Post stroke Gait Rehabilitation Strategy using EMG, FES and Exoskeleton Devices for Patient Controlled Exercise Programme

Kumar N¹, Kumar A¹, Sohi BS²

¹Senior Scientist, Biomedical Instrumentation Unit, CSIR-CSIO, Chandigarh, India
²Campus Director, CGC, Gharuan, Mohali, India

Abstract

The paper discusses the novel strategy to improve the post stroke gait rehabilitation process by integrating bio-signals, electrical stimulus, and powered assistive devices for patient exercise programme. The use of EMG as bio-signal gives the control to patient to manipulate the level of external stimulus and assistive power through wearable exoskeleton devices. The EMG mapping also gives information for fatigue level of patient. For better and improved rehabilitation use of external pulse pattern from functional electrical stimulator system along with exoskeleton is more beneficial.

Introduction

With the fast pace of life work and performance pressure is increasing day by day on human. Lifestyle disorders, eating habits and increasing average age of world population makes it difficult for the mankind to live healthy and perform naturally. The above mentioned factors are responsible for steep increase in hypertension cases which results in full or partial stroke [1, 2, 3]. Different cases of stroke can be categorized into Cerebral Thrombosis, Cerebral Embolism and Cerebral Haemorrhage. Out of which cerebral haemorrhage is caused due to hypertension, cerebral aneurysm, haemorrhagic diseases, trauma and tumours. The human gait is the most commonly affected body function in stroke patients [4, 5, 6]. The recovery of full normal gait is a challenging task. Its complete rehabilitation is long term clinical process which requires immense patient energy and patience for successful participation in such programme [12]. According to the World Health Organization, 15 million people suffer stroke worldwide each year. Of these, 5 million die and another 5 million are permanently disabled. Approximately 25% of permanently disabled patients remain wheelchair bound and in 60% of the subjects, walking speed and capacity are significantly reduced. Therefore the objective of this study is to propose a solution for independent movement of a completely stroke patient.

Rehabilitation Strategies

Early rehabilitation strategy involves assistive movement of affected organs with personalised care or mechanised devices. Uses of partially or fully automatic devices are increasing with an aim to provide faster and quality gait rehabilitation [10, 11]. These devices are commonly known as Exoskeleton devices (EXOD), which can be worn by patient and limb movement is performed with pre-programme controlled walking pattern. Such post stroke gait training programme is having limited control of user over the mechanised devices as there is very little bio-feedback involved [14]. These programmes can be more useful with giving more control to patient to operate these devices and manage his rehabilitation programme by himself.

Electromyogram (EMG) is used for providing voluntary control to stroke patient to manage their supporting aids and environment. Many commercial devices available which use EMG from limb segment to control the prosthetic and orthotic devices [15, 16]. The acquired EMG is analysed in time and frequency domain to extract the significant control parameters. The magnitude and frequency of EMG signal is mapped to variable muscle force.

Another important strategy to make gait resorting training programme is by applying external electrical stimulation with the help of Functional Electrical Stimulator (FES) directly to the motor points of affected limb [17]. The stimulus is given through surface electrodes or subcutaneous needle electrodes. With surface electrode it is not possible to stimulate a single motor point, which is possible with needle electrodes which have their inherent limitations and inconveniences. The magnitude, frequency and duration of applied electrical stimulation decided the grade of contraction [18, 19].
Authors have the experimental experience of implementing the mentioned strategies for device development and control, individually. In this paper, a novel rehabilitation strategy is proposed to give the better control to patient through EMG, using the developed exoskeleton device for assisted limb movement and intermittent use of FES system to give external electrical stimulation to motor points.

**Materials and Methods**

The scheme is explained with the help of block diagram given in Fig.1. The active electrodes SX 230 (M/s Biometrics Ltd) are applied on the selected muscles of upper arm (Extensor Carpi Ulnaris & Brachioradialis). The RMS envelope after suitable signal conditioning is extracted as control parameter. Time domain analysis of EMG signal gives dorsiflexion (flexion) and plantarflexion (extension) of hand. Data is recorded with prior consent from six healthy subjects (3 male & 3 female) of age (30± 5 years) to map any gender variability. The data is recorded for Isometric and isotonic contraction during the plantar flexion and extension of hand. The acquired bio signals give the adaptive control parameter of individual patient.

