

Pneumatic Muscle Actuated Robotized Arm for Rehabilitation Systems

Andrea Deaconescu, Tudor Deaconescu

Abstract— The utilization of pneumatic muscles in the actuation of robotized systems is still in its early stages, hence the requirement of a study of such constructive solutions. Consequently the paper presents the constructive solution and performance of a robotized arm actuated by pneumatic muscles. This system is mounted on a wheelchair for persons with locomotive disabilities. The main reason underlying the discussion of this specific system is a special property of compressed air, known as compliance, that allows a favourable response to commands of the actuated elements. Thus it is compliance that ensures a soft contact as well as safety of the human operator in interacting with operating equipment.

Index Terms— pneumatic muscle, rehabilitation robot.

I. INTRODUCTION

A multitude of international studies have revealed a continuous increase of the number of physically incapacitated persons worldwide. With the aggravation of their physical disabilities these persons gradually lose their autonomy and become dependent on the help of medical and caretaking staff in solving everyday tasks. Such a situation may lead to the financial overstraining of the respective social systems.

A modality for the prevention of such a development is the implementation of new technology in the assistance process. For these considerations and based on the option of physically incapacitated persons of attaining increased autonomy in everyday and professional life by means of modern equipment, the last three decades have witnessed intensive scientific research aiming at the development, improvement and implementation of robots in the fields of physical rehabilitation, medical assistance and professional support. The results of these studies are a host of so-called rehabilitation robots, available as finished products or laboratory prototypes. The range of applicability of these systems is wide and covers areas like “support in managing everyday tasks”, “care”, and “assistance in the professional environment” [1], [2], [3].

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Associate Prof. Dr. Eng. Andrea Deaconescu is with the Transilvania University of Brasov, the Faculty of Technological Engineering, Department of Economic Engineering and Production Systems, Bd. Eroilor 29, Romania, RO-500036 (phone: 0040-268-477113; fax: 0040-268-477113; e-mail: deacon@unitbv.ro).

Prof. Dr. Eng. Tudor Deaconescu is with the Transilvania University of Brasov, Vice-Dean of the Faculty of Technological Engineering, Department of Economic Engineering and Production Systems, Bd. Eroilor 29, Romania, RO-500036 (phone: 0040-268-477113; fax: 0040-268-477113; e-mail: deacon@unitbv.ro).

At international level scientific research is oriented towards continuously improving the efficiency of technological processes, entailing increased performance of machines and equipment by new requirements of the actuation and control systems:

- increased operational reliability and precision;
- improved dynamic behaviour;
- reduced energy and material consumption;
- miniaturized and modularized components and devices;
- simplified mounting, maintenance and repair operations.

New, innovative robotized solutions of technological processes with applications mainly in advanced fields like medical rehabilitation, entertainment or machine-tools servicing require light robots, of flexible structure and redundant, with more than 6 joints, a high useful load to eigen-weight ratio with integrated visual position control, efficient force/torque control, all offered at an affordable cost. Currently no robots are available to satisfy not even most of these requirements. The achievement of light manipulation systems actuated by pneumatic muscles thus represents a solution calling for further study, given its high potential of developing such robots [4], [5], [6].

Upon careful examination it can be noticed, that from user perspective rehabilitation robots not designed for specific applications but for flexible utilization can be serviced merely at a reduced level of abstraction. A reduced level of abstraction means direct detailed control of the respective system by the user. These systems include manipulators mounted on wheelchairs, the movements of which require direct control by means of a joystick or computer keyboard.

The manipulators mounted on wheelchairs have the highest degree of flexibility in relation to their applicability. They allow the gripping of objects places randomly in space, the opening of doors, drawers, taps or can carry out simple manipulation tasks like pouring liquids into a glass and raising it to the mouth. The costs of such flexibility depend on the cognitive capacity of the user during accomplishing a certain task, that is depending on the degree of their physical handicap.

