A Muscular Activation Controlled Rehabilitation Robot System

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Abstract. The number of people who need rehabilitation increases day by day because of reasons such as laceration, aging, work accidents and etc. Therefore, the need of rehabilitation aids is constantly increasing. There are many research studies about assistive technologies in rehabilitation. Especially, rehabilitation robots have a great importance. Existing rehabilitation robot studies have mostly focused on position and force control. Thus, it is muscular activation that should be evaluated to enhance control results, because the same joint trajectory and/or joint torque can be achieved through different muscular combinations. In this study a muscular activation controlled rehabilitation robot system for lower limbs is proposed. A probabilistic artificial neural network model, which can estimate posteriori probability, was used for discrimination of EMG patterns for robot control with EMG signals.

Keywords: robot, EMG, motion classification, pattern discrimination.

1 Introduction

Spinal cord injury, accidents causing damage in brain or brain vessels and similar diseases cause the need for rehabilitation to grow in the whole world. In parallel to this situation, related technologies are also developing since smart machines are required for supporting physiotherapists in the rehabilitation period. We can classify the systems developed in physical therapy such as smart patient chairs, assisting exoskeletal robots, intelligent orthosis-prosthesis (orthotic) and therapeutic exercise robots. The physiotherapy process requires extreme patience from both the patient and the physiotherapist besides being an exhausting and expensive process. Additionally, a physiotherapist can only treat single patient. Nowadays, in order to find solutions to these problems, intelligent therapy equipment is objective in research and development.

In physical therapy and rehabilitation-based health centers, therapy exercise appliances such as CPM [1], BIODEX [2] and CYBEX [3] have been used for a long time. However, these equipments only have a very limited ability to respond to the patient's reaction and to model the physiotherapist's movements. Accordingly, studies on rehabilitation-based robots have increased especially in the last 15 years. Rehabilitation

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robots have great importance in the fields of future physical therapy and rehabilitation, due to their features:

- the ability of doing the repetitive movements accurately throughout the therapy
- the ability of measuring the position, the speed and the force and recording these measurements by means of its sensors
- the data of these measurements reflects the result of the therapy.

MIT- MANUS [4], GENTLE/s [5], MULOS [6], ARM-Guide [7], MIME [8] are the most known rehabilitation robots designed for the upper limbs. These designs are developed for the therapy of disorders in motor functions. During the therapy, when the patients cannot do the exercises, the robot arm aids the patient. The effectiveness of robot-aided therapy has been approved by the clinical studies carried out to the present day; refer to [9] and [10]. Besides these studies, rehabilitation robots that aimed at modeling the exercises of the physiotherapist have been developed such as:

- TEM (Therapeutic Exercises Machine) [11]
- REHAROB [12]
- PHYSIOTHERABOT [13]

In all of the studies mentioned above, the force and position sensors detect the patient's reactions. The control algorithms of these robots were developed thorough these position and force feedback data. However, the muscle of the patient is the place where the intention of movement and reactions originally occur in.

When the patient's muscle activations can be evaluated under the control of the rehabilitation robots, the best information about patient's muscular-nervous system will be provided. Thus, this will bring out a more meaningful and more effective control and accordingly a better therapy process. Patient's muscle activation can be obtained by EMG (electromyogram) signals. Various EMG-based systems such as human-machine interfaces, prosthesis, patient chairs, and exterior skeleton robots have been developed to the present; see [14]-[18].

The applications where robot actuators are used as a control signal by means of processed EMG signals are concentrated especially in prosthesis arms and in exoskeletal robots. However, among the rehabilitation robots which aim to recover the motor skills of patients, the use of EMG signals as the robots control signal is limited, especially for lower limbs rehabilitation robots. An assisting robot that is controlled by EMG, BIODEX equipment, was compared with passive exercises in terms of the wrist joint actions. The analysis indicated that a better result is observed with the robot-aided exercises than the passive exercises. The actuators of MIT-MANUS were controlled by means of the EMG signals obtained from the muscles. A game aiming to improve the motor skills was set up on the patients monitor. The patient was told to do the given duties by using his forearm and upper arm together with the robot arm. At the states when the patients muscle signals decreased below a certain level, the robot arm helped the patient with the exercise. In this study four channel EMG signals were used which were obtained from the patients forearm and upper arm regions. In situations when one of these signals exceeded the level of logic 1, robot actuators were activated.

