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REHABILITATION EXERCISERS – FROM SIMPLE DEVICES TO ROBOTIC SYSTEMS

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Abstract: *Rehabilitation has as objective the reintegration of disabled in family and society. In this paper the field of Rehabilitation Engineering is described and general issues concerning the design of kinetotherapy equipment is emphasized as well as the authors' contribution in development of a large range of simple devices and powered systems for rehabilitation exercises.*

Key words: *rehabilitation, kinetotherapy, exerciser, prototype.*

1. INTRODUCTION

The actual medicine includes a new component, named rehabilitation or re-adaptation / re-education, which represents a complex assistive process that has as objective the reintegration of disabled in family and society, [1]. In this field, kinetotherapy promotes motion as a basic element of rehabilitation treatment, [2]. Its aspects are varied, from walking, running, gym, and games, to training using specialized equipment, rehabilitation of walk and grasping, hidro-kinethoterapy, and so on. The posttraumatic affections of the locomotor's apparatus, diseases of the nervous system, rheumatic illnesses, cardiac, metabolic and nutrition-related diseases are several cases where the kinetic treatment is recommended, [3].

In order to obtain positive results, the rehabilitation procedures must be applied methodically and persistently, carefully controlled, aided by technical systems, witch could make it more efficient. Thus, new component of Biomedical Engineering is developing: Rehabilitation Engineering (RE). It means application of science and technology for a more effective rehabilitation process. Similar with RE is the term Assistive Technology (AT). It contains all kind of devices and aids, which are meant to help or support the functional capacity of the human being. Particularly, the AT systems – especially produced or generally available- are used by disabled persons in order to prevent, compensate, relieve or neutralize an impairment, disability or handicap, [4]. The most representative examples of RE and AT products are: prosthesis, orthosis, mobility aids, wheelchairs, exercisers, rehabilitation robotics, aids for daily living, environmental control systems, aids for vision and hearing impaired.

This paper presents the authors' contribution in development of a wide range of rehabilitation exercisers, from simple devices, to complex robotic systems

2. ISSUES OF EXERCISERS DESIGN

The key concept in physical and/or sensory rehabilitation is that of residual function. Thus, the first rule to the design of exercisers is to maintain, develop and exploit the morpho-functional residual capabilities of the potential users.

The geometrical features of the exercisers are established according to the anthropometric data of the limbs and body and their biomechanics.

The design is largely influenced by the motion type. The *passive* mobilizations are those movements imposed to a patient's articulation by an exterior intervention, without its neuromuscular system to be involved. They are characterized by the range and speed of motion, both forward and backward. For passive exercises, the specific parameters are: the motion's sequence, the range of motion, the velocity and acceleration. The *active* mobilizations or movements are the ensemble of exercises performed by the patient, voluntarily putting in function his/her neuromuscular system. Active movements may be assisted, free – without exterior resistance or active movements against a resisting force. For the active exercises, the therapist learns the patient about the motions to be executed, and the exerciser gives the necessary resisting force, displaces trajectories and targets to be accomplished.

Both in active and passive exercises, the upper limb's motions can be monitored by using electrogoniometers or other measurement systems; the patient's parameters could be displayed, in order to diagnose.

Due to the fact that the kinethoterapeutic programs are made for each patient, taking into consideration the disease and the patient's characteristics, the exercisers should allow setting multiple functional parameters: range of motion, speed, acceleration, resistive force or torque, a.s.o.

3. THE DEVELOPED EXERCISERS

During the last years, several projects were undertaken in order to develop functional prototypes of different exercisers [5–8]. Figure 1 show three simple devices for forearm pronation-supination (Fig. 1a), wrist flexion-extension and abduction-adduction (Fig. 1b) and thumb flexion-extension (Fig. 1c).


a b c

Fig. 1. Devices for the forearm, wrist and thumb exercises

Figure 2a presents an exerciser for the forearm pronation-supination and hand flexion-extension. The mobile platform which is support of the hand is actuated by two D.C. motors through a screw mechanism, respectively a linkage mechanism. The ankle passive/active exerciser presented in Fig. 2b contains the foot support which is driven by two DC motors and linkage mechanisms in passive flexion-extension and abduction-adduction of the foot.


