

A Human-Machine Interface Design for Direct Rehabilitation using A Rehabilitation Robot

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ABSTRACT

During the physical rehabilitation various problems are of concern for a patient. The most important difficulties, accessibility, costs, and exercise duration, are troublesome and require patience for both physiotherapist (PT) and patient. This is the main reason that is speeding up research and development of robotic rehabilitation approaches. In this study, a human machine interface has been designed for controlling of a rehabilitation robot that can perform active and passive exercises for lower limbs. Also the rehabilitation system that consists of human machine interface and robot manipulator can learn PT manual exercises and perform them by itself like a PT. So, PT rehabilitation capability is conveyed to the patient directly. The human-machine interface includes an easy-to-use graphical user interface. With this interface, the treatment period can be observed and recorded. Furthermore, the interface has been designed to be fit for web-based remote therapy. Test results of this study are to be presented for direct rehabilitation of knee and hip.

Categories and Subject Descriptors

J.3 [Computer Applications] Life and Medical Sciences; G.4 [Mathematics of Computing] Matlab / Simulink; I.2 [Artificial Intelligence] Robotics – Manipulator, Operator Interface.

General Terms

Algorithms, Measurement, Design, Human Factors

Keywords

Rehabilitation Robots, Direct Rehabilitation, Human-Machine Interface, Human-Machine Interaction

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1. INTRODUCTION

Growing world population and increasing problems of peoples' limbs have increased the need for rehabilitation. Reestablishing and improving limb functionality and strength are major issues. Furthermore, it is most important to return patients to society, reintegrate them into social life and therefore improve the patients' quality of life. Injuries on extremities like arms and legs are caused mainly from old age, work and traffic accidents. The role of the rehabilitation process is to restore functionality of previously damaged limbs. Throughout therapy, physical exercises for extremities like arms and legs have a key-role in the recovery of the patient. Therapeutic exercises consist of active or passive physical movements of the patient, carried out through the therapist, or of movements carried out of the patient with the assistance of the PT, depending on the condition of the patient. For rehabilitation either the patient has to go to a healthcare center, or the PT has to come to the patient. Considering the often time-consuming process of rehabilitation, it is difficult and cost-intensive for both patient and PT, and demands a high amount of patience of all parties involved. Furthermore, a PT can only fully attend one patient at a time. Especially, during the last ten years, studies for robots in rehabilitation have increased. The reasons for utilization of robots in rehabilitation can be listed as following: [1]

- Robots easily fulfill requirements of cyclic movements in rehabilitation.
- Robots have better control of introduced forces.
- They can exactly reproduce required forces in repetitive exercises
- Robots can be more precise regarding required therapy conditions.

Studies carried out in the closer past have proved many advantages of rehabilitation robots compared to classic therapy methods [2]. In addition robotic therapy provides better possibilities to acquire and store information such as the therapy response of the patient [3].

Khalili and Zomlefer introduced a system with two robots, each having two degrees of freedom (DOF), for rehabilitation of lower

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extremities. This system is also used for prediction of the parameters of human body segments [4]. Lee and others developed a robotic system for rehabilitation of upper limbs of paralyzed patients using an expert system [5]. Lum and others introduced an assisted rehabilitation system for arms [6,7]. Another system developed for rehabilitation of upper extremities is a robot manipulator with 5 DOF called MULO [8]. Krebs and others have developed and have been clinically evaluating a robot-aided neuro rehabilitation system called MIT-MANUS. This device provides multiple-degree of freedom exercises of upper extremities for stroke patients [9,10]. Rao introduced another system using a Puma 240 robot for active and passive rehabilitation of upper extremities [11]. Richardson and others developed a 3 DOF pneumatic device for rehabilitation of upper extremities using PD control and impedance control methodologies [12-15]. Reinkensmeyer and others developed a 3 DOF system called ARM Guide (Assisted Rehabilitation and Measurement Guide) for rehabilitation of upper extremities [16]. Another system with 3 DOF, called GENTLE/s, is developed in England for the rehabilitation of upper extremities, controlled by admittance control method [17]. The robots and methods developed in these studies generally realize specific tasks or assist the patient throughout rehabilitation.

