TOWARDS ENHANCED BIOFEEDBACK MECHANISMS FOR UPPER LIMB REHABILITATION IN STROKE

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Abstract: This paper highlights a progressive rehabilitation strategy which details the development of a suite of biomedical feedback sensors to promote enhanced rehabilitation after stroke. The strategy involves promoting total upper limb recovery by focusing on aspects of each stage of post-stroke rehabilitation. For a patient with a complete absence of movement in the affected upper limb, brain signals will be acquired using Near-Infrared Spectroscopy (NIRS) combined with motor imagery to move a robotic splint. Once residual movement has returned, EMG signals from the muscles will be detected and used to power a robotic splint. For later stages and continuous enhanced rehabilitation of the upper limb, a Sensor Glove will be used for intense rehabilitation exercises of the hand. These combined techniques cover all levels of ability for total upper limb rehabilitation and will be used to provide positive feedback and motivation for patients.

1. Introduction

In Ireland approximately 8,500 people suffer from a stroke every year. Stroke causes a greater range of disabilities than any other known condition with approximately 80% of acute stroke sufferers losing motor skills in the arm and hand. Generally, rehabilitation focuses on the lower limbs and regaining the patients' mobility. Functional recovery of the arm and hand are, however, necessary for a high quality of life and independence.

Studies have shown that intensive, goal orientated, repetition of movements promotes recovery after stroke [1]. Often, the repetitive rehabilitation exercises become uninteresting and lack motivation and positive feedback during recovery. This results in patients abandoning many crucial rehabilitation exercises and tasks. By developing a suite of biomedical sensors, it is hoped that some of these issues can be addressed.

In the area of upper limb stroke rehabilitation there have been many technological advances aimed at improving the hemiplegic patients' mobility. Many of these systems involve virtual reality (VR) software and advanced electronics [2], including sensor gloves, positioning motes and robotics.

Three main areas are described in this paper. Firstly, when there is no response in the arm to attempted movement a Brain Computer Interface (BCI) is proposed. A NIRS system, developed by the Biomedical Research Group at NUI Maynooth, will be used in conjunction with motor imagery techniques to rehabilitate stroke patients [3]. Imagined movement will be recorded and used to drive a VR environment as well as a robotic splint to allow visual feedback for the patient, thus encouraging repetition of the exercise.

Secondly, when there is minimal movement in the upper limb, Electromyography (EMG) signals from the muscles will be read, amplified and used to direct a robotic splint generating the movement for the patient. Finally, when there is some movement in the hand and fingers, a Sensor Glove and VR environment will be used to enhance the dexterity of the patients' fingers. Through practice, exercises, and visual feedback, patients will receive the dedicated rehabilitation necessary for the upper limb that will enable them to perform the activities of daily living with more confidence and ease.

These three exercises cover many aspects of upper limb recovery and together create a substantial and influential stroke rehabilitation regime (Figure 1).

2. Near-Infrared Spectroscopy

This area of brain signal analysis is especially useful for stroke rehabilitation of the severely upper limb hemiplegic stroke patient. Imagined movement signals from the brain are analyzed by NIRS.

Motor imagery has been used by athletes for many years to help improve physical outcome [4]. It has been shown that this practice may also help stroke rehabilitation patients [5]. The patient imagines executing certain movements without physically performing them. It has been shown that while performing mental imagery, the same associated cortices of the brain are activated as during actual performance [6].

NIRS is a non-invasive assessment of the brain function that detects changes in blood hemoglobin concentrations associated with neural activity in the human brain [7]. NIRS enables continuous, non invasive, portable monitoring of changes in blood oxygenation and blood volume in relation to human brain function.

The system consists of a light source which radiates on the tissue and a light detector which receives the light after it has interacted with the tissue [8]. Specific

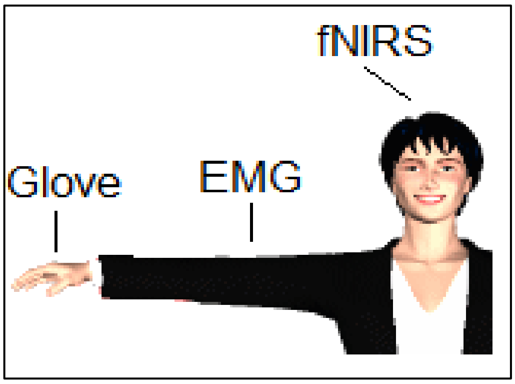

Figure 1. Total Upper Limb Recovery

wavelengths are used which easily pass through most tissue, except the oxygenated and deoxygenated hemoglobin. By calculating the differences between the sent and received light, brain function can be assessed.

