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ROBOTIC SYSTEMS FOR REHABILITATION

Dan Mândru, Călin Rusu, Emil Teuțan
Technical University of Cluj-Napoca, Faculty of Mechanics
B-dul Muncii, no. 103-105, 400641, Cluj-Napoca
Romania

ABSTRACT
In this paper two robotic systems designed to support the rehabilitation exercises are presented. First, an exerciser for active and passive movement of upper limb is proposed. Its structure is based on a five-bar mechanism that guides the patient's upper limb through a series of desired exercises.. Then the principle of a robotic system that allows several ankle exercises is presented. The proposed system is based on a tethraedical module which belongs to a new robotic class, called Tetrobot.
Keywords: kinetotherapy, robotics, exercisers.

1. INTRODUCTION
Rehabilitation is an important component of the actual medicine that has as objective the reintegration of disabled in family and society. Rehabilitation Engineering is a component of Biomedical Engineering that contains simple devices or complex systems (prosthetics, orthotics, mobility aids, exercisers, rehabilitation robotics, etc), [4, 18]. Kinetotherapy is defined as an ensemble of procedures which promote motion as a basic element of rehabilitation treatment, [1, 13].
A lot of exercisers were developed and already used for a more efficient kineto-therapeutic rehabilitation process. Baker [3] presented a therapeutic wrist rotator for the passive pronation - supination of the forearm. The device includes an electric actuator driving a reduction drive to provide relatively slow rotational speed and relatively high torque to the output shaft and handgrip. Gallasch et al. [8] proposed a therapeutic exerciser equipped with two angular voice – coil actuators coupled by levers to the upper limb. The development of a rehabilitation machine for upper limb including a wearable muscle suit without metal frame, actuated by McKibben actuators is presented in [15]. Saringer et al. [23] presented a continuous passive motion device including an upper arm support suitably fixed to a drive actuator and an adjustable forearm support. More recently, Solomon et al. [24] described a therapeutic mobilisation and positioning device of joints having a control device that measures the force through the deformation of an elastic component. There is an increasing interest in the use of *robotic exercisers* in an attempt to enhance the kinetic treatment. Gao et al. [9] propose a 2 DOF robotic arm used to play arm wrestling game with human for entertainment or physical exercises. Mavroidis et al. [17] described two compact, portable devices for elbow and knee rehabilitation. Kiguchi et al. [14] studied a 3 DOF exoskeleton system attached to the upper limb to assist its motion, controlled by a neuro-fuzzy controller. Other results are reported in [7, 10, 13].
The similar efforts were conducted in the field of lower limb. Cowans et al. [6] designed an ankle exercise device controlled by the user by successively pushing and pulling a control rod connected with a pivoted leg support. In [5] and [20] two rehabilitation apparatus for lower limb are described. First is based on a coupling between an attendant positioned either behind or in front of a patient on a treadmill. The second is training equipment with possibility to modify the exercise parameters and simultaneously is a computerized measuring apparatus for these parameters.
Current therapy devices with 1 DOF for rehabilitating single muscle groups are limited in the rehabilitation process because do not integrate sensors for diagnostics and the functional rehabilitation requires the rehabilitation of multiple muscle groups. Thus, robotic systems in the kinetotherapy processes are necessary in order to increase the flexibility and the functional performances, [21].

2. UPPER LIMB ROBOTIC EXERCISER

The exerciser was designed to responds to the requirements of passive or active motions of the upper limb (backward-forward projection, inner-outer rotation and abduction-adduction), of the forearm (flexion-extension and pronation – supination) and the hand (abduction – adduction and flexion – extension), [18]. It permits a large variety of exercises, which can be accomplished and modified automatically, and allows the disabled persons tele-assistance. The several patients control by a single therapist is possible and with the aid of adequate equipment, the system can monitories the most important patient's biomechanics parameters.

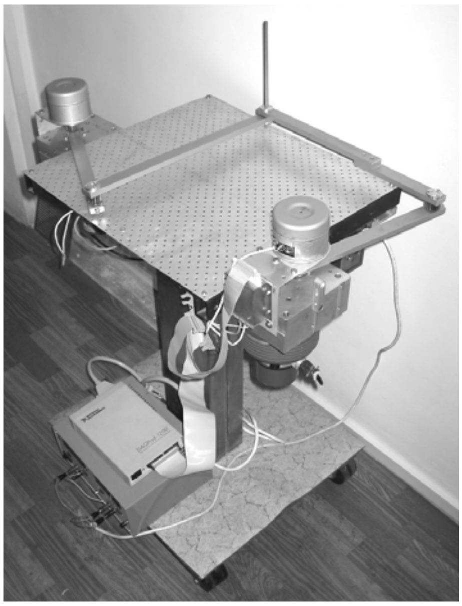

Figure 1. The prototype of the exerciser

In figure 1 is presented the prototype developed for active and passive complex motions of upper limbs taking into account individual needs. The mechanical structure is composed of a five-bar mechanism actuated by two DC servomotors. The exerciser offers the control opportunities of exercises parameters. It can adapt to anthropometric dimension and to the morpho-functional residual capability of each patient offering a more flexibility, concerning the exercise variety, [22].