There are several studies that use intelligent techniques and their aims are to transfer PT rehabilitation capacity to patient directly. For rehabilitation of upper extremities is the REHAROB project using two industrial robots. A knowledge base is formed by the necessary force and position produced by the sensors placed on the patients during rehabilitation process. Industrial robots then repeat the same procedure using this knowledge base [18]. Okada et al. employed impedance control methodology in a 2 DOF robotic system for lower limbs rehabilitation, where position and force information are received and recorded for the robotic system to imitate the corresponding motion [19].

In this study, a human machine interface (HMI) has been designed in order to control a designed and produced rehabilitation robot. Unlike other existing projects the robot manipulator (RM) that is used in this study can perform active and passive exercises for lower limbs and it can perform knee flexion-extension, hip extension-flexion and hip abduction-adduction movements. Also the rehabilitation system that consists of human machine interface and robot manipulator can learn PT manual exercises and perform them by itself like a PT. So, PT rehabilitation capability is conveyed to patient directly. So, single PT rehabilitates more than one patient at the same time with this system. The human-machine interface includes an easy-to-use graphical user interface. With this interface, the treatment period can be observed and saved. Furthermore, the interface has been designed to be fit for web-based remote therapy. Thus, difficulties of transferring patients to medical centers can be eradicated. Test results are presented for direct rehabilitation of knee and hip.

2. MAIN CONCEPT

The system consists of three basic components (See Figure 1). These are the PT, the HMI and RM. The system can perform PT's manual exercises as well as to carry out all standard active and passive exercises. The modeling of the manual exercises has been named "robotherapy". In the robotherapy mode, the system operates in two different modes. These modes are direct therapy

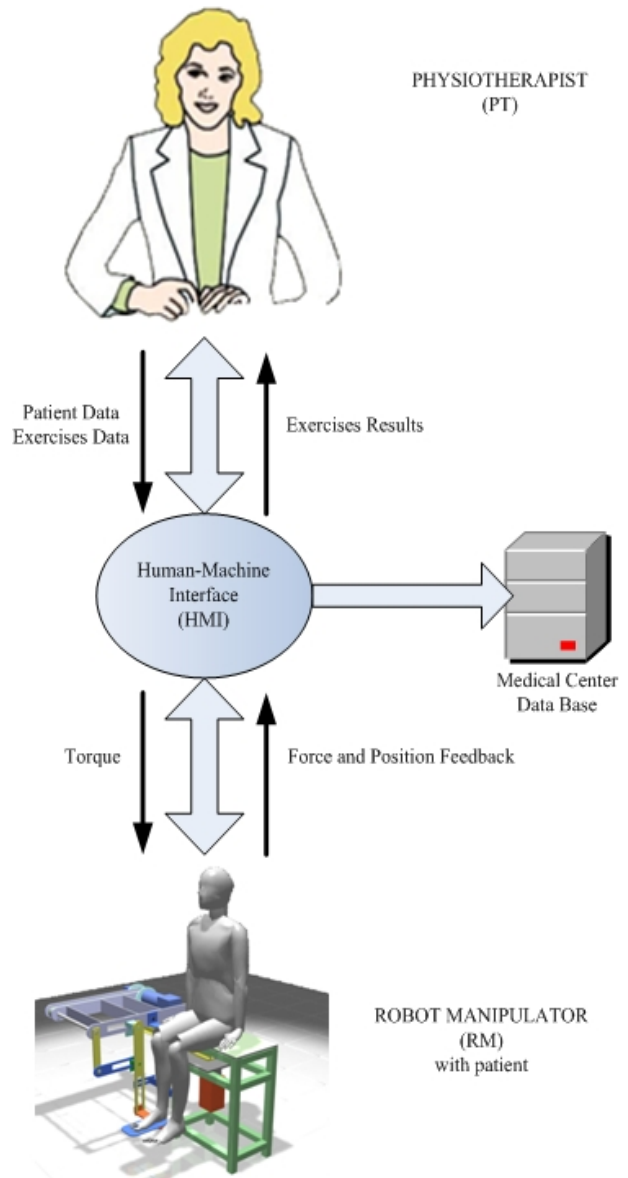


Figure 1. Main Concept

and reactive therapy. In direct therapy mode, the system can repeat movements taught by the PT for any required duration. In reactive therapy mode, the system responds according to the patient's reactions, the boundary conditions of the exercise carried out keep changing over the duration of the therapy. In both modes of operation the PT's individual therapeutic method is transferred to the system, and therefore frees the PT from repeating time-consuming repetitive exercises. In this study, only the direct therapy mode test results have been shown. For deeper information refer to [20].