There are only a few studies in the literature about EMG controlled rehabilitation robots for lower limbs. He and Kiguchi proposed an exoskelatal robot manipulator controlled by EMG signals to assist lower limb motions. This sytem is wearable and it transfers torques from motors through rigid links to the human joints. They developed a fuzzy-neuro controller to control exoskeletal robot manipulator [19]. Hoshino and et al. developed an assistive device for human locomotion. They used EMG signals to control of gait support mechanism [20].

In this study, we proposed a muscular activation controlled therapeutic exercise robot system for the rehabilitation of the lower limbs. In the system design, basic rehabilitation exercises were references (flexion–extension for knee and hip, abduction-adduction for the hips). A Cybernetic Human-Machine Interface was developed for the control of the proposed system. In this interface, a LLGMN (Log-linearised Gaussian mixture model) algorithm was used for detecting the patient's movements by using EMG signals [21]. The system performs the manual exercises of the physiotherapist besides the passive, active and active assistive exercises. Main differences of proposed system from other rehabilitation robot system for lower limbs are that the proposed system is a therapeutic exercise robot system that is controlled by biofeedback as well as force and positon feedback and the developed cybernetic interface can be classify patient motion in order to detect whether correct muscular activation is generated by him.

2 Robot-Aided Rehabilitation System

The structure and the elements of the system are shown in the Fig. 1. According to this, the system is composed of the physiotherapist (PT), the patient, the rehabilitation robot and the cybernetic interface. The PT enters the information about the therapy into the system through the user's interface. This information consist of parameters such as patient's identification (name-surname, date of birth, kind of illness, physical properties of the patient etc.), the limb that will perform the exercise, the kind of the exercise, the therapy period, the number of repetitions of exercise and the therapy's degree of difficulty. Furthermore the EMG electrodes are applied to the appropriate positions on the patient's limb by the PT.

The cybernetic interface is the main control center of the system. It evaluates the patient's EMG signals and the force-position feedback information coming from the rehabilitation robot. Then it produces the torque command which is required for the robot actuators. Regarding this torque command, the rehabilitation robot helps the patient's movement when it is need. More detailed information about the rehabilitation robot and the cybernetic interface are given below.

2.1 Rehabilitation Robot

In this study a robot mechanism with 3 degrees of freedom aimed at the rehabilitation of lower limbs, which was developed by the authors in the earlier studies, was used (figure2). The properties of the robot mechanism are given below. (For deeper information refer to [22])

- It is able to perform active, passive and active assistive exercises as well as model the PT's exercise movements.

- It is a 3-DOF robot manipulator. Thanks to this feature, it can perform the flexion-extension movement for the knee and hip and the abduction-adduction movement for the hip.
- It uses two special force sensors suitable for rehabilitation in order to measure the reacting force of the patient.
- Safety is ensured using both software and hardware.