For persons with severe physical disabilities, depending on the deployment of interfaces like vocal control or cursor control by means of eye movement, the servicing and thus the utilization of the mentioned systems becomes practically impossible. For example, in order to pour drink into a glass by means of a vocally controlled manipulator, the user would have to issue commands quasi-continuously and simultaneously in order to modify the position and orientation of the gripper (Fig. 1).

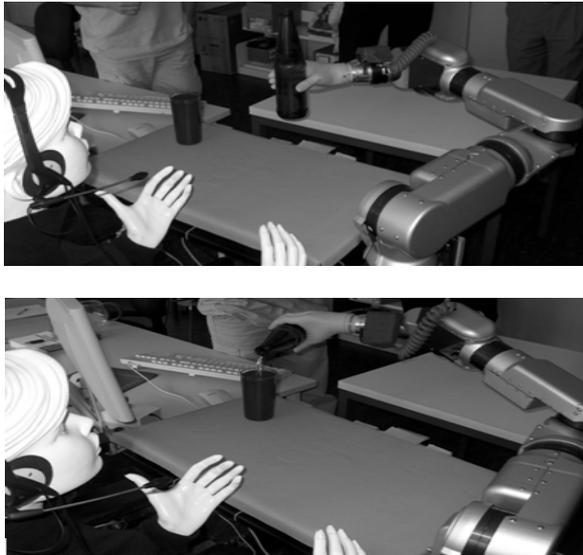


Fig. 1. Pouring drink into a glass by means of vocal control

For the above reasons it is desirable to achieve automation of tasks with a high level of abstraction. Upon the issue of simple commands the system needs to be able to plan and execute autonomously entire sequences of actions, required for the accomplishment of a given task [7], [8], [9].

Until recently the actuation of robotized systems was ensured in most cases by electric motors. Pneumatic actuating solutions have been generally avoided, due to control and compliance issues. Nevertheless, a series of advantages of this type of drives, like the compactness of the actuation elements, the favourable power (force) to weight ratio, reduced cost, easy maintenance, and a clean work environment have facilitated the increased use of pneumatic actuation systems in robotics [10].

II. CONSTRUCTION OF THE ROBOTIZED ARM

Research carried out over the last few years at the Transilvania University of Braşov, Romania, has highlighted the advantages of the utilization of pneumatic muscles in robotics. The paper presents such a utilization example, concerning a robotized manipulation system, effective in rehabilitation activities of the physically handicapped. The construction of the arm is achieved by easily standardized rotation and translation modules, their combination allowing the development of robots with several degrees of freedom. Robots actuated by pneumatic muscles entail an extremely light structure, have increased flexibility and meet the safety requirements for technology operated in the immediate proximity of man or in narrow spaces. Fig. 2 presents the structure of the robotized system actuated by pneumatic muscles. The linkage ensures two degrees of freedom (rotation – linear motion), all of the motions being achieved by a total of two pairs of pneumatic muscles. Rotation motion is achieved by means of a pair of muscles operating by the same principle as human ones (agonist and antagonist). By their antagonistic operation the muscles achieve their role of generation a $\pm 90^\circ$ rotation, as well as of ensuring the balance of a certain intermediary position (Fig. 3). The free ends of the two muscles are connected by a flexible steel cable drawn over a pulley of $2r$ diameter.



Fig.2. View of the robotized system

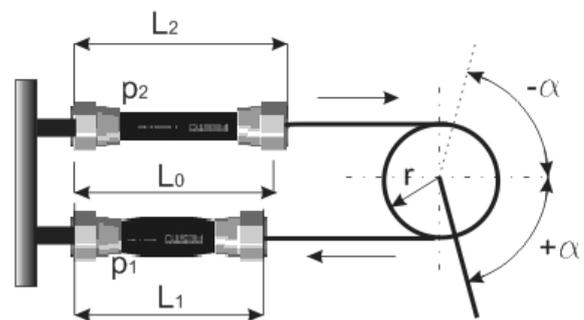


Fig.3. Kinematics of the rotation module

At rest the two muscles are inflated by the same pressure p_0 equal to $\frac{1}{2}$ of the maximum working pressure, thus achieving length L_0 . In order to carry out a rotation movement by a certain angle α , one of the muscles will be additionally fed air until the pressure reaches the value $p_1 = p_0 + \Delta p$, while the other muscle will be deflated until the pressure reaches value $p_2 = p_0 - \Delta p$. By feeding the two muscles at different pressures, their lengths will be modified in relation to their initial state as follows: the muscle inflated to pressure p_1 will shorten to a length of $L_1 = L_0 - \Delta L$, while the second muscle will be elongated to $L_2 = L_0 + \Delta L$.

