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Hybrid impedance control of a robot manipulator for wrist and forearm rehabilitation: Performance analysis and clinical results☆

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ABSTRACT

Therapeutic exercises play an important role in the physical therapy and the rehabilitation. The exercises that can be assisted by a physiotherapist are increasingly being performed by the rehabilitation robots partially or fully due to their various merits. This study aims to develop a complete rehabilitation system, which consists of a rehabilitation robot, an HMI and a hybrid impedance controller that can model all the therapeutic exercises for an upper limb rehabilitation. The 3-DOF upper limb rehabilitation robot is able to perform the movements of flexion–extension and ulnar–radial deviation for the wrist, and the movement of pronation–supination for the forearm. The experimental studies were conducted with healthy subjects and patients. First, the experiments were done with the healthy subjects to prove the control performance of the robotic system. The results showed that the hybrid impedance controlled robot can perform the therapeutic exercises very successfully. Then, the experimental studies were carried out with the real patients in a clinical environment. At the end of the treatment process, remarkable improvements were observed in terms of the limb force in all of the patients.

1. Introduction

Rehabilitation is a treatment process to bring an individual with a physical disability, which might be congenital or happen due to an illness, injury, or accident, to the best condition medically, socially and vocationally, and to reduce the negative results of permanent diseases to minimum [1]. A limb, which is injured due to the age-associated muscle disabilities, work or traffic accidents, wars and chronic diseases, needs rehabilitation to refunction fully or partially. Making a limb functional and increasing the force of a muscle are crucial problems. The return of those people to their social life is also highly important for themselves, their families, and the society they live in.

One of the elements of the rehabilitation is the refunction of the limbs, such as arms and legs. The therapeutic exercises play a crucial role in the process of refunction. A physiotherapist can make the patient perform the therapeutic exercises, which consist of the passive and active exercises, or the patient can perform by himself or herself depending on his or her physical condition. Especially, in populous countries, where the number of physiotherapists per patient is not enough (to set an example, in Turkey, physiotherapists are allowed to accept 16 patients in a day [2]), the transportation problems of patients, the cost of the rehabilitation process, and the constraints in the existing devices and equipments of the therapeutic exercises are the main problems of the rehabilitation process. For these reasons, the researches on the use of robots in the rehabilitation process have increased in the last 15 years [3]. The robots make a significant contribution to the rehabilitation process in terms of the cost, the duration of therapy, the objective evaluation, the remote control, and enabling home care. The rehabilitation robots can be classified in four groups [4]:

- "The assistive robots" supporting the movements of disabled people in the activities of their daily lives,
- "The prostheses" fulfilling the functions of the severed limb for amputees,
- The robots used for the gait rehabilitation,
- "The therapeutic exercise robots" help patients perform passive, active and resistive exercises.

The system of interest in this research, which aims the therapeutic exercises, is for the rehabilitation of the wrist and the forearm and belongs to the class of the therapeutic exercise robots.

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