The graphical user interface enables the PT access to all information concerning the patient and therapy mode, exercise type etc. The standard active and passive exercises are carried out

through the RM. However, for direct therapy the PT carries out movements while the patient is on the RM. In the meantime, the HMI monitors and stores position and force values. All process parameters are stored in the database. This mode has been named “direct therapy teaching” mode. The next step is to switch over to “direct therapy-therapy” mode. The RM is now reproducing the same positions and forces applied to the patient as in the previous teaching mode.

2.1 Physiotherapist

The system has been designed to be an aid for the PT. Therefore the primary user of the system is the PT him or herself. Single PT can only attend one patient at a time. By means of this system, one PT could possibly attend more than one patient at a time. Considering a fixed number of PT in society, more patients could be helped in a better way using this technology. Furthermore, rehabilitation sessions could be held longer, which is an additional advantage.

The system's aim isn't to replace the PT, it is to support him or her. The PT decides on the specific exercises to be carried out by the patient and teaches those to the RM. The RM is fed with information about the patient (age-weight-body length) and details about the exercise to be carried out. The PT then carries out the exercises together with the patient. In the next step, the RM carries out the exercises with the patient in the same way as done before with the PT.

2.2 Human Machine Interface

The HMI is the central unit between PT and the RM. It consists of the impedance controller, rule base, data base, graphical user interface and central interface units. A detailed block diagram of the HMI is given in Figure 2. The HMI programming is realized in Matlab/Simulink.

Central Interface Unit: The central interface unit provides communication between all system components.

Graphical User Interface (GUI): Enables the user to communicate with the HMI. The main menu as shown in Figure 3 is used to input the patients' data. These data is used in order to calculate a number of mechanical parameters. The body limb which is to be exercised and the exercise type are selected from the main menu as well. Results from previously carried out exercises can be accessed from the main menu and are displayed graphically as shown in Figure 4. The graphics display the patients' range of motion (ROM) and corresponding forces. These results are stored in the database for documentation and can be printed out optionally.

Impedance Controller: Impedance control aims at controlling position and force by adjusting the mechanical impedance of the end-effector to external forces generated by contact with the manipulator’s environment. Mechanical impedance is roughly an extended concept of the stiffness of a mechanism against a force applied to it. It is accepted to be the most appropriate control technique for the physiotherapy and is used in many rehabilitation robot applications (refer to [9,10] [13] [21-22]). Because of this it was used in this application as main control method. For direct rehabilitation, its parameters were selected as appropriate for PT moves patient limbs smoothly and easily. In order to select appropriate impedance parameters values, some experiments were realized with different parameters in different speeds.

Data and Rule Base: All data relevant to the patient is stored in the data and rule base. The stored information contains personal data, impedance controller parameters, saved exercises from the teaching mode and exercise results.

