SEMGBased Schemes in Neurorehabilitation for Robot Assist

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Abstract— The main cause of increasing disability in this present world is stroke. Positively it has enormous emotional and socioeconomic consequences. After stroke, rehabilitation helps patients in relearning the skills to live a normal life. Specialists provide therapies which prompt patients to recover fast but this a challenging job because it is time consuming and needs more labour. To reduce this load and consumption time, researchers are now focusing on the application of robots especially SEMG based exoskeleton robots in this field. Now a day’s, researchers are in search of various techniques which can reveal much more information from acquired SEMG signal to facilitate improved rehabilitation. This information will potentially help therapists/robots to monitor or analyze neurologically disturbed patients and provide them required therapy by controlling assistive devices intelligently. Disabled patients relearn the skills by wearing exoskeleton robots on affected muscles, so their control should be precise and accurate. It is a challenging job to achieve this precision. In this, we reviewed the use of SEMG in designing and controlling of robots with an ability of precise evaluation of disorder caused by stroke patients and discussed the challenges.

Keywords: surface electromyography signal; End-effectors based Robots, Neurorehabilitation; Exoskeleton robots; Stroke.

I. INTRODUCTION

Stroke happened when blood supplied to the brain is not proper. It leads to the death of brain cells causing neurological disturbances in cerebrovascular system. It may cause death of a person if proper medication is not given within 24 hour window [1]. Stroke can permanently damage central nervous system which leads to disability. In 1990, stroke caused 4·4 million deaths worldwide and was declared as second commonest cause responsible for deaths. In 1999, death rate increased highly and was reported to vary from 11.7% to 32.4%. In 2001, according to the survey of Indian Council of Medical Research (ICMR), death rate was further increased to 41 per cent of total deaths and led to 72 per cent of disability. By the estimates made in 2005, it was indicated that 60% deaths were due to stroke [2]. By 2050, it is expected that stroke events will increase to 80% of present level [3].

After stroke, rehabilitation process helps patients in relearning skills of everyday living to live a normal life. Neurorehabilitation field deals in rehabilitating patients suffered from neuromuscular injuries [4].

Neurorehabilitation technology which includes therapeutic robots has much more promising results than conventional physiotherapies given by specialists [5]. Earlier end effector based therapeutic robots were used in rehabilitation process but recently these robots have been shifted to exoskeleton robots. Exoskeletons are the wearable robots which are designed to attach at multiple locations of affected part, providing wide range of movement as compare to end effector based robot [6].

The control objective of an exoskeleton depends upon the evaluation of patient’s disorder so that therapeutic exoskeleton robot must know the type of therapy or training required by the patients. For this evaluation of patient’s disorder, bio-signal must be acquired from human body. This bio-signal can be used to control therapeutic robots. The generation of these signals to control active prostheses and orthoses can be from different sources. The main categories are:

1. Biomechanical signals
2. Electromyography (EMG) signals
3. Peripheral nervous system signals
4. Central nervous system signals [7].

Out of all these signals, EMG signals are very easy to acquire during contraction or relaxation of muscle fibers using skin electrodes, thus highly appropriate to control robots. For each movement, there is specific pattern of muscle activation; therefore multi-channel electrodes need to be used to analyze various movements together [8].

So, this paper is restricted to Surface EMG based schemes only to improve Neurorehabilitation.

II. SEMGBASEDSCHÉMES IN NEUROREHABILITATION FOR ROBOT ASSIST

There are various schemes based on SEMG which are presently used in Neurorehabilitation technology with exoskeleton robots like increasing miniaturization, compactness and integration of various hybrid units etc with an ability to evaluate patient’s disorder precisely to give required therapy or amount of training to rehabilitate them. This paper is restricted to review various SEMG
based schemes which facilitate improved neurorehabilitation technology.

Jacob Rosen et al [9] investigated the use of Human–Machine interface (HMI) to control elbow joint of exoskeleton robot. This study proposes a new generation of exoskeletons by setting the interface at the human neuromuscular junction level, using myosignals (processed electromyography signals) as command signals for the system. Muscle activation levels and joint kinematics were given as inputs to the Hill based muscle model for the prediction of movements

Kazuo Kiguchi et al [10] presented electromyogram (EMG) signals based hierarchical neurofuzzy method for controlling upper-limb exoskeleton system. For better assistance by robot, the cooperative motion of elbow and shoulder joints was examined.

