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MANIPULATOR FOR UPPER LIMB REHABILITATION

Abstract: This paper describes the development of a robot for functional movement training of arm, forearm and hand after stroke. Introduction presents statistical data about upper limb motor disability. This new solution of manipulator gives a chance to realize controlled passive and active exercises. Particular attention was paid to the spastic hand. In the document we present also the kinematics and dynamics of manipulator. Moreover, the device will be prepared to carry out diagnosis and allowed to summarize the results.
Keywords: stroke, spasticity, manipulator for rehabilitation

1. INTRODUCTION

Upper limb motor disability relates to more and more people. Accidents, diseases and congenital malformations cause the disease. A special attention was focused on patients after stroke. This is a very important issue for our society. A stroke is the third most common disease in Europe (after heart disease and cancer), and fourth in Poland (after accident) cause of mortality. It is estimated that over 400,000 people live with permanent consequences of this disease [1]. In developed countries, in patient group who survived a stroke: 31 – 50% is dependent and 17 – 25% stays under constant long term care. In Poland disability rate is 70% [2]. Scary thing is that it is estimated that only about 12% of people after stroke regain full fitness of hand [3]. One way to help this patent is to correctly implement the rehabilitation process. In addition to traditional methods and equipments, we can find a new manipulator for upper limb rehabilitation. Therefore, we made an analysis of this type of manipulators. It takes into account not only the division: parts of limb for rehabilitation, the type of exercises, the solutions construction, the type of bio – feedback, the availability, but also the opinion and expectations of the therapists and patients. Very universal approach has been used in a manipulator with an ending that keeps the patient (MIT – Manus, RENUS – 1). It was created for patients who have a minimum ability to move and they should practice range of motion and precision. The next step, this time for people with flaccid paralysis, was the creation of the rehabilitation based on a mirror – image (Bi Track Manus, MIME). In this method patient use a healthy limb to helps second limb to move. Patient devotes more attention to rehabilitation. Then there were attempts to prepare the construction based on exoskeleton. In most cases, they focused on arm and forearm rehabilitation. Rehabilitation is based on active or passive exercises (ARMin, ARM – 100, Cyber Glove). At the beginning of the 21st century, it attempts to use industrial robots also in rehabilitation. GENTEL/S is based on the Haptic Master Control robots. REHABOR uses two ABB robots. Another approach is presented in ARMEO. It is a project which is an attempt to connect arm, forearm and hand rehabilitation. ARMEO uses a virtual reality (VR) to prepare rehabilitation more interesting and exciting. Many projects are still in progress, for example MUNDUS. MUNDUS is an attempt to adapt the device to the current state of the patient (different ways of control) [4-14].

2. MATERIAL AND METHODS

Based on our experience and expertise, the decision to construct a new manipulator for the comprehensive rehabilitation (arm, forearm and hand in the same time) was made. Manipulator enables the realization of controlled passive and active exercises. After manipulator's analyzing it is observed tendency of separation hand from other parts of upper limb. This new manipulator treats limb as one part. Initially, the range of motion will be realize in the same plane but in the future the exercises will be realize in 3D space. Particular attention was paid to the spastic hand. Therefore, a specially designed ending allows to open spastic hand.

3. MECHANICAL DESIGN

Manipulator consists of three functional components (links). The ending is replaceabling elastic element, which is responsible for the opening – rehabilitation a spastic hand. Proper limb arrangement is possible by using the arm rest and hand rest. Three functional components were used electric motors. For the opening the spastic hand we used pneumatic drive. Manipulator has force and torque speed sensors, which were located at the points of contact with limb and rests.

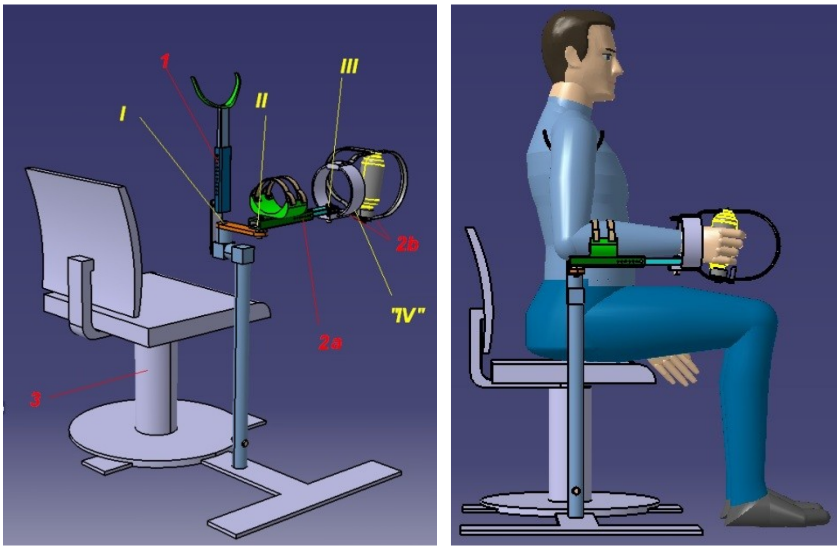

Fig.1. Parallel Manipulator for upper limb rehabilitation. I – IV degrees of freedom; 1 – 3 length adjustments