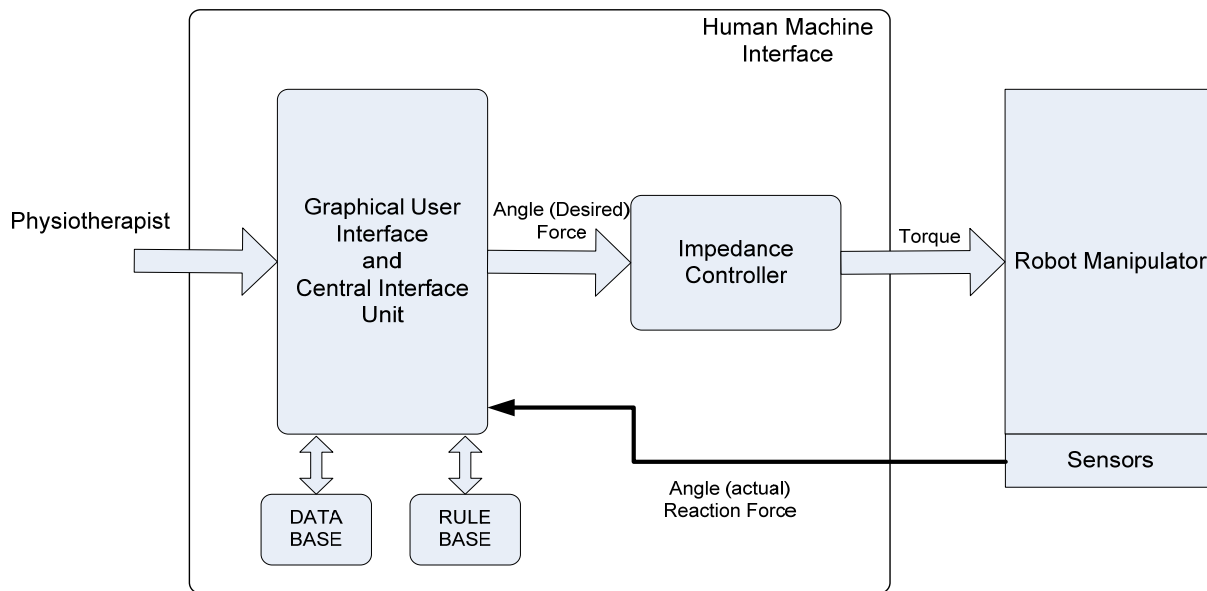


Figure 2. Detailed Block Diagram of the HMI

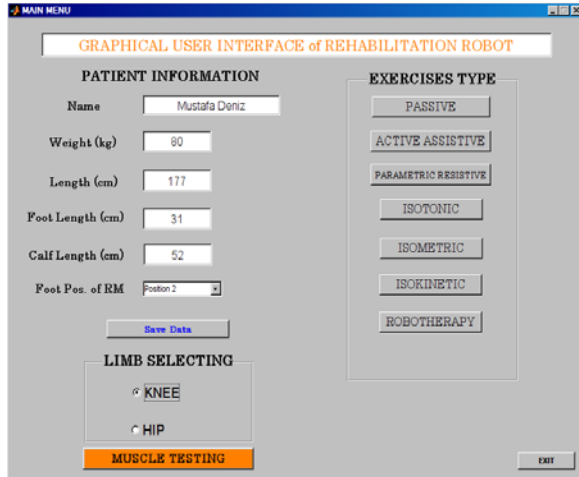


Figure 3. Graphical User Interface Main Menu

2.3 Robot Manipulator

The robot manipulator (RM) is suitable for both left and right knee and hip. The mechanism is adjustable for different body and limb lengths. The manipulator can perform the flexion – extension motion for knee, flexion – extension and abduction-adduction motions for hip rehabilitation. The design of the rehabilitation manipulator is shown in Figure 5.

3. EXPERIMENTAL RESULTS

In the experiments with the RM, healthy test persons are used. Each test person's leg is connected to the RM with two points, thigh and ankle. "Direct therapy - teaching" mode is selected from the GUI. The experiments carried out cover knee flexion-extension, hip flexion-extension and abduction-adduction. The PT teaches the exercises together with the test person directly on the RM. Position and force measurement results from taught exercises are stored in the database. In the following step "direct therapy – therapy" mode is selected from the GUI. The RM now