For the active exercises, the therapist learns the patient about the motions to be executed, and the exerciser displaces trajectories and targets to be accomplished. In this exercise the patient has to displace the mechanism's characteristic point on the target circle, with displaying the precision of this task. The application is intended for active exercises. The user interface for this application is presented in figure 2, [21]. In order recover the control abilities, it is necessary that the cursor *6* to overlap on the target *4* by moving the mechanism of the exerciser. The target is placed on the circle *1* and its position can be modified. The proximity is marked by indicators *8*. The positioning error can be controlled with button *7*. Position and radius of the circles *1* and target *4* can be modified using cursors *2* respectively buttons *3* and *5*. If the positioning error is into the admissible range the position of the target circle can be automatically changed. This facility allows various motions in the shoulder, elbow and wrist joints.

In the second application, the patient can move a circle, representing the position of his arm attached to the mechanical structure of the exerciser, into a labyrinth. The patient must pass through the corridors of the labyrinth as quickly as possible with as few collisions as possible. A similar application is presented in [2]. The user interface is depicted in figure 3.

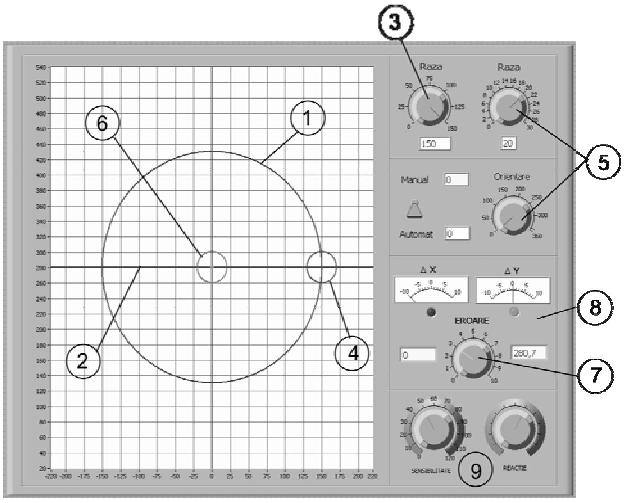

Figure 2. The user interface for the first application

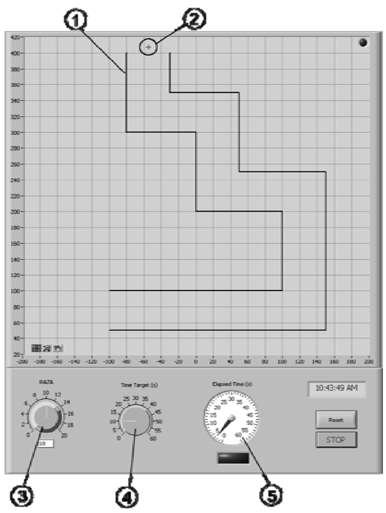

Figure 3. The user interface for the second application

3. ROBOTIC SYSTEM FOR LOWER LIMB REHALIBILATION

The ankle joint, that represents the link between the human body and the ground during current activities (walking, running, etc.) facilitates the following types of motions (figure 4), [1]: flexion – extension of the foot with an amplitude of maximum 60^o (25^o count for the dorsal flexion and 35^o for plantar flexion or extension, fig. 4a); supination and pronation with an amplitude of maximum 90^o, (maxim 30^o for supination or perronian inclination and maximum 60^o for pronation or tibias inclination, fig. 4b); abduction - adduction motion, with an amplitude of maximum 70^o, which motion at this level can be compensated by the internal and external rotation at the knuckle joint (fig. 4c).

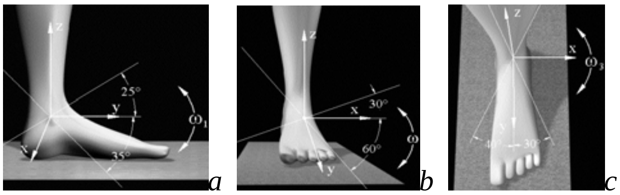

Figure 4. The biomechanics of the distal extremity of the lower limb

The proposed system is used for passive and active mobilizations to the lower limb, to recover the movement capacity at the level of distal joint extremities. Figure 5 shows the mobilization scheme. The equipment consists of an actuating system of a tetrahedral module base (1) of a Tetrobot –structure type, [11], a mobile platform (2) connected in points O and A, on which the patient leg is fixed.