The location of the two muscles on the robotized system and the generation of the rotation movement can be observed in Fig. 4. The construction includes two pneumatic muscles of 300 mm length, 10 mm diameter and 25 mm stroke, the mass considered to be displaced by the rotation system being of 20 kg.

The linear motion of a sliding block placed on the robotized arm is achieved also by a pair of pneumatic muscles, that in this case move synchronously. The location of the muscles on the arm is shown in Fig. 5.

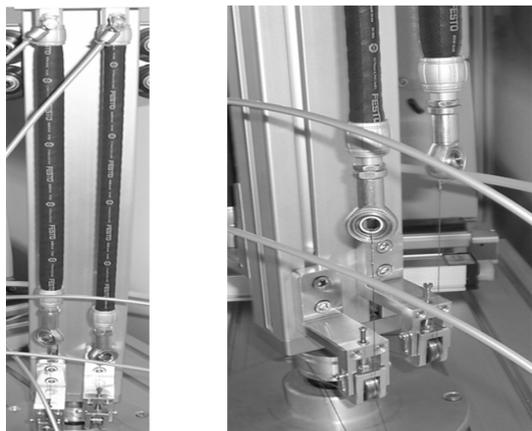


Fig. 4. Achievement of rotation

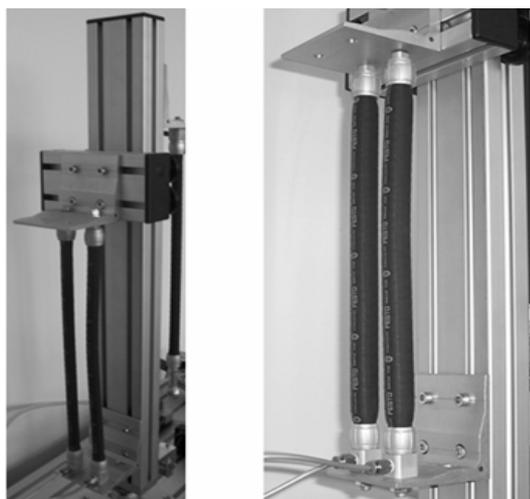


Fig. 5. Achievement of the linear motion

Fig. 6 shows the actuation diagram of the two pairs of pneumatic muscles. As due to its novelty, the dedicated software for the design of actuation diagrams does not include a symbol for pneumatic muscles, they have been represented as cylinders with simple control and the spring mounted behind the piston. This type of linear motor simulates the behaviour of a pneumatic muscle to a satisfactory degree.