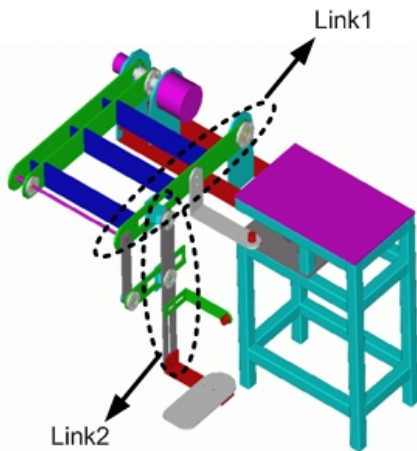


Figure 5. Robot Manipulator

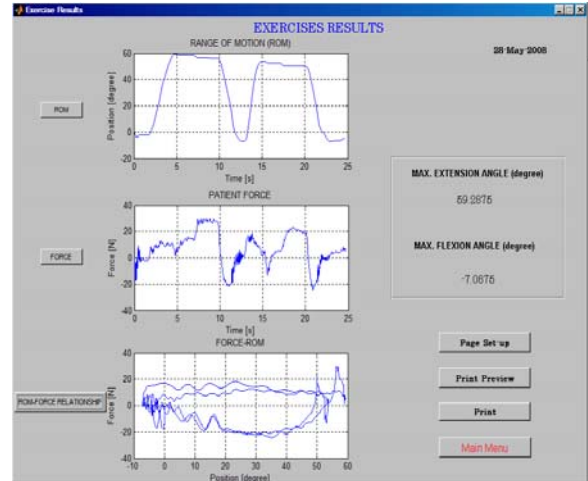


Figure 4. Graphical User Interface Exercise Results Screen

carries out every stored exercise for the patient independently from the PT.

Figure 6 shows exemplary test results for knee extension-flexion. In this figure, first graphic shows PT's exercise trajectory in teaching mode, second graphic shows RM' exercise trajectory in therapy mode and the last graphic shows trajectory error between PT and RM exercises. The results show a very much accurate repetition of the PT's movements as learned in teaching mode.

In Figure 7, teaching and therapy results are shown for hip flexion-extension movements. RM's Link 1 is the hip link, Link 2 is the knee link. For hip flexion and extension both hip joint and knee joint are moving simultaneously. Every graph shows the teaching trajectory as well as the therapy trajectory. As for Figure 8, abduction-adduction movements are shown. Abduction-adduction movement is realized by the drive mounted underneath the patient, by moving the hip about the vertical z-axis of the RM. Both Figures 7 and 8 show successful realization of hip movement previously taught by a PT.

4. CONCLUSION

In this project a human-machine-interface has been designed to translate the capabilities of a physiotherapist directly to a robot manipulator. Furthermore, standard active and passive exercises can be performed by this HMI. The graphical user interface created for the HMI gives the user an easy access to all functions of the HMI. Using the developed HMI the PT can teach exercises into RM through performing exercises directly on the patient. The exercises covered are knee and hip flexion-extension as well as hip abduction-adduction. The previously taught exercises can be repeated effectively by the RM itself. The exercise results are evaluated automatically and displayed by numerical and graphical means. The results are stored in a database for later use. The realized interfacing system is made of flexible nature to be fit for web-based application. Furthermore, single PT can treat more than one patient at the same time and the transporting problem of patients to medical center can be eradicated with this system. For the future it is planned to improve the system by using EMG signals from the patient for a better feedback to the PT.