D. S. Andreasen et al [11] developed a robotic device with the potential to greatly aid neuro-motor rehabilitation in individuals who are suffering from neuro-logical injuries like stroke. Feasibility of EMG active assistance by combining EMG signals with an impedance control algorithm was demonstrated. The research was mainly concentrated on the use of EMG signals as control signals for force amplification in able-bodied humans. The exoskeleton described in this paper is able to detect the participation of the patient, and use this information to either decrease or increase assistance and resistance as is appropriate to progress the patient

Zeeshan O Khokhar et al [12] developed wrist exoskeleton prototype (WEP) of 2-DOF using pattern recognition technique to estimate the torque applied by a human wrist. SEMG data was gathered from four forearm muscles by using a commercial EMG measurement system and a custom designed rig. EMG amplitude, root mean square, waveform length and autoregressive model coefficients were the features extracted from acquired raw signal. From acquired signals, two sets of classes (19, 13) of different force intensity were extracted using Support Vector Machine (SVM) with average accuracy for 19 classes was about 88% and for 13 classes was 96%. Proposed experimental setup is shown in fig.3 where (A) SEMG leads, (B) EMG measuring device, (C) torque measuring device for wrist flexion-extension, (D) torque measuring device for wrist, (E) data acquisition board, (F) classifier and force controller in Lab VIEW, (G) WEP, and (H) force sensor.

S. Parasuraman et al [13] developed a socially inspired robot technique to facilitate stroke rehabilitation. Information collected from patient’s muscle activity is used to derive a rehabilitative robot which will assist patient’s arm. The main advantage of this system was that it had minimized patient’s inconveniences due to the movement by robot. This system was based on torque feedback control. In this, the conventional mode of control had been replaced by sliding mode control due to various advantages like robustness, insensitive and unpredictability etc

Michal A. Mikulski et al [14] developed three electromyography signal based control algorithms from single muscles as well as biceps and triceps muscle pairs for Single degree of freedom (DOF) Exoskeleton robot in Upper Limb rehabilitation. Electric actuation with spur or planetary gearboxes was used instead of direct electric actuation of mechanism due to the advantage of high holding torque. To maximize user’s instinctive control over the exoskeleton system proposed algorithms were:

- Single channel proportional algorithm,
- Single channel threshold algorithm,
- Dual channel differential threshold algorithm.

Sang Wook Lee et al [15] proposed a new subject-specific technique for pattern classification based on electromyography (EMG) to detect the intent of stroke survivors. This proposed classification system was able to differentiate tasks of a distinct nature like opening of hand, gripping tasks etc. but its classification accuracy specifically in severely impaired subjects for similar gripping tasks was relatively low. Classification accuracy was highly affected by two variables (subject impairment level and the number of training sessions) so, two-way
analysis of variance (ANOVA) was performed to examine those variables. Linear discriminant analysis (LDA) classifier has advantages of faster training process and ease of implementation due to which it was selected over other types of classification methods.

Feng Zhang et al [16] presented a motion recognition technique based on newly extracted feature of SEMG using discrete wavelet transform (DWT) for controlling upper limb rehabilitative robot. Other traditional features of SEMG were also extracted for comparison. Compared results presented 98.9% recognition rate of newly extracted feature than all of the traditional features but also concluded the improved recognition rate (99%) with the combination of traditional features.

Hardeep S. Ryait et al [17] proposed a prosthetic control strategy based on acquisition from acupressure points and multi-channel control of an artificial limb for elbow amputees. Two channel approach was used to differentiated four elbow movements using root mean square value of SEMG signal as single parameter where as comparison of SEMG parameters with grip force was done using single channel approach. To identify the data for group comparison for the best two channel combination to verify the elbow movement discrimination Principal component analysis was done. Results showed that for the interpretation of all four movements the Combination II is the most preferred location for two channel system for two channel elbow prosthetics. Combination II was found to be the combination where maximum movements can be realized as two channel system. Control methodology of this type will help in the development of controller based hardware.

Li Dapeng et al [18] developed an artificial neural network (ANN) using root mean square value (RMS) of raw SEMG signal from biceps brachii and triceps brachii muscles as input which makes the convergence speed of network more rapid to predict elbow joint angle. A three-layer BP neural network which is acyclic multi-level network training algorithm was constructed and trained for predicting elbow joint angle by improved back propagation algorithm (BPA). Positive results were concluded and thus this model can be used in controlling of angle movement.