Six channels FES stimulator is developed using ATMEGA RISC controller (Fig. 2). The prototype unit house embedded system for generation of output pulse pattern. The user can select the amplitude and frequency of the output pulses. The range of output pulses varies from 10Hz to 40Hz with 0.3msec pulse width at the amplitude level of 24V to 100V @ 100mamp max. Carbon rubber surface electrodes are applied at the quadriceps and hamstring location of the affected limb of a paraplegic patient.

The exoskeleton device is developed for providing gait assistance to patients. Patient can wear the prototype of active exoskeleton devices as shown in Fig.3. Two prototypes are developed with different number of actuators required for performing gait function. The EXOD provides assistance to the required limb movement here it is lower limb flexion and extension.
The Command Generation Unit (CGU) received the inputs from EMG control unit and pulse pattern from FES unit. The EMG signal is mapped to the user desired level of contraction and command unit switched between the stimulation amplitude pulses. Based on the actuation level for EXOD generated by the CGU, gait speed is decided. In the control scheme, provisions are there for independent working of EXOD based on the pre-programmed rehabilitation programme selected for a particular patient.

**Results**
The raw EMG signal from two muscles of arm is analysed in time domain and RMS values are analysed for male and female with Datalink software (Fig. 4).

![Fig. 4: EMG acquired in Data link s/w](image1)

The computed values for male and female subjects are tabled in Table 1. Variation is reported in EMG contraction level for isometric and isotonic contraction for flexion and extension of hand.

<table>
<thead>
<tr>
<th></th>
<th>Extensor Carpi Ulnaris</th>
<th>Brachioradialis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isometric Contraction (in mv)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.15 ± 0.05</td>
<td>0.95 ± 0.04</td>
</tr>
<tr>
<td>Female</td>
<td>0.087 ± 0.04</td>
<td>0.04 ± 0.05</td>
</tr>
<tr>
<td><strong>Isotonic Contraction (in mv)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.13 ± 0.07</td>
<td>0.10 ± 0.06</td>
</tr>
<tr>
<td>Female</td>
<td>0.09 ± 0.06</td>
<td>0.04 ± 0.06</td>
</tr>
</tbody>
</table>

The experiments of applying electrical stimulation through developed FES system is given to completely paraplegic patient. All the experiments are conducted on completely paraplegic patient. Mono-phasic pulses are applied with 0.2mm rubber surface electrode at quadriceps and hamstring muscles. Different contraction grades are achieved with application of different stimulation levels. At low voltage 24 V, grade 1 contraction is achieved which represents tremor produced by external stimulus and at high voltage level 60 V and higher, grade 5 contraction is achieved which is sufficient for limb movement. The contraction achieved with applying FES to completely paraplegic patient is shown in fig. 5.

![Fig. 5: Without FES; b: With FES applied](image2)

Programmable flexion/extension and walking pattern are generated and stored into the PSOC controller on EXOD. The output actuation signal from EMG map is given as control input to PSOC for its operation. The actuation and gait speed of EXOD can be controlled through the control generation unit. Figure 6 shows the quantification of programmable gait generated using indigenously developed LED based marker system.

![Fig. 6: Gait quantification of developed EXOD](image3)

**Conclusions**
The EMG mapping from normal upper body of a stroke patient gives more precise, voluntary and adaptive control to the patient exercise programme. The depleting amplitude of EMG signal also represents the fatigue level and act as self-generated bio feedback to monitor the efficacy of programme and also reduces burden on patient to involuntary participate in the programme. The strategy presented is advantageous to the present day method of mechanised rehabilitation which is pre-programmed routine and does not take care of individualism. The scheme also adopts an integrative approach to apply FES pulses along with the powered assistance provided by EXOD. The use of FES is increasing day by day for preventing muscle dystrophy and in physiotherapy applications. The integrative...
use will give a boost to the post stroke rehabilitation process.

References

Acknowledgements
The authors are very grateful to Dr. Pawan Kapur, Director CSIR-CSIO Chandigarh for permission to carry out research work and funding the work in SIP 0022.10.

Authors Address
Neelesh Kumar
Senior Scientist, CSIR-CSIO, Chandigarh
Email: neel5278@gmail.com