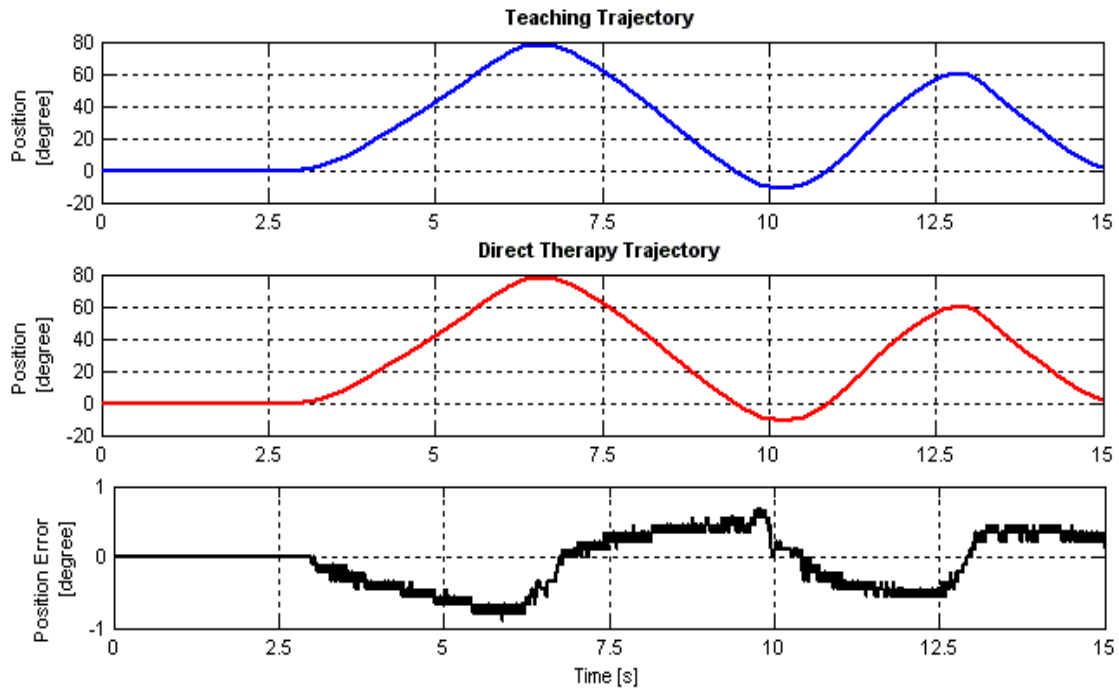


Figure 6. Teaching Position, Direct Therapy Position and Error

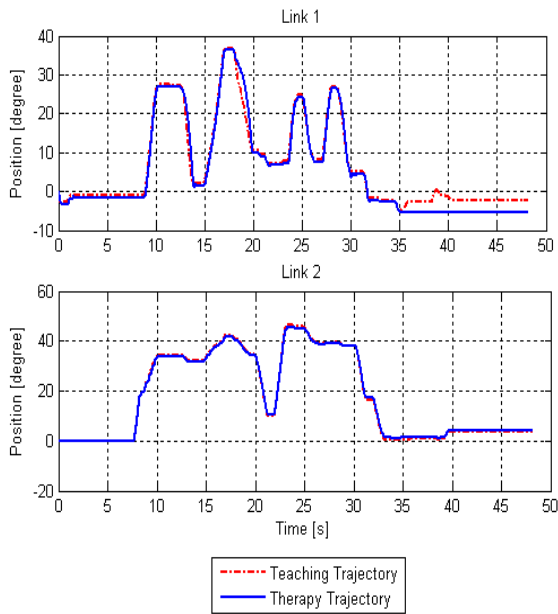


Figure 7. Hip Flexion-Extension Movements Teaching and Therapy Results

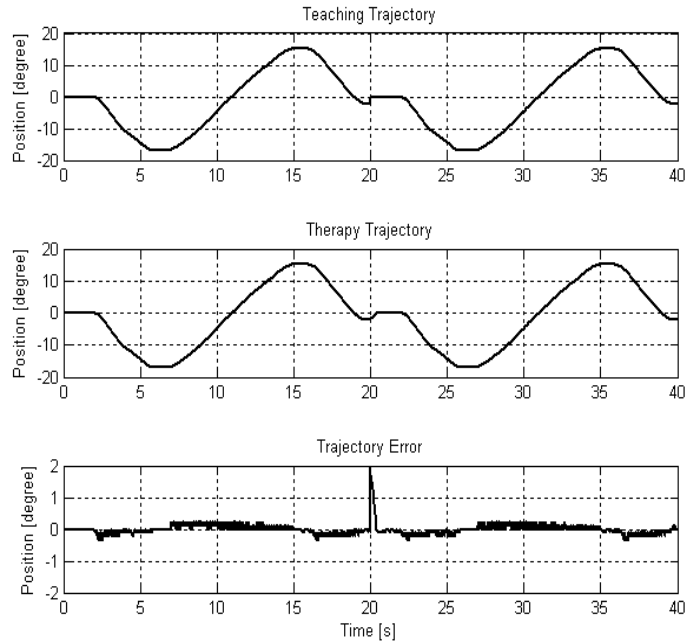


Figure 8. Hip Abduction-Adduction Movement Teaching and Therapy Results

5. ACKNOWLEDGMENTS

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