) control. Termed the "J-Glove", this device is targeted toward severely impaired patients who need to work on spherical grasp and release. The J-Glove utilizes the asymmetry between the MCP extension and the MCP flexion, to reduce complexity and consequently reduce cost by providing assistance for finger extension, and relying on residual finger flexion for performing grasping tasks.

## II. DESIGN

### A. Hardware

The J-Glove provides assistance of finger extension in order to permit repeated practice of specific tasks. Extension torque is produced by tendon-like cables running across the dorsal side of a glove. The cables pass through chains of custom-fabricated Delrin pieces which serve as cable guides (Fig. 1). These guides not only maintain the line of force and moment arm of the cable but also prevent hyperextension of joints; hyperextension can be a major issue in stroke survivors when applying external forces to the hand as certain joints may be much stiffer than others within the

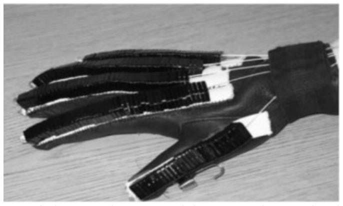

Fig.1. Structure of the J-Glove. Cables run through chains of cable guides.

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same digit. The cables from the 5 digits merge into a single cable at the forearm (cable displacements necessary to produce full extension of each digit are sufficiently similar across digits to permit use of a single actuator). The cable is guided to a small beltpack, worn on the back, where it is connected to the shaft of an actuator, a DC Micromotor (1724 DC-Micromotor, Gearhead 20/1, Encoder IE2-512; Faulhaber, Inc.). A custom plastic splint (thermoplast) maintains the wrist in a neutral posture.

With the gearhead, the selected motor is able to produce the desired maximum of 130 N needed to open the hypertonic stroke hand [13]. Feedback of both force and position are provided by a custom tension sensor and the motor encoder, respectively. The in-line tension sensor consists of two strain gages (Model # SGD-1.5/120-LY11) on a cantilevered beam (Fig. 2).

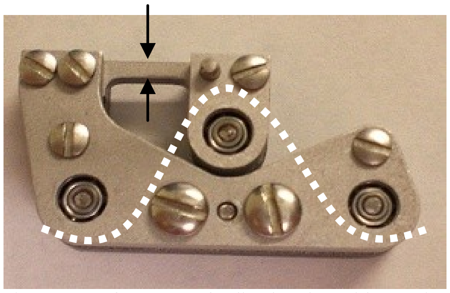

Fig.2. Tension sensor for torque feedback. The cable coming from the glove goes through the pulley (white dotted line emulate the cable) and then it is connected to the shaft of the motor.

The user may control the J-Glove through voice recognition, EMG, or manual buttons. Voice recognition is implemented using a commercially available chipset featuring a HM2007 speech recognition chip (SR-07, Electronic Express, NY). The voice recognition system can decode up to 40 words and can be trained for each individual within minutes. To train the circuit, the headset microphone, the keypad and digital display have to be attached to the main circuit board. The associated number of each word to be trained is indicated with the keypad; the chip then starts listening for the training word [14].

When a word is detected, the system identifies that word by its number (1-40) in binary-coded decimal. The 10 output lines from the chipset are connected directly to I/O channels in the RabbitCore microprocessor (Fig.3). Identification of a given command is accomplished by reading these values.

Surface EMG can also be used to drive the J-Glove. Custom printed circuit boards were produced to condition the EMG signal from passive electrodes and to create an envelope of the filtered, rectified EMG signal in hardware. The outputs of these PC boards are read by the RabbitCore through A/D conversion channels. Thus, the amplitude of the given muscle or the amplitudes of a group of muscles can be used to drive the device (Fig. 4).

### B. *Software*

The motor is controlled by a small microprocessor board, (RabbitCore RCM4500W, RABBIT Semiconductor Inc, Davis, CA). The RabbitCore includes analog-to-digital (A/D) conversion, pulse-with modulation (PWM) capabilities and quadrature decoder channels (QDC). It was programmed with the software Dynamic C (Version 10.11, Rabbit Semiconductor, Inc).

Limits of hand opening (digit extension) and hand closing (digit flexion) are first recorded through the motor encoder. The glove then moves between these limits according to user input.

The program code uses the action of saying a word (“open”, “close” or “stop”), activating a muscle, or pushing the button to control the system. In the “open” state the motor actively pulls the cable until the desired extension limit is reached under PWM control from the RabbitCore. In the “close” state, the system strives to maintain zero force in the cable. Thus, the user can use residual digit flexion function to close the hand with the motor providing no resistance. The J-Glove can enter the “stop” state at any time; movement of the glove immediately ceases, and after leaving this state the motor starts moving in the direction opposite to the prior state.