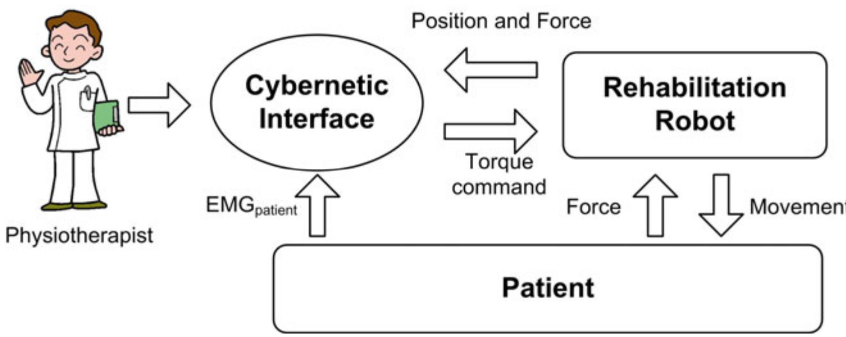

Fig. 1. Robot aided rehabilitation system

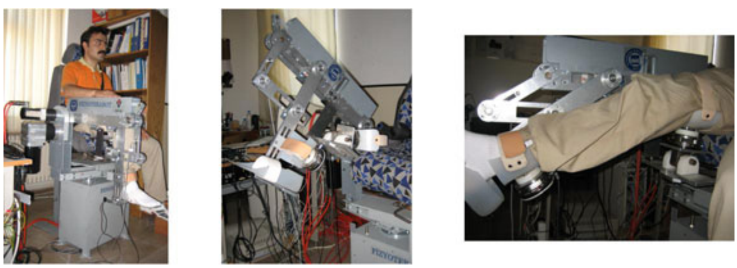

Fig. 2. Rehabilitation robot and positions of force sensors

2.2 Cybernetic Interface

The Cybernetic interface is the control center of the system. The block diagram of the interface is given by figure 3. Explanations regarding its units are given below.

2.2.1 EMG Signal Processing Unit

At the EMG signal processing unit EMG signals coming from the electrodes that are tied to patient's skin are evaluated and used for controlling. This process is performed as follows (see also figure 4). EMG signals coming from L pairs of electrodes are linearized, amplified and filtered respectively. The filtered signals are exemplified sampled with 1 kHz frequency by DAQ cards. Sampled signals are defined as $EMG_i\ (t)$ (i = 1, 2,…, L). $EMG_i\ (t)$ signal is normalized as the sum of the signals coming from L channels electrodes to be 1. The normalized EMG signal is defined in Equation (1).

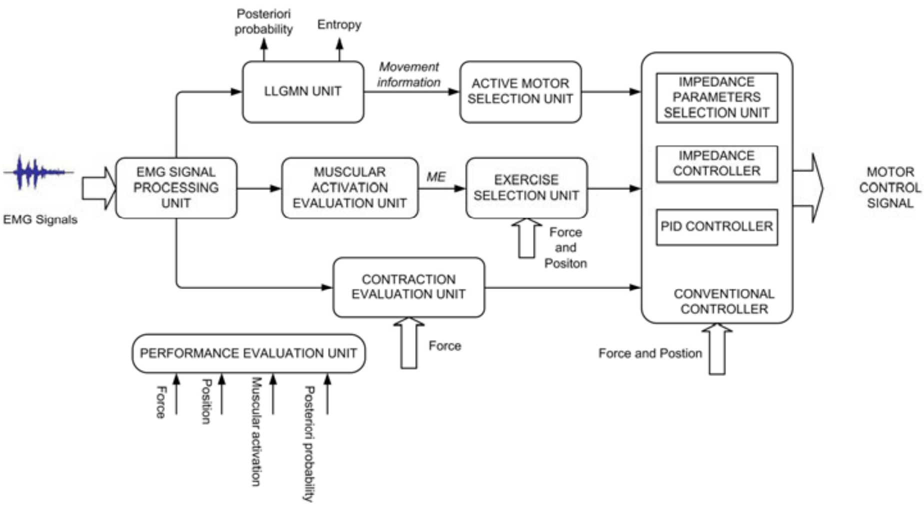

Fig. 3. Cybernetic interface

$$EMG_i'(t) = \frac{EMG_i(t) - EMG_i^{rest}}{\sum_{i=1}^{L}(EMG_i(t) - EMG_i^{rest})} \quad i = 1, 2, \ldots, L \tag{1}$$

In this equation, $EMG_i'(t)$ represents the normalized EMG signals, whereas EMG_i^{rest} represents the mean value of $EMG_i(t)$ of the related limb at rest. Normalized EMG signals are transmitted to related units as shown in Figure 3.