Xu Zhang et al [19] presented a method with high-density surface EMG recording and pattern-recognition technique as feature extraction tool for analyzing stroke survivors. 89 channels were used to recorded SEMG signals from 12 hemi paretic stroke subjects while they were trying to perform 20 different movements. High accuracies (96.1% ± 4.3%) were obtained when 20 different movements of arm, hand, finger/thumb involving the affected limb are classified. Results proved the effectiveness of this proposed technique. This information will potentially control the assistive devices and facilitate improved stroke rehabilitation.

Kazuo Kiguchi et al [20] proposed an EMG-based impedance control method for power-assist upper limb rehabilitative robot. This impedance control is applied to the user’s hand trajectory to realize humanlike motion. 16 channels were used to obtain EMG signals. A neurofuzzy muscle model matrix modifier was applied to make the controller adaptable to every upper-limb posture of any user. Various advantages like it is simple, easy to design, humanlike, and adaptable to any user showed the effectiveness of this proposed control method.

Shuxiang Guo et al [21] used wavelet packet decomposition method which is a kind of time-frequency domain for finding effective coefficients between upper limb movements for Activities of Daily Living (ADLs) and EMG signals. These coefficients were used as the input to BP neural network. During continuous movement, BP neural network was used for movement classification. This proposed technique offers a high range of possibilities for revealing signal information and providing better way for controlling rehabilitation robots. Experimental results proved that on-line identification rate was not so perfect but this method was effective offline.

Michael A Delph II et al [22] developed a rehabilitative wearable robotic glove which aids in the movement of fingers and gripping exercises for stroke patients. Robotic glove used a cable system actuated by servomotors to provide assistance in the flexing and extending of the users fingers over a full range of motion across 1-DOF. Interface circuitry, surface EMG signal
acquired from the extensor digitorum communis muscles and the flexor digitorum profundis muscles of forearm were integrated into the forearm sleeve for detecting user intent and controlling the device

Keunyoung Park et al [23] presented a rehabilitative exoskeleton system of 2-DOF for upper limb. Two motors each with 0.26° resolution encoder for velocity and position control were used to actuate cable-driven differential mechanism. Exoskeleton system was trained by using detected movements of subjects. This detection was done using SEMG signals. Torque sensors (strain gages) were used to measure exerted torques on elbow and wrist axes.

Brian Jeon et al [24] examined the structural changes of motor unit (MU) in paretic muscle post-stroke to assess neural mechanisms of paresis. Motor unit (MU) data was extracted from SEMG signal acquired from first dorsal interosseous muscle (FDI) using decomposition system. Identification of a large number of MUs was done using analytical spike triggered averaging (STA) technique to examine the MU structural change in stroke survivors for rehabilitation. Explored results revealed motor unit action potentials (MUAPs) of stroke survivors with reduced amplitude and longer duration in the paretic muscle as compared to contra lateral muscle which contributed to muscle weakness. This method developed an assessment tool for muscle weakness post-stroke which will help in rehabilitation process.

Flávia Aparecida Loterio et al [25] assessed the applicability of a SEMG based rehabilitative robot assisted gait-walker for individuals with post-stroke hemi paresis. Preliminary tests were done with the proposed methodology to analyze the robotic walker, but first using a conventional walker two frontal wheels as assistant gait. Data were collected firstly with the aid of the walker and then without the aid of walker. After comparing data, results concluded that with the use of the walker the gait speed in healthy volunteers was reduced and consequently, changes occurred during muscle activation.

Dongqing Wang et al [26] decoded neural control information hidden in the surface EMG recordings from partially paralyzed muscles in stroke patients. In this study, wavelet packet transform (WPT) which offers flexible time-frequency resolution of a signal was explored as a tool of feature extraction. Taking advantage of such properties of WPT, myoelectric pattern recognition based on WPT was examined for discriminating 20 different functional movements involving the affected limb of the stroke subjects. The experiment results showed high classification accuracies (above 94%) by using WPT proved the use of WPT in myoelectric pattern recognition.

He Wang et al [27] improved the efficiency of the lower limb rehabilitation by presenting a model based on human-computer interaction. Two problems were faced when EMG signals were applied to the lower limb rehabilitation robot:

1) Decoding method of SEMG
2) Control method of the lower limb rehabilitation robot using SEMG.