a b

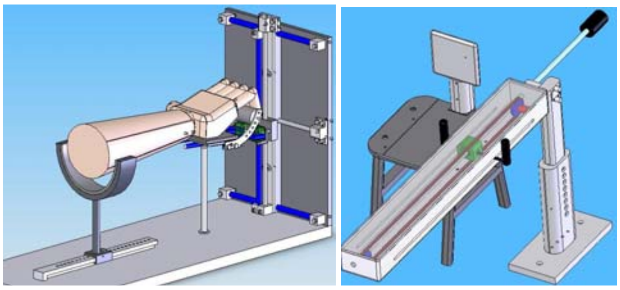
Fig. 2. Two DOF exercises for the wrist (a) and ankle (b)

The wearable powered therapeutic device presented in Fig. 3 provides continuous controlled passive motion and adjustable range of motion for the rehabilitation of the forearm. The device comprises an upper arm support, and an adjustable forearm support, actuated by an actuation unit located behind the elbow. The cuffs are placed so a patient can secure upper arm above the elbow and the forearm bellow the elbow. The rotational motion of pronation and supination is created by aligning the actuation unit's rotational center with the anatomical rotational center of the forearm.

Fig. 3. Wearable exerciser for passive forearm pronation-supination

The forearm is fixed in 90 degrees of flexion. The forearm support is comprised of two components, slidably mounted, adjusting in length to accommodate anthropomorphic forearm lengths. On the distal end is mounted a hand piece, tilted to allow the hand's natural grip angle in the wrist neutral position. In order to a patient can comfortably wear the device while ambulating, the shoulder strap can be mounted on the distal end of the support. The actuation unit is based on a D.C. motor a belt transmission and a gear reduction subsystem, so a slow speed and a high torque for passive forearm motion are provided. To control the range of pronation - supination, two mechanically set limit switches are placed in the actuation unit's housing. An oscillatory motion is achieved. The device can offer a complete range of motion or be limited to operate between a specific set range of motion. The patient can also control the ON/OFF switch placed on the patient control unit and the speed of operation. The control unit contains a rechargeable battery. The developed prototype was tested and it performs a good operation.

Figure 4 shows two exercisers for the wrist, respectively, shoulder and elbow rehabilitation. It is possible to adjust the dimensions to each user. The equipments meet both passive and active requirements: variable speed motor assists the user in the passive mode and in the active mode, variable resistance levels according to the desired workload - allow useful exercises.