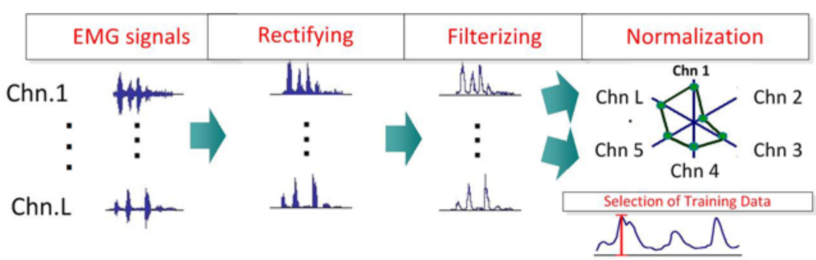

Fig. 4. EMG Signal Processing

2.2.2 Log-Linearized Gaussian Mixture Model Network (LLGMN) Unit

In this study, a probabilistic artificial neural network model, which can estimate posteriori probability, was used for discrimination of EMG patterns in order to determine the EMG-based joint movement [21]. The network structure was built on a statistical model which is composed of log-normal gauss components. Normalized EMG signals are taken by the LLGMN unit for classifying the movements. At first, the signals are processed into a non-linear transformation and then transmitted to LLGMN network model.

The output of the network is the information of the posteriori probability values obtained from the sampled EMG patterns or the information of the movements, the interpreted state of these values. These phases are shown in Figure 5. Besides this, the entropy value is also calculated in order to detect the patterns which cannot be decoupled by the network. If the value of entropy is near to zero, it indicates a right discrimination. If it is near to one, it indicates a wrong discrimination. The network does not give any output in case of exceeding the previously determined entropy value.

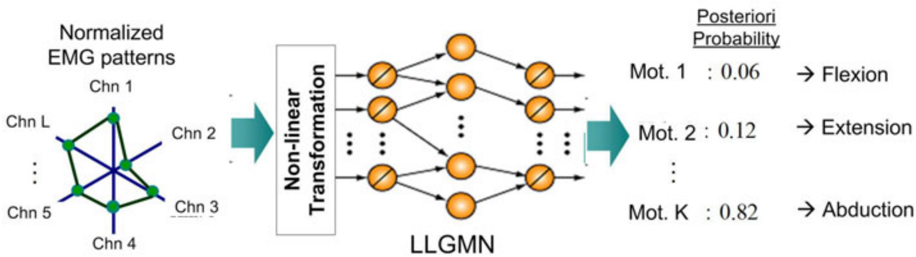

Fig. 5. Log-linearised Gaussian mixture model network (LLGMN)

2.2.3 Muscle Activation Evaluation Unit

The muscle activation (MA) is defined in the equation (2).

$$MA(t) = \frac{1}{L}\sum_{i=1}^{L}\frac{EMG_i(t) - EMG_i^{rest}}{EMG_i^{max} - EMG_i^{rest}} \tag{2}$$

In this equation, EMG_i^{rest} represents the limb at rest and EMG_i^{max} represents the mean value of EMG_i (t) when the maximum muscle contraction occurs. The calculated value of muscle efficiency is transmitted to the exercise selection unit and is used as a selection parameter for appropriate kind of exercise.

2.2.4 Exercise Selection Unit

The proposed system can perform passive, active-assistive, active and resistive exercises. The exercise selection unit selects the appropriate exercise type through switching method, by using the value of muscle efficiency obtained from the force, position and EMG feedback data and by using the information about the exercise type determined by the physiotherapist.

2.2.5 Contraction Evaluation Unit

A muscle contracture is a shortening of a muscle or joint. It is usually in response to prolonged hypertonic spasticity in a concentrated muscle area, such as is seen in the tightest muscles of people with conditions like spastic cerebral palsy. In case of contracture, this evaluation unit, which is designed for preventing the system from hurting the patient, analyzes contracture. Depending on this analysis, the robots movements are regulated in an appropriate way. Then the necessary information is sent to the conventional control gear.

