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Original Research Article

Human impedance parameter estimation using artificial neural network for modelling physiotherapist motion

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ABSTRACT

Physiotherapy (physical therapy) is a form of therapy aimed at regaining patients their bodily limb motor functions. The use of what are called therapeutic exercise robots for such purposes is gradually increasing. Therapeutic exercise robots have been developed for lower and upper limbs. These robots lighten the workload of physiotherapists (PTs) by providing the movements on patients' relevant limbs. In order to get robots to perform the movements that the PT expects the patient to perform, it is required to determine the mechanical impedance parameters (inertia, stiffness and damping) due to the contact between the PT and patient's limb's, and to ensure that the robot moves according to these parameters. The aim of this study is to estimate these impedance parameters by using artificial neural networks (ANNs). Data from experiments on real subjects were used to train the network, and success was obtained using new data not presented to the network before. Subsequently, the previously acquired output was re-directed to the network with the purpose of developing a network, which can learn more accurately. Results have provided the designed ANN structure can generate necessary impedance parameter value to imitate PT motions.

1. Introduction

Nowadays, improving the innovative rehabilitation technologies to increase the life qualities of people who lost their physical abilities of their limbs due to reasons like muscle or joint diseases, neurological deficits, and spinal cord injuries is an important study area. These technologies provide people with a fast recovery of their physical abilities [1]. For this reason, studies on developing intelligent rehabilitation

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devices have gained momentum especially in last 15 years. Especially the use of robotic systems with user-friendly interfaces in the area of physiotherapy and rehabilitation, besides reducing the workloads of PTs, provides an easy and fast rehabilitation process that would otherwise be long, troublesome and expensive for patients nowadays [1,19]. The rehabilitation robots provide repeated, monitored and easily adjustable exercise movements. Also by using the control techniques like adaptive control or impedance control, robot can provide needed amount of movement support to the patients, ensuring their active participation to the therapy.

Physiotherapy aims to restore proper functioning to the body or, in the case of permanent disease or injury, to reduce the impact of any dysfunction. The human limbs' interaction with their environment can be modelled by using mass–spring–damper system. The mechanical impedance can be represented by these parameters. The interaction between physiotherapist and a patient can be thought as limb interaction (PT hand movement) with its environment (patient limb). A robot can behave such a PT, if PT's manual therapy can be modelled. To this regard PT's hand impedance parameters can be obtained and transferred to a robot. So, this robot can perform manual exercise as the PT.

Researchers have done various studies on estimating mechanical impedance parameters on rehabilitation robots. Zhang et al. [2] used the stiffness coefficient tuning in the force feedback on the horizontal lower limb rehabilitation robot to estimate the impedance. In another study Zhang et al. estimated the impedance parameters for a prosthetic hand, but they ignored the inertia [20]. Piovesan et al. [3] used time–frequency approach to estimate single joint upper limb impedance based on a reassigned spectrogram and can track the frequency modulation of biomechanical system after perturbations. Palazzolo et al. [4] used a low impedance robot for rehabilitation (MIT-MANUS), and by holding the human arm to a desired position with various forces. They measured movements with sensors, thus estimating the impedance parameters by both experimental (by using real springs, dampers and masses) and analytical methods. In two different studies Rouse et al. [5] and Satici et al. [6] estimated the impedance parameters of human ankle joint by using the difference between applied and measured torque. Yuan et al. [7] used electromyogram (EMG) signals to estimate the impedance on a lower limb rehabilitation robot. They aimed to relate EMG signals to impedance parameters changing during the flexion-extension movement on the knee joint, and to test the operability of changing impedance control. The estimation with an error lower than 1% was observed in this study. Xu and Song [8] used adaptive on-line learning impedance control on their upper limb rehabilitation robot. They estimated the damping and stiffness parameters by using fuzzy neural networks method. They aimed to maintain the stability of the rehabilitation robot system in the case when the patient's physical condition makes a change. In another study, their purpose was to develop a fuzzy adaptive control strategy based on traditional impedance control for providing optimal force to stroke patients. An on-line identification of parameters was used to estimate impaired limb's mechanical impedance. By using fuzzy adaptive algorithm, the desired force and impedance control parameters were adjusted automatically according to the patient's physical/physiological condition and rehabilitation phase [9]. Xu et al. used the adaptive impedance control based-on evolutionary fuzzy ANN method on their upper limb rehabilitation robot to estimate the impedance parameters. Here, they used the adaptation rule based on regaining the movement capability of injured human arm [10]. In another study, they used the recursive least squares (RLS) method for online parameter estimation on their upper limb rehabilitation robot [11].

Patients who need rehabilitation can have varying physical properties. Further, the exercises needed by each patient can be varied depending on their joint problem. In robotic terminology, this difference is known as "the range of the motion" and "torque that should be applied". Especially in the rehabilitation process, the manual therapy made by PT's hand is very important. The force and position data, measured by sensors during the PT's movement of the patient's limb, are transferred to the robot so that it can do the PT's movements by applying the same therapy conditions. Using this method, Akdogan et al. [12], and Okada et al. [13] modelled the PT's motions.

Unlike previous studies, an ANN model was developed in this study to estimate the impedance parameters during the exercises the PT gets the patient to perform by using the force and position data. So, the PT's motions can be modelled by an impedance controlled rehabilitation robot whose impedance parameters are estimated by the ANN developed. The network estimates the inertia, damping, and stiffness parameters. The network is feeding the previous output as input itself to develop a more accurate learning network structure. The learning data were obtained by experiments with real subjects on impedance controlled real rehabilitation robot system for lower limbs of human body. The network trained by healthy subjects data that obtained from position and force sensors were tested. The results demonstrated that the ANN developed highly accurately. The ANN estimated impedance parameters less than 3% in terms of mean square error. The detailed about results are given in Section 3.

The study contributes to the therapeutic exercise robots field by helping to estimate the impedance parameter values during the PT's manual exercises, thus enabling a full modelling of the PT's movements. This study fills a gap in the literature on modelling the PT's motions by impedance parameter estimation, which, to the best of our knowledge, has not been done before.

2. Material and method

2.1. *Lower limb rehabilitation robot system (Physiotherabot^{TM})*

We used the Physiotherabot^{TM} to have experimental results and to test our network (Fig. 1) [12,14]. The Physiotherabot has 3 degrees of freedom, and it can make rehabilitation both for the right and the left leg. The structure of this robot lets flexion-extension and abduction-adduction for hip and flexion-extension for knee. Using the force and position sensors, this robot can measure force and position parameters in the