EMG signal was decoded by using Hill muscle model to obtain the quantity of force and torque that was acted on the joint by human muscles to move the body and then model’s parameters were amended by using stimulated annealing algorithm. This was used to control robot keeping assist coefficient (AF) constant throughout the process. AF is the ratio of assisted force to the total force the patients need to move. Experimental results concluded that the difference between the actual decoding torque and EMG ideal decoding torque after torque compensation is small which made the robot assist people like human muscle so as to achieve the purpose of recovery.
Yee Mon Aung et al [28] presented a shoulder joint angle prediction in real time method based on surface electromyography (SEMG) signals in both offline and online modes. Muscle activation model was used to extract signals from anterior deltoid (AD), posterior deltoid (PD) and upper trapezius (UT) muscles. Trained and tested data were fed into extreme learning machine (ELM) for angle estimation where as in online mode; estimation of shoulder joint angle is based on the trained result. Webcam captured actual joint angle was then compared with estimated joint angle. Compared data proved the accuracy of this method as 0.96 in offline and 0.93 in online mode with processing time less than 32ms in both cases for the estimation which proved the effectiveness of proposed prediction method in rehabilitating stroke survivors.

Fig. 7. Block diagram of proposed prediction system

Willy Chou et al [29] presented a design of a wireless and wearable monitoring device for precise evaluation of swallowing coordination in dysphagic patients with unilateral stroke. An algorithm of bilateral muscle pattern detecting was also developed to extract and analyze the different swallowing feature of SEMG patterns. Patterns were extracted from bilateral muscle groups of orbicularis oris (OO), the masseter (MS), the submental muscle groups (SUB), and the laryngeal strap muscles (LSM). Experimental results showed that the amplitude and latency variation for dysphagic patients were significantly larger than those for healthy subjects. This explained that the dysphagic patients were producing more muscle activities during a shorter duration than the healthy adults under swallowing conditions. This proved that dysphagic patients were anxiety at swallowing attempts and the amplitudes of the SEMG signals were influenced by that anxiety emotion. This verified precise and accurate monitoring of presented design.

Ghulam Rasool et al [30] analyzed the changes in stroke-affected muscles using SEMG patterns. 128-channel grid was used to record the SEMG signals from both long head (LH) and short head (SH) of Biceps Brachii muscles. For each head of muscle, EMG data was collected from both affected and contralateral side of stroke subjects as well as from healthy participants at various force levels from 20 to 60% of maximum voluntary contraction (MVC). Study concluded that spatial SEMG patterns remain consistent across all force levels of MVC and spatial patterns on affected and contralateral sides of stroke subjects were dissimilar. The active SEMG region on affected side was shrunk at all force levels and on both the LH and SH of BB muscle, indicating muscle atrophy due to stroke. This enquiry provided information about the changes in affected muscles after stroke and thus led to the development of better intervention therapies for rehabilitating stroke subjects.

Chien Hung Yeh et al [31] proposed phase amplitude coupling (PAC) analysis based novel index to evaluate spasticity disorder. To maintain signal’s information, Empirical Mode Decomposition (EMD) method was applied to decompose SEMG signal (from quadriceps and hamstring muscles) into intrinsic mode functions (IMFs). Shannon entropy was used for PAC analysis which was based on angular velocity (related to IMFs) as phase and envelope of filtered EMG signal as amplitude. PAC results were compared to the results of other traditional methods and concluded that proposed novel parameters (based on PAC) is the only approach which can effectively discriminate spastic from non-spastic limbs (p<0.0001*). This indicated the feasibility of using the novel indices based on the PAC in evaluating the spasticity during rehabilitation process among the hemiplegic stroke patients.

III. DISCUSSION AND CONCLUSIONS

Rehabilitation is a potentially growing field as the population of the stroke patients is increasing day by day which increases the work load of therapists. Thus SEMG based various therapeutic robots are employed in this field to reduce the fatigue level of therapists. The information presented in this paper serves as compilation and review of the use of SEMG signal in stroke rehabilitation field for monitoring stroke patients and controlling therapeutic robots based on that information. Various techniques are also developed to analyze patient’s disorder by evaluating acquired SEMG signal from affected muscles which will further help in rehabilitating patients.

As per the survey, robot assisted therapy showed exponentially growing results. Earlier, robot–aided therapy for stroke subjects was based on “on-off” control strategy; resulting robotic systems operating with a predefined trajectory or action once the system was triggered by EMG signals. But EMG feature extraction and pattern recognition technique have recently drawn researcher’s attention for further development of myoelectric control systems. It uses extracted feature of EMG signal acquired from affected muscles for having precise information about patient’s disorder so that based on that information robot can be controlled easily to assist patient during rehabilitation.
There is a great need of reliable and safe rehabilitation process, so further research need to be done for implementing such techniques in real time to make this SEMG based approach best for rehabilitating stroke survivors

REFERENCES