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The design and control of a therapeutic exercise robot for lower limb rehabilitation: Physiotherabot

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ABSTRACT

This study explains the design and control of three degrees of freedom therapeutic exercise robot (Physiotherabot) for the lower limbs of a patient who needs rehabilitation after a spinal cord injury (SCI), stroke, muscle disorder, or a surgical operation. In order to control this robot, a "Human–Machine Interface" with a rule-based control structure was developed. The robot manipulator (RM) can perform all active and passive exercises as well as learn specific exercise motions and perform them without the physiotherapist (PT) through the Human–Machine Interface. Furthermore, if a patient reacts against the robot manipulator during the exercise, the robot manipulator can change the position according to feedback data. Thus, the robot manipulator can serve as both therapeutic exercise equipment and as a physiotherapist in terms of motion capability. Experiments carried out on healthy subjects have demonstrated that the RM can perform the necessary exercise movements as well as imitate the manual exercises performed by the PT.

1. Introduction

Rehabilitation aims to bring back the patient's physical, sensory, and mental capabilities that were lost due to injury, illness, and disease, and to support the patient to compensate for deficits that cannot be treated medically [1]. After the spinal cord injury (SCI), stroke, muscle disorder, and surgical operation such as knee artroplasticy, patients need rehabilitation to recover their movement capability (mobilization) [2–7]. The number of those who need rehabilitation is steadily increasing every day. Parallel to this, equipment and techniques used in the field of rehabilitation are becoming more advanced and sophisticated. There are two basic elements in the total rehabilitation program: therapeutic modalities and therapeutic exercise. While the goal of therapeutic modalities is to treat and resolve the effects of pain, spasm and edema, the ultimate goal of therapeutic exercise is to return the injured patient to pain-free and fully functional activity. Specific parameters must be addressed sequentially to an effective exercise program during the therapeutic exercise. In order to have the patients safely resume fully normal activity, each of these parameters must be restored to at least pre-injury levels. In their proper sequence these parameters are [8]:

- flexibility and range of motion
- strength and muscle endurance
- proprioception, coordination and agility.

They are sequentially related to each other. A previous one is the precondition of the next. As can be seen from these parameters, a rehabilitation program starts with a passive range of motion and continues with assistive exercises followed by resistive exercises.

To restore the flexibility and range of motion passive range of motion exercises are applied to the patient, for the strength and muscle endurance resistive exercises are performed by patient, and for the proprioception, coordination and agility, strength exercises are applied to the patient by the physiotherapist [6,9]. In general, a person with movement disabilities due to arm or leg problems needs to undergo periods of therapeutic exercise sessions spread over a long period of time. The sessions comprise a series of repeated and routine physical movements with the assistance and under the observation of a physiotherapist. Transporting the patient to the medical center or calling a PT to where the patient is located are factors that further increase the cost of this process. The process of strengthening muscles to their normal values is costly and requires time and patience. In order to solve these problems in rehabilitation, the number of studies about the usage of robots in rehabilitation has increased, especially in the last 10 years. Some important reasons for the utilization of robots in rehabilitation can be listed as follows [10]: Robots easily fulfill

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