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Spatial Robots for Lower-limb rehabilitation

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Research Snippets

ABSTRACT

Lower limb rehabilitation is one of common medical challenge. Its treatment being human intensive gives robotics a chance to suggest solutions. The treatment of lower limb mobility involves continuous motion of affected limb. Robotic motions facilitate such continuous motions in presence of variation in limb weights and sizes. The accuracy and speed control of the robotic devices are incomparable and hence suitable to support physiotherapists and doctors. This allows doctors to plan suitable recovery strategy for patients with lower limb disability.

1. Introduction

Lower limb treatment refers to regaining neural control over the paralyzed limbs through therapeutic motions. A lot of researches addressed such mechanisms and robots in last decade. This has shown effective improvement in treatment efficiency using such robots [1]. These robots are used to treat patient undergone limb disability due to stroke, spinal cord injury and accidental disability. For regaining limb strength, treatment with repeated physiological movements is performed, which is also known as motor rehabilitation therapy [2].

The spinal cord injuries (SCIs) are caused by damage to the spinal cord which is the central transmission unit for the neural activities in the body, based on the severity of the injury the patients are classified as paraplegic and tetraplegic. In tetraplegic cases most of the time patients remains on the wheel chair and bed. The most common neurological impairment caused by stroke, accidental injuries, paralysis which reduce the patient's control on voluntary movements. Even after basic rehabilitation training patient's limb strengths are not completely restored [3]. Recovery after a severe damage to the nervous system is the main concern of physiotherapy. The systematic recovery treatment is called motor rehabilitation therapy. Rehabilitation process has maximum effect in case of early treatment after damage. During motor rehabilitation therapy, specific set of tasks are to be performed repetitively. i.e., patient should perform or undergo repetitive exercises of physiological motion patterns with the affected limbs, as frequent and intensely as possible [4].

These rehabilitation treatments are limb specific, which are broadly classified as upper limb treatments and lower limb treatments. Upper limb rehabilitation refers to the recovery of inability to use the full functionality of hands and while lower limb rehabilitation refers to the various treatments for the recovery of leg movement i.e., movements of hip, knee and ankle joints. In this thesis, the lower limb treatments using an assistive device are focussed and demonstrated in the real-time. The possible movements of the lower limbs are ina sagittal plane and coronal plane. The abduction and adduction are the movements of the lower limbs in a sagittal plane whereas the flexion and extension are the movements in a coronal plane. The generalized rehabilitation treatments in the clinical environment are broadly classified as passive range of motion, active assistive, and special treatments namely isokinetic, isometric, isotonic and other manual treatments.

Passive range of motion consists of gait movements or movement of the limbs specified by the therapist as per the recommended rehabilitation strategy. In this type of therapy, the patient's limbs are not subjected to any resistance. In other words, the patient will not provide any effort for the therapeutic movements. In active assistive type of therapy, the patient tries to stretch and contract the limbs up to his capacity then he is helped by the therapist to further extend or contract the limbs to the maximum capacity of the limbs. In isokinetic treatments the patient needs to counteract the maximum resistance and keeping the motion speed of the limb at a stable level. In isometric treatments the limb angles do not change for constant load acting on their joints. This kind of treatment is generally performed for the knee joint. In isotonic treatment, a high resistance movement is to be provided on the patient's limb for a small amount of time. This therapy aims for the strength improvement of the joints and mainly suggested for the patients who are suffering from muscle contraction. The manual exercises consist of cycling, symmetric jumping, etc. which generally aiming to gain coordination among the limbs.

2. Usage of robots for lower limb rehabilitation therapy

These recommended therapies are relying only on experienced therapists, who can suggest appropriate physiological treatments which will accelerate the recovery process. These therapies and treatments are labour intensive and need huge manpower to train the patients for the therapeutic movements, often three to four personnel are needed to support the patient's body and his/her lower limbs. These training and treatments are physically strenuous and demanding for the therapists. This restricts longer hours of practice which is essential for recovery [5]. To increase the effectiveness of treatments, the therapists wanted to use some mechanized devices which can assist them to perform rehabilitation therapies and hence the rehabilitation robotics came into existence. This robotic rehabilitation focuses on mechanization of the therapeutic treatments using robotic devices which enhance the effectiveness of the treatments in terms of longer training hours and quick patient's recovery. Longer training session and variegated task trajectories without making the trainer fatigue, constitutes as central objective for robotic therapy. These robotic trainers can replace the physical trainer's effort and provide more intensive repetitive motions. While performing a treatment on these robotic devices, it is possible to measure limb movements and force patterns of the patient's limb which help in post processing and analysis of patient's recovery. Further, it can provide a basis to communicate the patients limb strength improvements and history of their training (training data) to the physiotherapists through the help of cloud computing and internet of things.