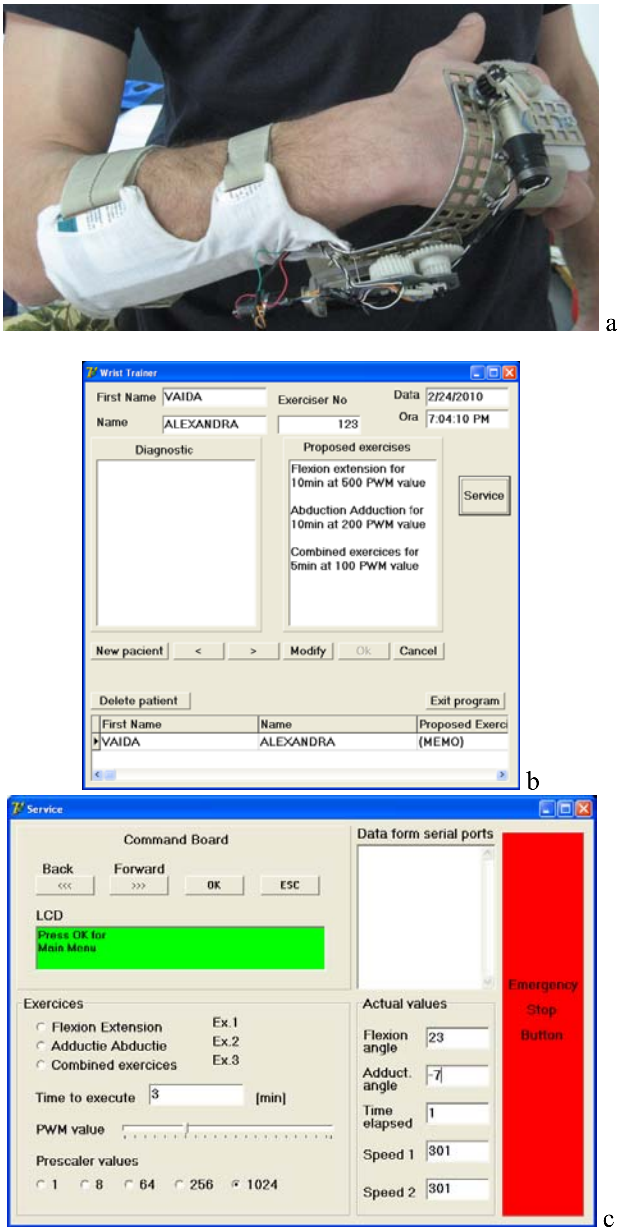


a b

Fig. 4. Active/passive exercisers for the wrist (a) and shoulder (b)

Fig. 5. Wearable wrist robotic exerciser – the first variant

We paid special attention to portable rehabilitation systems. In Fig. 5 a wearable wrist robotic exerciser that passively moves the hand in flexion-extension and abduction-adduction is presented. A control system based on a microcontroller allows adjusting the exercises characteristics for each patient. An improved design was implemented in the second prototype, given in Fig. 6a.



First Name VAIDA

Name ALEXANDRA

Exerciser No 123

Data 2/24/2010

Ora 7:04:10 PM

Diagnostic

Proposed exercises

Flexion extension for 10min at 500 PWM value

Abduction Adduction for 10min at 200 PWM value

Combined exercices for 5min at 100 PWM value

First Name	Name	Proposed Exerci
VAIDA	ALEXANDRA	(MEMO)

Data form serial ports

LCD

Press OK for Main Menu

Exercices

○ Flexion Extension Ex.1

○ Adductie Abductie Ex.2

○ Combined exercices Ex.3

Time to execute 3 [min]

PWM value

Prescaler values

○ 1 ○ 8 ○ 64 ○ 256 ● 1024

Actual values

Flexion angle 23

Adduct. angle -7

Time elapsed 1

Speed 1 301

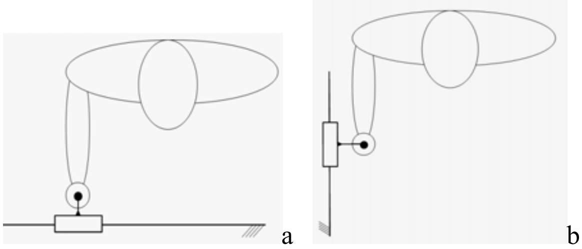
Speed 2 301

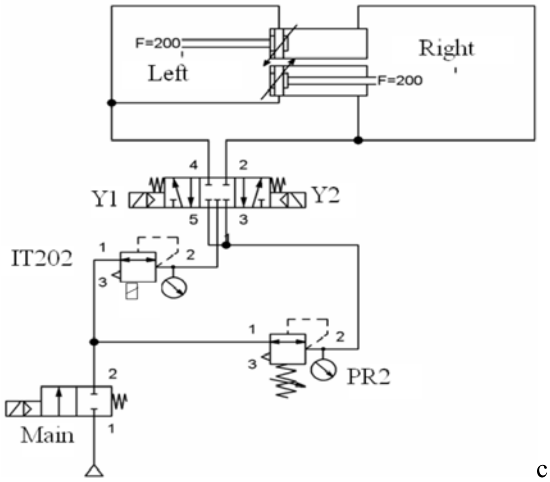
Fig. 6. Wearable wrist robotic exerciser – the second variant

It is more compact and lightweight and can be used in a chair, while standing, or even during ambulatory. The target anatomical movements are flexion-extension and abduction-adduction of the hand. Its role is regaining the wrist joint's functions, enhance strength of muscles and stability, and improve the firmness and flexibleness of the muscles and ligaments in safe operation during the performed exercises. The hardware component of the exerciser is based on a 2 DOF mechanism. The mechanism is actuated by two DC motors through geared transmission. In order to limit the amplitude of movement in accordance with the wrist biomechanics, four software limits were programmed based on angle measurements by encoders. The imposed design data are:

- maximum abduction / adduction angle: ±30° ;
- maximum flexion / extension angle: ±60°;
- maximum angular speed: 0.15 rad/sec.