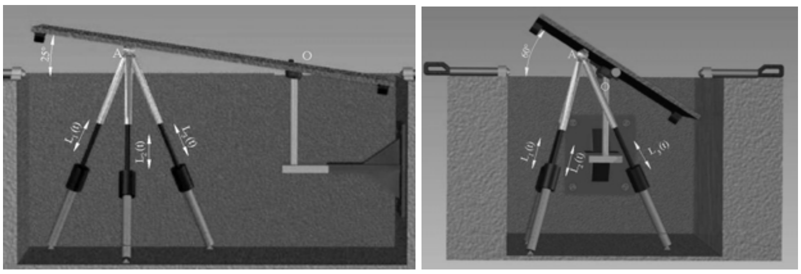

Figure 5. The mobilization schemes

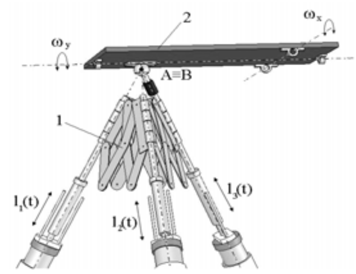

Figure 6. The actuation system

The dimensions of the mobile platform (2) are established according with [16], for men – the dimensions are 450x240 [mm] and for woman – 360x200 [mm].

Since the mobile platform performs motion over circular paths about axes OX and OY respectively, the motion of characteristic point A will be modelled along two circular trajectories at angular speed ω_x respectively ω_y within planes XOZ and YOZ, (figure 7). Two cases are considered: the amplitude $\Delta\alpha=60^o$ is achieved in t_1=5s and in t_2=2s. These values along with the position of the tetrahedron with respect to the movable platform, are employed for determining the variation law $l_1(t)$, $l_2(t)$, $l_3(t)$ for the control of three motors of the tetrahedral module shown in figure 6, as follows:

$$l_i(t)=\sqrt{(x(t)-x_i)^2+(y(t)-y_i)^2+(z(t)-z_i)^2},\ i=1,2,3; \qquad (1)$$

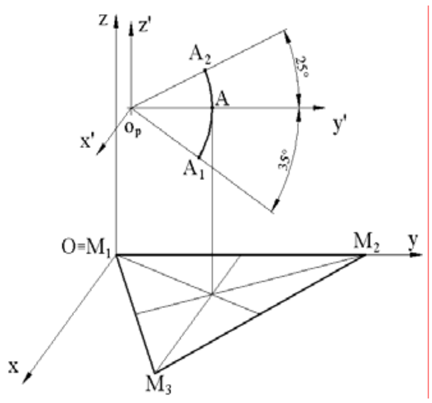

Figure 7. The trajectory of the characteristic point

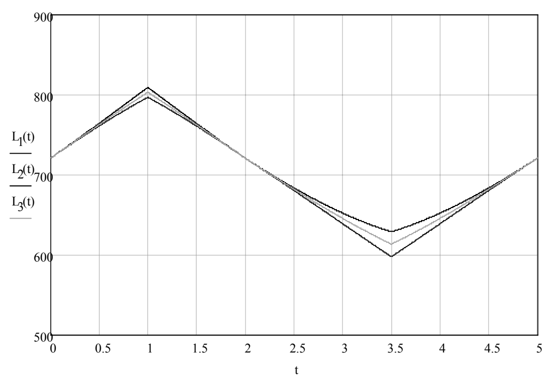

Figure 8. The variation law for the $l_1(t)$, $l_2(t)$, $l_3(t)$

With these motion laws and an adequate control algorithm one can provide the motion of the platform and of the patient's foot, respectively in this flexion – extension motion. Likewise, considering a different plane of motion we can determine the laws of motion for supination-pronation motion, [25]

4. CONCLUSIONS

Limbs injuries are a frequent problem. The aim of this paper is to present a compilation of two robotic systems for accelerating the rehabilitation procedures of upper and lower limbs. Conceptual design, mechanical structures, hardware realizations and user interfaces are presented.

The system designed for upper limb can be used in the early stage of therapy, when passive exercises are preferred; in this case, it moves the upper limb with the muscles remaining passive. In the next stage of rehabilitation (which is active-assistive moving phase), the device offers external assistance to the muscles moving the joints for a neuromuscular control reestablishment.

An important feature of equipment for lower limb consists in its potential of being used in automatic exploitations regime, in accordance with various exercises using an adequate interface. Both exercisers offer the control opportunities of exercises parameters.

There are several drawbacks and limitation in our developed prototypes, thus our efforts are focussed on improvements of the mechanical structures and actuation systems and developing new control strategies according with the requirements of several new exercises.

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