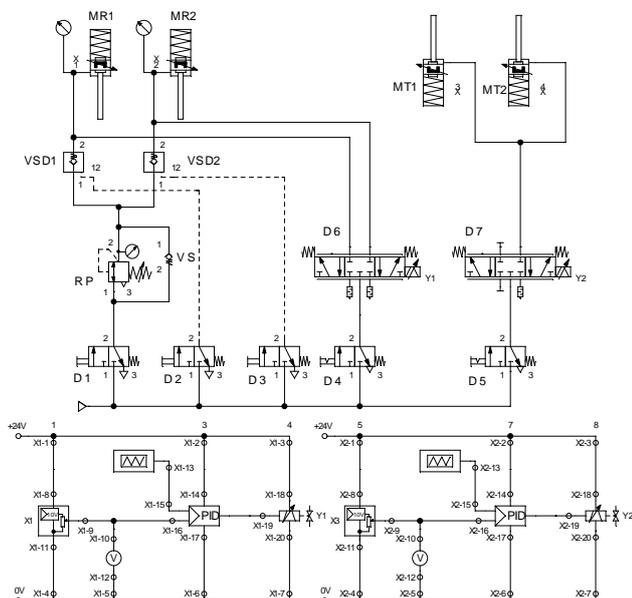


Fig. 6. Control diagram of the pneumatic muscles

The control of the counter time movement of the pneumatic muscles is achieved by means of a proportional 5/3-way directional valve, of a PID-controller and of a displacement encoder. The electronic test equipment to create stimulus signals included a function generator capable of sine, square and triangle waveform generation. Following the feeding of a triangle signal of 2 Hz frequency and 5V amplitude into the system, the movement diagrams of the two muscles shown in Fig. 7 were obtained.

III. SYSTEM PERFORMANCE

The completed experimental research was aimed at analyzing the evolution of the pressure required for actuating a pneumatic muscle, as well as at establishing the response times of the muscle for inflation and deflation, respectively. Measurements were carried out by the successive charging of the pneumatic muscle with compressed air at various pressures, the values of which were recorded by a pressure transducer [11]. Fig. 8 shows two diagrams related to the variation of the feed pressure.

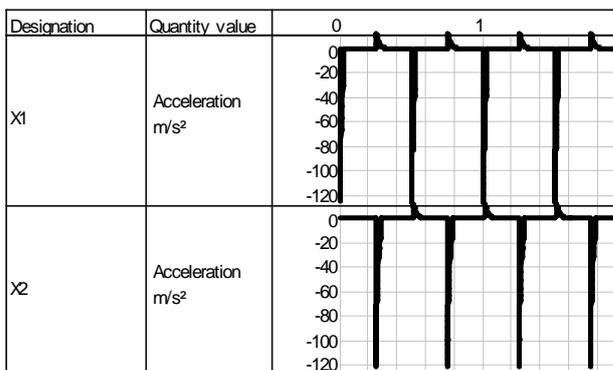
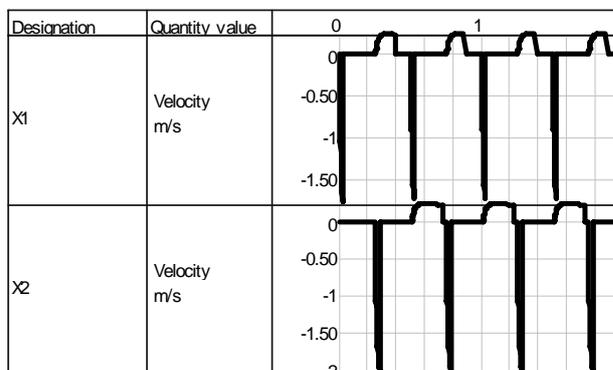
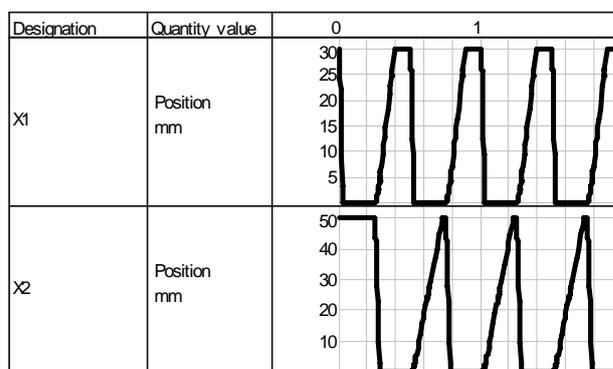


Fig. 7. Motion diagrams of the two pneumatic muscles generating the rotation motion