The control of the device is made using a microcontroller ATmega8535, one power amplifier L293 DNE for DC motor drives, two incremental encoders for reading the angles of the mechanism, four switch buttons for menu navigation, a LCD for displaying menu, one MAX 232 used for serial communication with the PC, angular potentiometer for varying the DC motor speed. The menu of the controller is as simple as possible; it can be scrolled by pressing “OK”, ”ESC”, “UP”, “DOWN” buttons and after the patient reach the desired exercise, a confirmation is waited by pressing the “OK “ button. An interface was developed: the main window is dedicated to the patients’ data (Fig. 6b) while the operating window (Fig. 6c) enables the therapist to control the wrist trainer in same way as the patient.


a b



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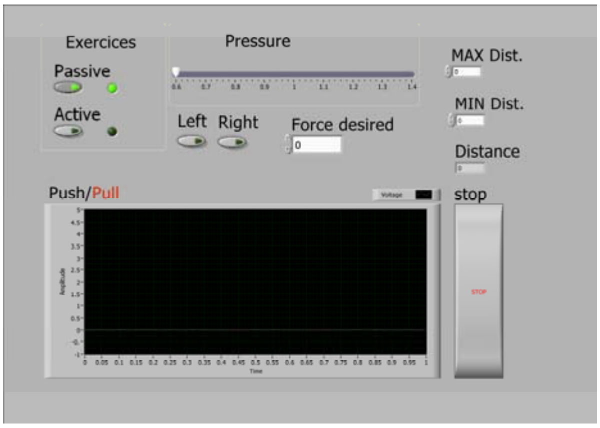
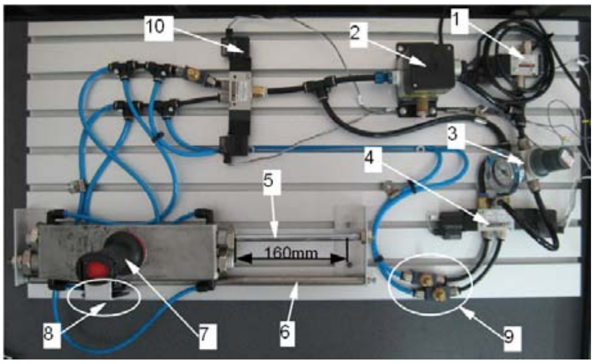


d



e

Fig. 7. Linear exerciser with pneumatic actuation

The rehabilitation robotic system presented in Fig. 7 is also dedicated to both active and passive exercises. User, in the sitting or standing position, has its upper limb “linked” with a mechanical structure (the hand is in direct contact with a handle). Thus the upper limb is mobilized, actively or passively, in front or side work positions (Fig. 7 a, b). The exercises further diversify if the system works in a tilted plane from the horizontal, even in a vertical plane.

The pneumatic components are*:* two C85E25-160 pneumatic cylinders, one EVZ512 3/2 solenoid valve, one IT202-F003B, electrically adjustable pressure regulator, one EVZ5320 5/3 solenoid valve and one manual pressure regulator. An electronic part has been designed staring from the considerate to use a galvanic separation, with CNY74-4 optotransistors, between the NI – USB 6009 control board and the power connections. Also power amplifiers L293 were used to drive the solenoid valves. The IT202 pressure regulator it’s controlled in 0-20mA DC current range through one BC639 transistor. The NI – USB 6009 read two Force Sensing Resistors (FSR) sensors mounted in the handle and one optical linear encoder

When the “Main” solenoid valve is open the compressed air set at 4bar flows into the IT202 and PR2 pressure regulators. The PR2 is set at 2 bar and is connected at the 3 and 5 terminals of the 5/3 valve and the output of the IT202 is connected at the terminal 1 of the 5/3 valve. The terminals 2 and 4 are connected at the cylinders terminals as shown in Fig. 7c.