In the voice recognition mode, the desired state is indicated by the corresponding spoken word. In the EMG-driven mode, the relative magnitude of activity from FDS and *extensor digitorum communis* (EDC), for example, can be used to determine intended state. In the manual mode, sequential presses of the button shift the glove from the “open” to the “close” to the “stop” states.

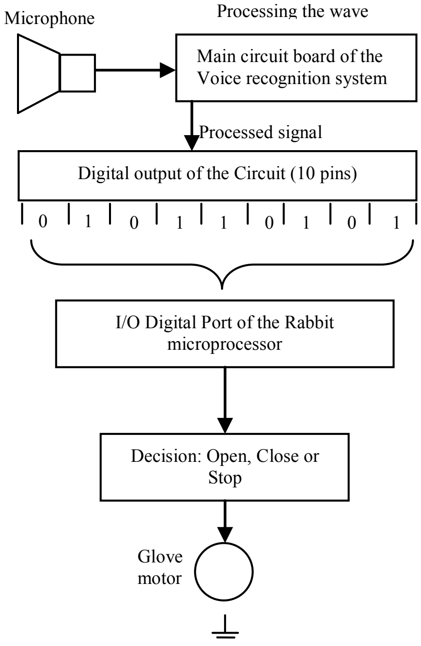

Fig.3. Schematic of the Voice recognition system. Sound is transduced by a sensor (microphone). Then this wave is processed by the commercial chipset, and the associated numbed of the word is sent to the RabbitCore microprocessor, producing a possible state change.

The J-Glove, as controlled by the microprocessor, can provide either force or position servocontrol during extension assistance depending on the needs of the user. The modes can also be used in conjunction such that the glove assists only as needed (e.g., motor enters position servo mode when cable force exceeds a certain level).

The system's flexibility allows the user and therapist to control the degree of assistance. As the user improves, the J-Glove could even be used to provide resistance to finger extension.

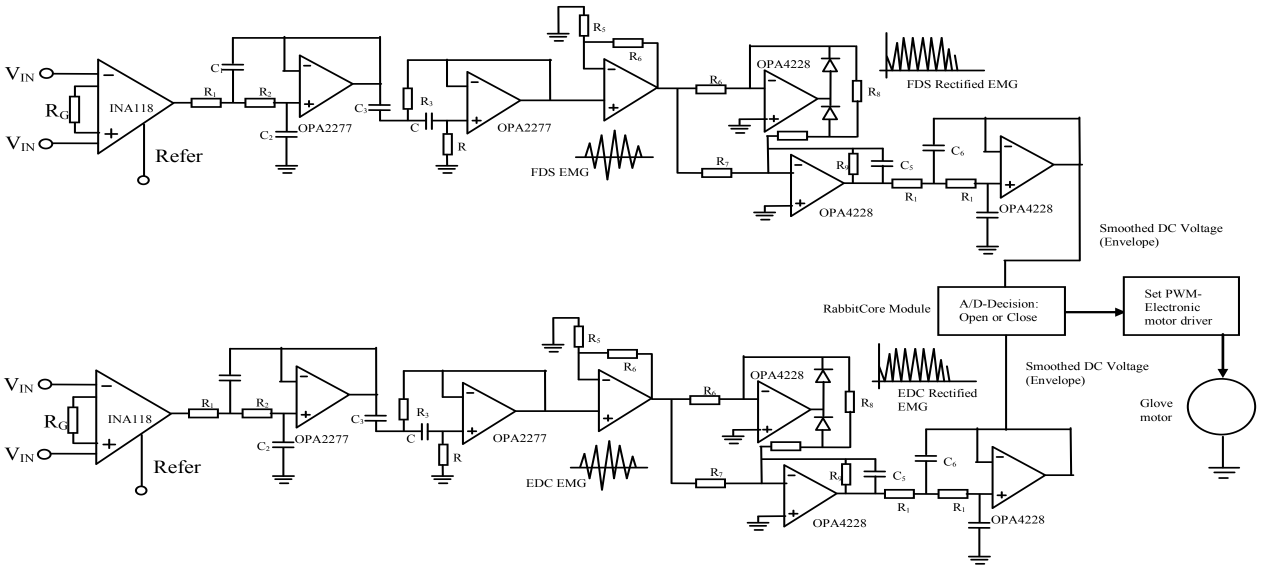

Fig.4. Schematic of the myoelectric processing scheme used in the printed circuit boards. The schematic consists of a differential bandpass amplifier. The amplified signal is then rectified and subsequently filtered to obtain the envelope of the EMG signal. This is all performed in hardware to facilitate use of the EMG signals for real-time control. The envelope is then sampled by the A/D channels of the microprocessor to take a decision, and then the Rabbit core Module set the PWM to activate the motor.