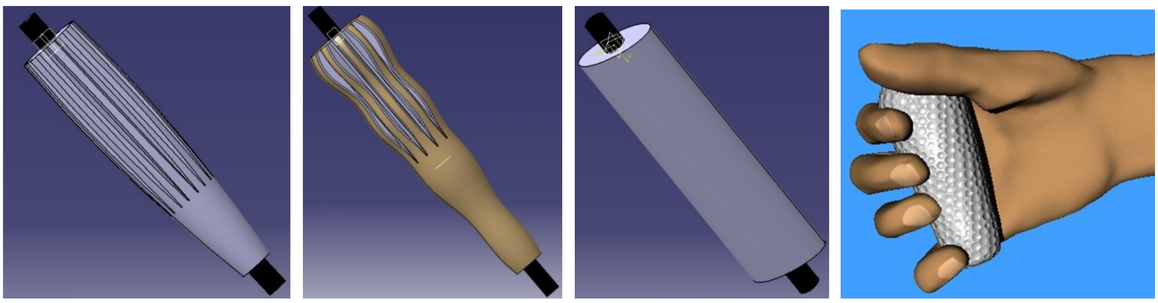

Fig.2. Examples of manipulator's ending

4. KINEMATIC AND DYNAMIC ANALYSIS OF MANIPULATOR

Kinematics is the study of motion without regard to forces that cause it. Dynamics is the study of motions that result from force. This analysis provides the information necessary for selection servomotors. During data collection there was a problem of finding spastic limb force. In literature we can find some information about this forces but they are not suitable for the use in this analysis [15,16].

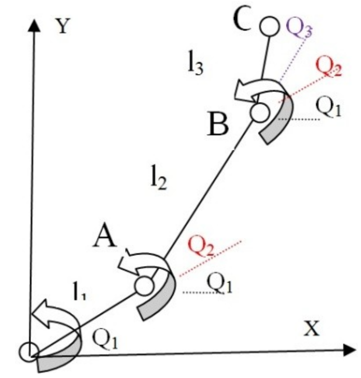

Fig.3. The kinematic model

4.1 Trajectory of manipulator

The parallel manipulator's ending is point C. Trajectory of this point will be describe in Pascal's snail. The patient is a 95 centile man (in statistics and the social sciences, a percentile or centile is the value of a variable below which a certain percent of observations fall).

$$x^2 + \quad - \quad = \quad + \qquad \text{where} \quad l = \quad a =$$

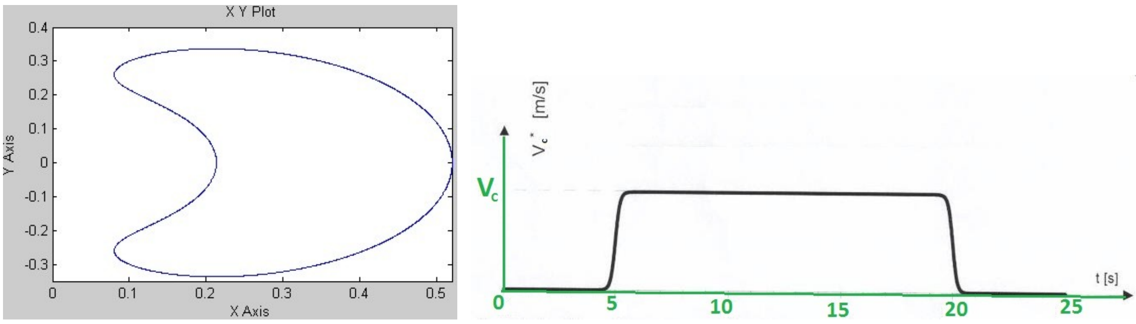

Fig.4. Trajectory of ending – "Pascal's snail" and the velocity profile of ending V_C

The velocity profile is given by the following formula,

$$V_C^* =$$

Velocity ending is tangent to the trajectory. It must be satisfied the following equation,

$$gradf_C * \overline{V_C} =$$

The above equation can be written in the form,

$$f_x V_{Cx} + \quad = \qquad \text{where} \quad f_x = \frac{\partial}{\partial} \qquad f_y = \frac{\partial}{\partial}$$

After solving the above equation we obtain,

$$V_{Cx} = \dot{} = \mp \frac{f\,V}{\sqrt{f_x^2 + }}$$

$$V_{Cy} = \dot{} = \pm \frac{f\,V}{\sqrt{f_x^2 + }}$$

4.2 Kinematic model

Forward kinematics – it is the geometrical problem of computing the position and orientation of manipulator's ending given its joint angles.

$$x_C = \quad + \quad + \quad + \quad + \quad +$$

$$y_C = \quad + \quad + \quad + \quad + \quad +$$

where l_1 , l_2 , l_3 are the links length.