By placing light nodes at specific places on the scalp, imagined movement may be detected and used to drive a robotic splint and virtual environment that can be seen by the patient.

3. Upper Limb Rehabilitation

For shoulder and elbow rehabilitation, it is proposed to use an EMG triggered robotic splint. This would be used when the patient has very little movement but activation signals are still reaching the muscles. The device will allow up to 3 degrees of freedom to the user.

Non invasive EMG electrodes [9] are placed on specific muscles on the skin. Signals are observed when the patients' muscles are in a relaxed state and also when they are in a tense state. Signal analysis is also done during attempted movement of the muscles. Differences in the states are calculated and the EMG signals can then be amplified to produce a motor reaction within the splint. This will allow the patient to achieve movement in the appropriate direction.

The EMG can be used to sense isometric muscular activity where little or no movement is actually produced but is attempted. This enables the control of interfaces like a robotic splint or virtual environment, without the need for full limb movement. This will strengthen the arm muscles and provide a positive outcome to the exercise.

4. Data Gloves

As a patients' finger dexterity is the final aspect of the upper limb to recover, it tends to have less focus in rehabilitative regimes. It has been shown that finger extension can be a positive indicator towards upper limb recovery [10]. A problem arises in that patients are often well enough to return home before it is time to intensely rehabilitate the hand. Minor grasping and flexing tasks are usually easily performed but dexterous movements, such as picking up coins, are often too challenging. Finger movements need to be continually practiced to regain and maintain dexterity. For this a home rehabilitative tool is required to keep patients engaged and involved in their rehabilitation.

Figure 2. VR representation vs. Patient movement

A number of Sensor Gloves are available for purchase today for use in Virtual Reality games. These include the Rutgers Master 2 Force Feedback Glove and the Cyber Glove [11]. These have been evaluated in trials by Merians et al [12] as possible upper limb rehabilitative tools. The conclusion from these trials was positive yet these devices were not taken on by therapists.

We propose a more defined, specific glove for stroke rehabilitation. The Glove is wireless making it light and flexible. Two piezoresistive sensors in each finger accurately measure flexion throughout the hand and translate the information gathered to a PIC situated on the patients' wrist. The PIC has 12 analogue to digital converters and is equipped with a Bluetooth transceiver. The information from the fingers is then sent wirelessly to the PC.

A Graphical User Interface (GUI) enables the patient to interact with the system. The GUI was designed to be easy to use with a quick start up. The program was written in C# utilizing DirectX libraries and the .NET framework 2.0. A data acquisition program was written to receive data from the PIC and sensors and display the movements of the fingers on-screen in real time (figure 2). The GUI contains exercises and games for the patient to follow using the Glove as an interface. The Glove tracks finger position and measures patient accuracy during the tasks. Tasks focus on finger flexion and extension, abduction and adduction. Scores are recorded in a history database to track user progress.

A prototype of the Sensor Glove is currently under controlled trials within a hospital environment for efficacy and feasibility studies.

5. Conclusion and Future Work

This paper depicts the overall recovery of the upper limb through engaging activities and exercise. The system covers three ranges of abilities, from minimal movement of the arm and hand, to the final stages of rehabilitation in the fingers.

The patient acquires positive feedback throughout all stages of recovery through physical movement of a splint or visually through a virtual reality environment on a PC. Exercises and games are used to motivate and encourage the patient to finish the sessions.

This suite of biomedical sensors has the potential to enhance the efficacy of stroke rehabilitation in the hospital and home environment. The first stage in this is the Sensor Glove. A prototype has been developed and is currently being trialed at the Adelaide and Meath Hospital, Tallaght, Dublin. The EMG Splint and NIRS elements will follow.

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