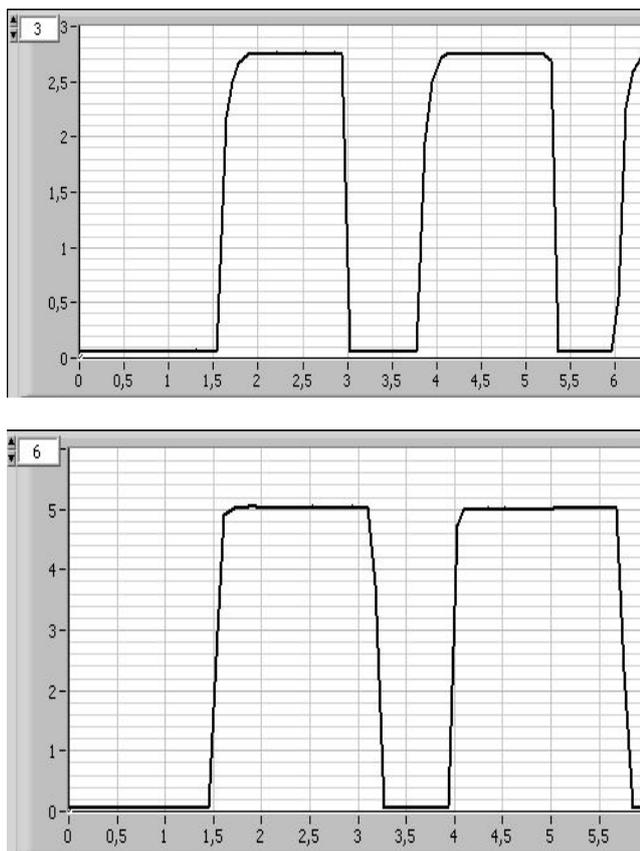


Fig. 8 Evolution of pressure in the tested pneumatic muscles

The analysis of these diagrams allows establishing of the time values required for inflation and deflation of the pneumatic muscle, respectively.

For a pressure of 2.7 bar, for example, the graph in Fig. 9 allows determining of the values of the two times ($t_i = 0.184$ s and $t_d = 0.050$ s). As can be noticed, the sum of the inflation and deflation times of a pneumatic muscle is of about 0.25 seconds, yielding the conclusion that these actuation elements can be used at working frequencies of approximately 4 cycles/second (4 Hz).

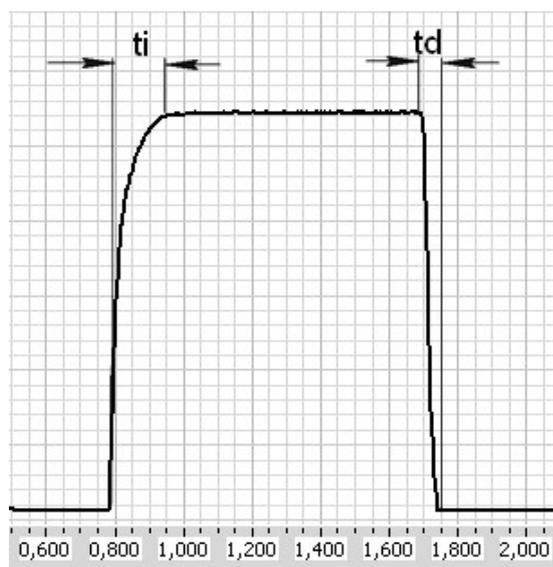


Fig. 9. Determining inflation/deflation times

The completed experimental studies have shown that the utilization of pneumatic muscles in the construction of the robotized system has determined a 50% increase of the velocity of the final element, compared to the utilization of single acting pneumatic cylinders for the same purpose. Also, the weight of the entire assembly is smaller by about 20%. In addition other few advantages of the utilization of pneumatic muscles are:

- actuators have exceptionally high power and force to weight/volume ratios $>1\text{kW/kg}$;
- being pneumatic in nature the muscles are highly flexible, soft in contact and have excellent safety potential;
- force and position control is possible by using antagonistic pairs of muscles for compliance regulation. This is once more comparable with the action of natural muscles;
- the actuators are highly tolerant of mechanical (rotational and translational) misalignment, thus reducing engineering complexity and cost.

IV. CONCLUSIONS

The robotized arm presented in the paper, actuated by pneumatic muscles shows that this type of drive, yet insufficiently known and applied offers numerous advantages from the perspective of both dynamic behaviour and involved costs. Acquiring detailed knowledge of the performance of pneumatic muscles will allow their gradually replacing simple control cylinders in an increasing number of applications.

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