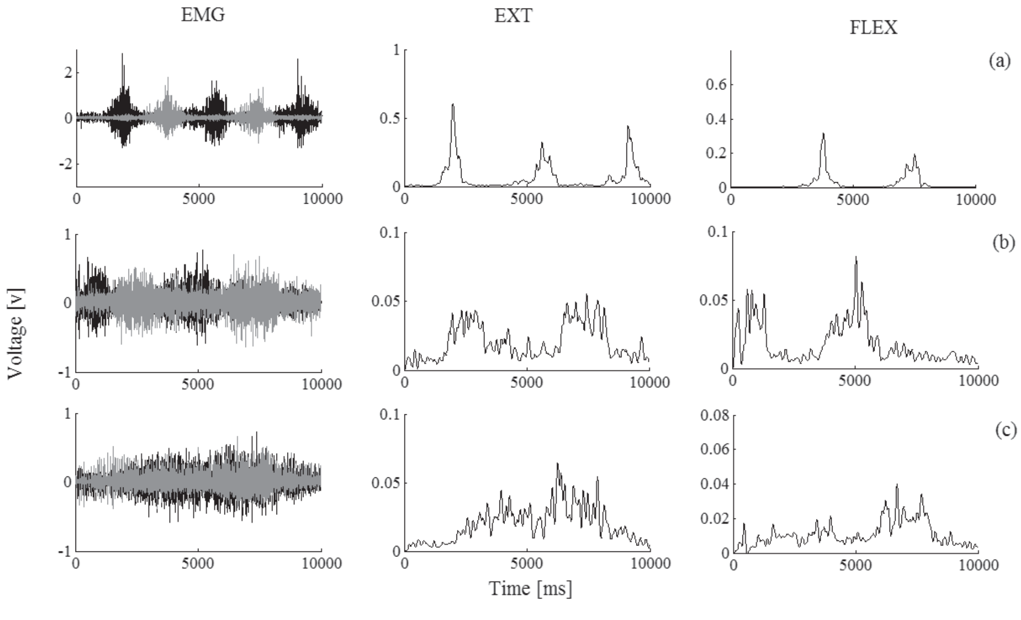

Fig.5. EMG signals recorded over FDS and EDC in 3 stroke patients. The signals are filtered in MATLAB and plotted for each muscle in black and gray, respectively. The EMG signals are then rectified, and the resulting envelopes are plotted in the FLEX and EXT graphs.

## III. RESULTS AND DISCUSSION

The J-Glove was tested with two neurologically intact volunteers. Additionally, three stroke survivors participated in trials to examine the feasibility of employing the EMG-driven mode. The stroke survivors had chronic hand impairment (Stage of Hand 3), as rated on the Chedoke-McMaster Stroke Assessment scale [15].

Subjects gave informed consent in accordance with the procedures approved by the Institutional Review Board of Northwestern University. The software and glove final performance met all requirements, as expected, when worn by the neurologically intact subjects. Training voice recognition could be performed in as little as 30 seconds.

Fig.5 shows the EMG signal of the 3 stroke participants after rectification and filtering in MATLAB to simulate the actual output from the printed circuit boards for the J-Glove. It is apparent that intended direction could be discerned from the EMG signals from EDC and FDS for two of the subjects (Fig 5, a and b); FDS is largely active during attempted flexion and EDC is largely active during attempted extension. Relative activation can even be determined visually. On the other hand, in the third subject (Fig. 5c) it is difficult to discern, from the EMG signals, when flexion and extension were intended to occur. Consequently, it is doubtful that EMG alone could be used by this subject to control the J-Glove. EMG, however, could be used in conjunction with voice recognition. For example, the user could indicate the desired state with voice control and then EMG could drive the degree of assistance. Once in the "open" mode, finger extension could be driven entirely by EDC EMG while FDS EMG would be ignored.

Fig.6. Picture of the Final prototype. It shows the electronics components: Motor, tension sensor, buttons, EMG circuits, microphone.

The developed device is entirely portable so the user can take the glove home and practice grasp-and-release as part of normal daily activities. By providing user control of the J-Glove, the device compels active user participation in the movements, especially as closing is not actuated.

## IV. CONCLUSION

The software and hardware have been implemented and show promise for the potential performance of the proposed device with stroke survivors. We are currently in the process of determining the best means of providing user control of the J-Glove to ensure maximal user effort while still enabling successful completion of the movement.

The next step will be to modify the design to increase robustness for use at home. Therapeutic trials will then be performed at home in accordance with the regimen established by a research occupational therapist.

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