By adjusting, through the “Pressure” slider of the interface, the IT202 at a higher pressure than PR2 and activating the Y1 solenoid of the 5/3 valve, both cylinder roods will travel into “Right” direction. By activating the Y2 solenoid, the cylinder will travel in the “Left” direction. In this way passive movements of the upper limb are possible. When the “MIN Dist.”(minimum value of the distance set on the interface) or “MAX Dist.” (maximum value of the distance set on the interface) are reached the system automatically changes the direction.

If the patient doesn’t want his exercise to be assisted by the program behind the interface, he can manually adjust the force by setting up the IT202 through the “Pressure “slider. For the active assisted movements the pressure of IT202 has to be adjusted in accordance with the force read by the FSR in the handle and the desired force set in the interface.

In the case of exercises with desired low amplitudes and forces the system reads the encoder, the “MAX Dist.” and “MIN Dist” and “Force desired” edit boxes of the interface. The system activates the Y1 and Y2 in accordance with the displacement and direction and adjusts the force by setting the IT202 output according with the requirements of the exercises.

Lab View 8.6 was used to build the interface of the system (Fig. 7d). The program which runs behind this interface allows setting up the type of the exercises, the pressure of the IT202, the force and the distance desired. The interface also offer a visual feed back for the patient by displaying the force and distance read by the sensors. The buttons “Active” / “Passive “ allow the user to set the desired exercises with an interlock function that do not allow the execution in the same time. The “Pressure” slider is connected at the “A0” analog output channel, of the NI USB – 6009 console, that controls the BC639 transistor. According with the base voltage the transistor feed the piezoelectric pressure regulator. For counting the traveled distance the program reads a digital input port with a linear encoder attached. Also the program has the capacity to limit the traveled distance. The system will change the travel direction automatically if the maximum or minimum distance, from the afferent edit boxes, is reached. The force desired edit box is used to set a maximum force allowed for the exercise. If this force is reached the system will adjust the IT202 in order to lower the handle force.

The prototype of the system is given in Fig. 7d; the following notations were used: 1 – main valve, 2 – IT202 pressure regulator, 3 – manual pressure regulator, 4 – EVZ5320 5/3 valve, 5 – cylinder rod 160mm stroke, 6 – stability circular beam, 7 – handle mounted on the cylinders case, 8 – encoder and slip bush case, 9 – pneumatic speed controllers, 10 – EVZ5320 5/3 valve.

Using the buttons in the interface, the user can switch between active and passive exercises and has the possibility to stop the system in any functioning phase. The forces are varied according to the muscle capabilities of each user. The described exerciser permits a large variety of exercises, which can be accomplished automatically, and modified by programming them.

4. CONCLUSIONS

There is a real need for high-performance rehabilitation exercisers designed as robotic systems which allow remote sessions or autonomous recapitulation of a session, and quantify the patient’s progress, permitting the exercises to be tailored to the patient and maximizes the rate of recovery. Using such systems, a therapist rehabilitates multiple patients at once, and training therapists is possible. On the other hand, it is a real need of small and simple portable exercisers, easy to use at home by patients. Wearable technology is now used in various health-related fields to develop advanced monitoring and rehabilitation solutions. Both electrically and pneumatically actuated exercisers offer multiple adjustment options for a large variety of exercises. The above-described functional prototypes are experimentally tested and used as values educational tools.

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Echipamente pentru exerciții de recuperare – de la dispozitive simple, la sisteme robotizate

Recuperarea are ca şi obiectiv reintegrarea în societate şi familie a persoanelor cu dizabilități. În această lucrare este descris domeniul Ingineria Reabilitării şi sunt sistematizate aspectele generale referitoare la proiectarea echipamentelor pentru kinetoterapie, precum şi contribuția autorilor în ceea ce priveşte dezvoltarea unei game largi şi diversificate de dispozitive simple şi sisteme complexe pentru exerciții de recuparare.

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