A Sensor Glove System for Rehabilitation in Instrumental Activities of Daily Living

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Abstract. Paralysis with weakness on one side of the body is common after stroke, affecting over 50% of people and significantly impacting their quality of life. Research shows that high intensity, task-specific activities focused on the use of the affected limb are important for encouraging neuroplasticity. Unfortunately, due to the pressure on healthcare systems internationally, the length of stay at an inpatient rehabilitation facility is limited. Consequently, to maximise recovery it is critical that patients engage in their rehabilitation exercises both between sessions and long after the end of formal treatment. We describe here the design, development and test of an interactive sensor glove system capable of translating captured movements into hand gestures as a basis for augmentative control and rehabilitation function. The system described here is designed from an occupational therapy perspective where functional assessment and therapy requires an ecological validity and a context within activities of daily living.

Keywords: Stroke, Motor Rehabilitation, Occupational Therapy, Sensor glove, Augmentative control.

1 Introduction

Globally stroke is one of the leading causes of serious long term disability, with over four million stroke victims currently living in the United States [1]. Paralysis with weakness on one side of the body is common after stroke affecting over 50% of people. The increase in survival rates for stroke is testament to the advances in primary treatment made over the past decade. However, as a consequence the demand for outpatient services, especially rehabilitation is at an all-time high, putting tremendous pressure on healthcare systems. High intensity, task-specific exercises are known to be important for encouraging neuroplasticity [2-3]. Consequently, it is crucial that patients engage in continuous rehabilitation exercises long after the end of formal treatment. However, the debilitating physical deficit combined with the absence of trained supervision, often leads to a loss of motivation in patients resulting in poor therapeutic compliance which has a corresponding negative impact on recovery.

Many previous attempts have been made to address these problems. Virtual Reality (VR) and Augmented Reality (AR) are commonly used in an attempt to add an engaging context to rehabilitation training and to encourage and motivate patients to keep

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up their exercises. However, the reality is for each decade after age 55, the risk of stroke doubles[1]. Therefore, most stroke patients are 55 or older and have spent a considerable part of their lives without exposure to computers or video games. Furthermore, interviews show they have little or no interest in this form of therapy.

Our approach instead tries to engage the patient in activities identified as personally relevant (in this case to be able to control household appliances via a universal infrared remote control) while at the same time facilitating a suitable motor challenge and a measurement of movement ability.

2 Design Motivation

Studies of animal models of stroke-induced paralysis reveal that sessions of 400 - 600 repetitions are required for good recovery and that simple repetition of an exercise will have little benefit if it does not provoke motor learning [4]. Subsequently, our glove has been designed to encourage the user to perform gestures which are derived from therapist-specified motor exercises, the successful execution of which acts as control input to an environmental control system (ECS). Through interviews with careers and therapists it was determined that patients spend a considerable proportion of their day interacting with entertainment systems and that the interfaces to such devices can be very challenging to operate. Consequently we designed the ECS around an IR-based augmented controller for personal appliances (TV, DVD, radio etc.). Such a design places the rehabilitation process at the heart of relevant activities of daily living which are both personalized to the specific user and should elicit motivational engagement. A further design requirement is that the movement activity and operational context is recorded over time such that numbers of repetitions and performance scores can be reviewed by an occupational therapist at a later stage. A final feature is the inclusion of a dynamic task difficulty mechanism which increases or reduces the gesture challenge according to the user's performance. This feature is designed to provoke the necessary motor learning associated with effective therapy.

3 Hardware

3.1 Flex Sensor

The glove uses lightweight flex sensors to record the patient hand movement and gestures. A deflection-to-voltage conversion can be obtained using the flex sensor Rs in conjunction with a fixed resistor R_f. The output of this configuration is described by (1):

$$V_{out} = V_{in}\left(\frac{R_f}{R_s + \mathrm{R_f}}\right) \tag{1}$$

In the shown configuration, the output voltage increases with increasing deflection. Although the flex sensors output is non-linear, a value for R_f can be chosen to maximize the desired deflection sensitivity range and subsequently the linearity of the corresponding results.

3.2 PIC Microcontroller

At the heart of our design is a microcontroller (PIC 16F688, Microchip Technology Inc, USA) which converts the analog sensor values into their digital equivalent. This device was chosen for its 8 analog to digital channels (10-bit resolution), five of which are needed, one for each finger. This device is also low profile (14 pins) and has High-Endurance Flash/EEPROM Cell allowing it to be reprogrammed up to 100,000 times, ideal for reprogramming new hand gestures.