2.2.6 Active Motor Selection Unit

In this unit, the servo drives which should be allowed are determined in accordance with the movement information coming from LLGMN unit.

2.2.7 Performance Evaluation Unit

This unit is used to evaluate the patient's performance during the rehabilitation session. According to the exercise type, three different performance indices are used. These are EMG pattern index, EMG amplitude index and mechanic parameters index (angle of joint, torque, speed). Each index has two different evaluations: patient index and error index. Patient index reflects only patient's performance, whereas error index detects the error between the patient's performance and the commands sent to patient from the system. In patient index, three different values are calculated: time-dependent instantaneous values, the mean value of time for each trial and the total mean value of all trials in a session.

The normalized EMG signals, the value of muscle efficiency and mechanic parameters (torque, speed, position) are calculated or measured for instantaneous values. By using the time mean values, patient or PT can evaluate the result of the therapy after every trial. The daily therapy evaluation can be done with the total mean value which is calculated at the end of all trials.

The error index indicates the patient's performance ratio and the mean value of the errors in the process.

2.2.8 Conventional Controller

Among the exercises performed by the system, the passive exercises require position control, active-assistive exercises require force and position control, active and resistive exercises require force control. In the proposed system, impedance control method will be used for force control, whereas proportional-integral-derivative (PID) position control method will be used for position control. The conventional control unit will select the control method. Additionally, impedance parameters selection unit, which is located in this unit, will select the appropriate impedance control parameters in accordance with the exercise type.

3 Materials and Method

The system has the two separate working modes learning and therapy. The learning mode aims the patient's movements to be learned by the system by means of EMG signals. With this purpose, EMG electrodes are placed on the related muscles in accordance to (regarding) the limb to be rehabilitated and the kind of movement (flexion-extension, abduction-adduction, etc.). The related movements are done by the patient. For each movement EMG signals are recorded. The learning data is selected from within these recorded signals. The network is trained by the selected data. After the training is completed, the network is ready to classify the movements and the learning phase ends.

In the therapy phase, the patient is attached to the rehabilitation robot without replacing the position of the EMG electrodes. The related exercise type is selected by PT. In therapy stage, the duties of the patient are reflected to the patient's monitor.

The patient is asked to perform these duties, although he is attached to the robot arm. The cybernetic interface, which evaluates the EMG signals and force-position data coming from the rehabilitation robot, produces the motor control signal.

Thus, the rehabilitation robot moves. During the active exercises, patients EMG signal level (measured by muscle efficiency) and decrease in force or contracture case are evaluated by cybernetic interface. The rehabilitation robot helps the patient with the exercise as much as required. In case of contracture, in order to prevent injury, the rehabilitation robot moves with appropriate force and position regarding feedback signal levels or stops the whole movement. Rehabilitation robot has also the ability to perform passive exercises and resistive exercises. Also during these exercises the patient's state is controlled continuously by the feedback information. When needed the system can make some changes in the applied force and position. This process increases the software security besides hardware security elements (limit switches, emergency buttons, mechanical limitations).

4 Conclusion

In this study, we proposed a muscular activation controlled rehabilitation robot system for lower limbs. The system is designed to imply the patient's muscle signals to the force-position feedback control method. A probabilistic artificial neural network model, which can estimate posteriori probability, was used for discrimination of EMG patterns for robot control with EMG signals.

Physiotherapists scale human muscles with six different levels from 0 to 5. Zero level represents the muscles with no contraction, whereas level five represents the strongest muscles. The type of the applied exercises change according to this scale [22]. The system can especially be used for rehabilitation of the patients with muscle levels 0, 1, 2 and 3. There may occur some problems in classifying the EMG signals obtained from the patients with 1 and 2 level muscles, because the patient cannot use his muscles properly and contracture may occur. For this reason, the patients who will use the system will require training which will provide them the knowledge to use their muscles properly. This training will be constituted by games based on performance. In the future study, the performance of the proposed robot-assisting system will be tested by healthy subjects and then patients.

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