Inverse kinematics – gives the desired position of the robot's hand, what must be the angles at all of the robot's joints. In addition, You can see another relationship in order to eliminate infinitely many solutions $\omega = \cdot$. The coefficient 0,5 was introduced on the basis of range of movement.

4.3 Dynamic model

Dynamic equations describe the motion of the manipulator associated with driving forces and moments or external forces applied to the manipulator.

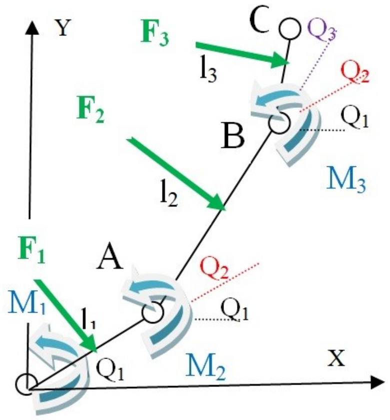

Fig.5. Diagram of manipulator for upper limb rehabilitation from above (M – torque motors, F – force from spastic limb, Q – generalized coordinates)

Dynamic model of the above specification type of manipulator has been derived using the Euler – Lagrange'a formulation,

$$[\quad]\left(\quad\right) - \left(\quad\right)$$

where E is kinetic energy, Q_i is for generalized moment and q_i denotes the generalized coordinate of the i^{th} joint.

Kinetic energy of the moving mass in the form,

$$E_1 = \frac{1}{2} \qquad E_2 = \frac{1}{2} + \frac{1}{2} \qquad E_3 = \frac{1}{2} + \frac{1}{2}$$

where J – moment of inertia, V, ω – velocity

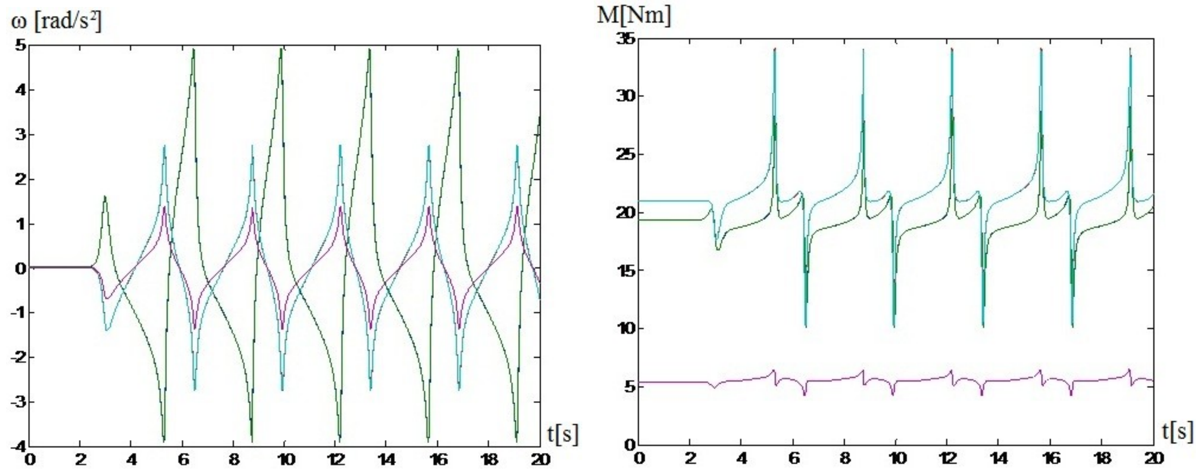

Fig.7. Kinematics parameters ω_1 (green colour), ω_2 (blue colour), ω_3 (violet colour) and dynamic parameters M_1 (green colour), M_2 (blue colour), M_3 (violet colour)

5. SOFTWARE DESIGN

From the viewpoint of control it will be possible to choose among a few programs:

- Learning – therapist leads the first movement of the spastic patient's limb. Or he chooses the exercises and their parameters from base.
- Passive – manipulator realizes the imposed trajectory. Patient only thinks about this motion but he has not force to realize this trajectory self.
- Active – patient purses exercises without therapist's help. Therapist only supervises this exercises and gives a good advices.
- Manipulator calibration (determination of the zero position).
- Safety (stopping an exercise program at any time and return to the starting position)

The manipulator will also be prepared to carrying out diagnostic tests and summaries of the results. This will allow for better plan and carry out rehabilitation.

6. CONCLUSIONS AND DISCUSSION

When the manipulator were developing it has become necessary to make cooperation with experts from various fields (therapists, doctors and engineers). It is related to the interdisciplinary nature of the project. As a result, mechanical design of this manipulator differs from the known devices. Opinions of doctors on the other hand were taken into account, as well as the latest developments in the field of mechatronics. This document presented only a description of this project, which it is currently in the prototype phase. When the prototype is ready, the proposed solution will be verified. In addition we want to perform tests on patients after stroke. In this way we obtain complete information about the proposed solution from therapists and patients. They are potential group of future customers.

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