We chose a lightweight flexible fabric for the glove which offers little resistance to movement to ensure no extra strain is put on the patient efforts by the device. A custom PCB was designed to house the microcontroller, voltage dividers, IR LED and power source. The flex sensors are connected to the PCB via flexible ribbon cables and are guided through loops at each segment of the finger. The flex sensor is only attached at the tip of the finger, allowing it to slide back and forward through these loops as the user flexes their fingers.

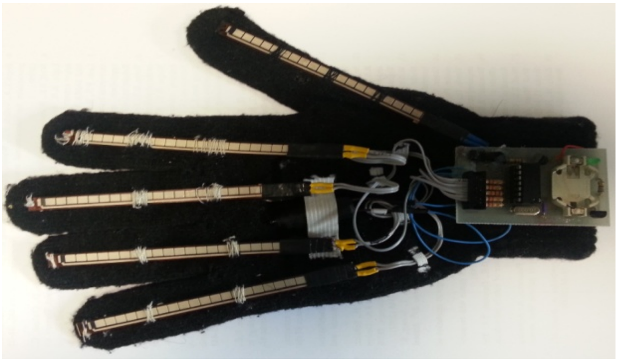

Fig. 1. The IR Glove

4 Software

4.1 Hand Gesture Recognition

By using a simple two stage calibration process we can determine an upper and lower threshold which will correspond to the hand being fully open (fingers extended) and closed (clenched fist) respectively.

The glove is easily programmed to allow an occupational therapist to define gestures suitable from the perspective of functional rehabilitation. A gesture is simply defined as a specific sequence of poses, $G=[P_S,P_M,P_E]$ taken from a predefined discrete set characterized by a pose vector $P=[p_1, \ldots p_i, \ldots p_N]$. In this case N=5 (one for each digit) and p_i is a dimensionless normalized scalar in the range [0,1] derived from the minimum and maximum deflections for each digit acquired during calibration. P_S, P_M and P_E corresponds to the beginning, middle and end poses of a gesture respectively.

(a) (b) (c)

Fig. 2. Hand poses, (a) beginning pose, (b) intermediate pose, (c) end pose

A gesture is correctly identified when the glove detects each of the three poses that make up that gesture, in sequential order and within a defined time limit - *T*. Pose recognition is very simple and is based on the individual component differences d_i of the difference vector $D=P_T-P_U = [d_1,\ldots d_i,\ldots d_N]$. Where P_T is the target pose and P_U is the current pose. A pose is correctly identified if $\forall d_i \in D$: $d_i < e$ where *e* corresponds to a hard class boundary threshold which is interpreted as a task difficulty parameter in this application.

Depending on the recommendations of the occupational therapist, the difficulty of a task can be increased or decreased by changing the error threshold *e* or adjusting the time limit -*T*. Dynamic difficulty adjustment (DDA) is a useful method often used in gaming to optimize engagement through matching player's ability with an appropriate challenge [5]. We currently use a DDA approach which adjusts *e* or *T* based on a running average of the relevant performance measures (D_A or T_A) for the previous *M* gesture attempts. When D_A (or T_A) is greater than *e* (or T) we gradually increase *e* by an increment each gesture iteration until an appropriate balance is obtained and similarly if the gesture is too easy the difference measure is used to increase the difficulty level.

5 Evaluation and Discussion

The following data was downloaded from our glove after a preliminary test, in which the glove was worn by a healthy test subject and used to control a TV during a 10 minute session. The time limit chosen in which a gesture needed to be performed was 500 (ms) and an error threshold *e* was chosen to be 8%.

Table 1. - Results of preliminary test

Gesture (P_T)	**Attempts**	**Successful**	**Failed**	**Avg. Time (ms)**	**Avg. Difference (d_i)**	**Context**
1	15	14	1	443	5.3%	Channel Up
2	14	12	2	459	6.5%	Channel Down
3	6	6	0	462	6.1%	TV ON/OFF
4	20	19	1	426	5.5%	Volume Up
5	15	13	2	463	6.2%	Volume Down

From our preliminary results we can extract useful information such as how many times a gesture was attempted, and of these attempts how many were accurate and completed within the time limit. The IR glove is now under review for application in a clinical setting. Trials with stroke patients will help identify whether stroke patients benefit from an interactive form of therapy and if this concept will increase the amount of practise a patient engages in.

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