These lower limb rehabilitation robots can be classified as: treadmill based, foot-plate based, over ground gait trainers, stationary robotic gait trainers, stationary robotic trainer for ankle rehabilitation and active foot orthoses [6]. These devices are specific tools according to the ailment and recovery condition of the patient. The schematic arrangements of these devices (classification)are as shown in Figure1.1. The treadmill based trainers have a body weight support (BWS) system with a robotic exoskeleton and the patient's foot is or feet are placed on a treadmill (trainer). These treadmill-based trainers improve the functional mobility of the patientâ€™s limbs [7]. However, some minimum level of fitness of the patient is prerequisite for these trainers as the patient is in standing position and body weight support system is involved in the overall system arrangements of these trainers. The footplate based trainers use a BWS with a footplate for each leg of the patient. These footplate movements are controlled by a robotic manipulator which can be programmable as per the therapeutic motions. The overground gait trainers allow the patient to put their own effort rather than following a predetermined path over the ground and give necessary support when it is required to the patient's physical movements. Stationary robotic gait trainers treat the patient in a bedridden condition by facilitating the guided movements for a longer duration. This improves the endurance and mobility condition of an affected limb. For ankle recovery there are some unique devices designed specifically for the rehabilitation of the ankle joint, since the ankle joint tends to remain less active and takes a longer span of time to recover completely.

In specific, the proposed work is focusing on the treatment of lower limb using a passive range of motion. This kind of treatment includes following different gait patterns as per therapeutic motions and under the guidance of physiotherapist.

3. Advantage of parallel manipulator based robotic trainer

Among these trainers, the stationary robotic gait trainer is used to provide treatments for bedridden patients for the quicker recovery of their limbs. These stationary robotic trainers provide flexibility to the therapist to perform a variegated gait patterns as per the patientâ€™s fitness and health conditions. These devices need to provide the desired gait motions recommended by the therapists with a high accuracy and a high endurance. To perform such operations (manipulations of the limbs) there are two kinds of manipulators available, the popular one is having a serial kinematic configuration (open-chain arrangement) and the other one is having a parallel kinematic configuration (closed-chain arrangement). Serial configuration based manipulators may create a bulky system which may end up with a poor dynamic performance while the parallel kinematic configurations can provide better rigidity with a high speed as their configurations can be made with low moving inertia components and, they have less error accumulation as well [8]. Since these devices are used for clinical purpose, the safety in the real-time operation or function is a top priority for the design engineers. The active rotary joints generally need a stopping arrangement for a power off or a standby condition. While the prismatic joints which are made of linear ball screws have a high mechanical advantage and a low back-drivability or sometime with no back-drivability, which is an inherent safety feature of these actuators. So, usage of prismatic joint in a parallel kinematic configuration would give the lower limb rehabilitation device more capable in delivering the therapeutic motions.

Parallel manipulators are composed of one or more closed kinematic chain that connects a moving platform (usually called as an end-effecter) with a fixed base where one of the joint in each leg is active and rest of them are passive. The kinematic and structural arrangements allow the actuators of the parallel manipulator to be in a fixed base. In contrast, serial manipulators do not have closed kinematic chains and usually have actuators on their moving links, which further implicates load on the base actuator or on the previous joint actuator and the overall system becomes bulky. Although, these parallel manipulators have the advantage of having precise movement, higher stiffness, lower inertia of moving components and high payload capacity, it comes with the drawback of smaller workspace and presence of interior workspace singularities. The serial kinematic chain has an advantage of workspace over the parallel kinematic chain but faces relatively poor load bearing capability. So, if any parallel manipulator comes with a larger singularity-free workspace would make it a competent candidate to render motion tasks.

The serial configuration based rehabilitation robots have their actuators on their links and they are bulky and look massive system, also uncomfortable to the patients because of their structural arrangements. But the parallel configurations can facilitate the removal of the active joints from their serial limb orthoses. This can be done by the help of foot-plate operated limb orthosis and the foot-plate is connected to an end-effector of a parallel kinematic configuration. Generally, the foot-plate based systems do not provide an active orthosis but a parallel configuration with a passive orthosis can provide better alternative in terms of training and safety. Since, the parallel kinematic configuration can handle high speed operations and gives a higher bandwidth of operational speed for the therapies.

4. Need of Spatial Robot for rehabilitation

Most of the Lower limb rehabilitation devices works in sagittal plane shown on Fig 2. Which allow therapeutic motion in the vertical plane. This restricts us to perform many other therapies which need spatial motion. Sagittal plane contains major part of the treatment as this plane associated with the walking of patient. While for people need overall improvement in lower limb mobility should practice all kind of motions i.e. hip flexion-extension, hip adduction-abduction, knee flexion-extension and ankle flexion-extension and ankle abduction-adduction. We are looking to develop a device which can work in spatial range to provide all these therapies. One of the ongoing concepts is shown in Fig 3. This parallel manipulator can move the patients limb in required trajectory as mentioned by the expert. The system is capable of having spatial motion in all three axis. Studies involving therapeutic motions will be done on this setup this will be our future work.

5. Conclusion

Robots make the recovery process faster as it doesn't face fatigue as humans. This will able to provide more practice time for the patients which lead to faster recovery. Available systems allow only gait recovery but off-planar motions which is not taken care earlier, is the area of interest of this research. The spatial robots will be able provide off sagittal plane motion for recovery strategy. This will help doctors to give multiple therapies using one device and plan multiple stage therapy for faster recovery of the patients.

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