Prospects of Robotics Development for Restorative Medicine

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Abstract. In this paper the automation of massage as one of the most effective restorative medicine techniques is considered. The aim is to increase the working ability of people. The implementation of robotics in preventive restorative medicine is the first phase of automation. The general problems of robotics are connected with the features of non-invasive interaction of the robot with viscous-elastic soft tissues. The method of most natural training by demonstration of the necessary trajectory, taking into account the deforming of soft tissues and then the reproduction of recorded data, is proposed. The method of force points training with program input of assigned forces is a special case of spatial training by demonstration with manual input of assigned forces. Some biomechatronic modules for the realization of training by demonstration and reproduction of recorded data are proposed. For experimental investigations the method of imitation of patient's mobility while breathing is considered. The research results open perspectives on several projects of robotic systems. The robotic systems performing more fine massage techniques for injured people with consequences of cerebral palsy and stroke will be further developed. The reasons of the lack of demand and prospects of development of robotics for restorative medicine are also analysed. AQ1 AQ2

Keywords: Prospect · Robotics · Restorative medicine · Human - machine system · Massage · Surgery · Demonstration training · Compliant control · Biomechatronic module

1 Introduction

Among many directions for restorative medicine (balneotherapy, hirudotherapy, electrical stimulation, ozone therapy and others) the methods associated with mechanical action on the human body, including various massage techniques occupy a certain place as a non-drug method [8].

Many nations of the world created for centuries a culture of healing, where movement and mechanical impact had the leading role. In Eastern physical culture the alternation of loading and unloading, concentration and relaxation, active and passive

A. Rodiã and T. Borangiu (eds.), *Advances in Robot Design and Intelligent Control,*
Advances in Intelligent Systems and Computing 540, DOI 10.1007/978-3-319-49058-8_54

recreation are of particular importance. For the modern man there is particularly relevant physical culture, which is characterized not only by active intentional movements, but also by passive ones including a variety of massage, post isometric relaxation and other relaxation and mobilization techniques. The new techniques of combined application of massage, for example, with melotherapy, thermotherapy, aromatherapy and active movements can be effective [9].

Fatigue as a result of physical and mental efforts is one of the reasons for the declining of working ability that is studied in the labour hygiene. Physical fatigue is accompanied by a number of objective characteristics, expressed in muscle compaction, muscle pain, difficulty of movements and others.

Massage is an effective and widely accessible means to recover someone's working ability after physical fatigue and it is also a reliable means of occupational diseases prevention. Massage of tired muscles not only restores an initial muscular working ability but also increases it. Manual therapy and massage are necessary for a much wider range of people. Often there are people for whom the labour activity is exposed by hypodynamy. They are conference participants, administrators, lecturers and students, PC users, workers on the conveyor, truck drivers. Manual therapy and massage are necessary for physically overloaded people - athletes, astronauts, pilots and military men [14]. Apparatus as masseur assistants appeared and massage chairs and robots are the most developed means for this scope.

2 Robots in Preventive Medicine

The implementation phase of robotics in preventive medicine is most simple and safe technically. It is necessary to solve a number of problems before solving the problem of finer controlled mechanical effects for athletes, injured patients and the effects of cerebral palsy and stroke.

Academician N. Pirogov said that "the future belongs to preventive medicine. This science, going hand in hand with medical science, will bring undoubted benefit to humanity". Nobel Prize winner Pavlov I. emphasized a special role of preventive medicine. He said that "preventive medicine reaches the social purposes only in case of transition from pathology medicine to medicine of health of the healthy".

The Russian scientist N.V. Zabludovsky wrote in his dissertation "Materials to a question on massage action on healthy" in 1882 about the necessity of applying massage apparatus for healthy people: "Is it possible to take advantage of mechanical improvements to design machines that would replace manual actions, or even machine action would be more preferable than manual action? It would be necessary to invent the machine in which the force could be defined in numbers during each moment and deal with numbers instead of the masseur's work, depending on subjective muscular feeling", [8].

Currently, there are mobile robots and robot chairs to perform the mechanical impacts on the patient, but manipulative robots performing movements similar to the doctor's hand are the most effective.

Considering the above, the concept of development and implementation of adaptive and intelligent manipulation robots to improve the health of people and to improve their working ability on a large scale is very important.

3 Methods of Robotics for Restorative Medicine

In terms of mechanics, massage task is the deforming of soft tissues (ST). Also, at massage the blood and lymph vessels are deformed causing a draining effect, although the main massage effect is a reflex one. There are studies of the properties of ST [11] related to the diagnosis of tumours and research [12] related to the development of copying surgical manipulators. However, the problems of tumour recognition of and surgical manipulations on the ST differ from the tasks of controlled non-invasive ST deforming.

The developed framework of force interaction theory and control in contact problems suppose the interactions, mainly with solid bodies of non-biological nature, whereas the control objects of systems in massage are biological ST, having a number of features as the viscous-elastic bodies with non-linear characteristics and different properties [2].

The need for taking into account the interaction of the robot with ST leads to the idea of robot training trajectories, which reflect the assigned movement X_0 and force F_0, moreover in the most natural form of training - showing the necessary movement [6]. The training system is of man-machine type, in which the forces are not given programmatically by knowledge base, but by the sensitive masseur's hand. This is not a video screening but the reproduction of the masseur's force induced sensations by the robot. The scheme of performance of robotic massage modes is shown in Fig. 1. The first control phase is training by demonstration.

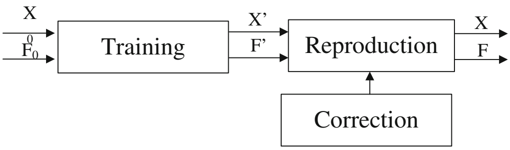

Fig. 1. The scheme of performance of robotic massage modes

The method of training by demonstration, considering ST deforming is significantly different from the well-known non-contact method of training of continuous geometric trajectories [10], such as they are used in spray painting or from the non-contact method of training of selected nodes from manual panel. The functional scheme of the robot trained by demonstration [6] is shown in Fig. 2. The purpose of the control is that a real force of interaction of the operator-masseur tool with ST should be developed by the operator on the handle to which the instrument is attached, in other words $F \rightarrow F_0$.

Since the operator-masseur deforms the ST not directly hand but using a tool, a definite training of the masseur to feel the ST through the instrument is necessary.

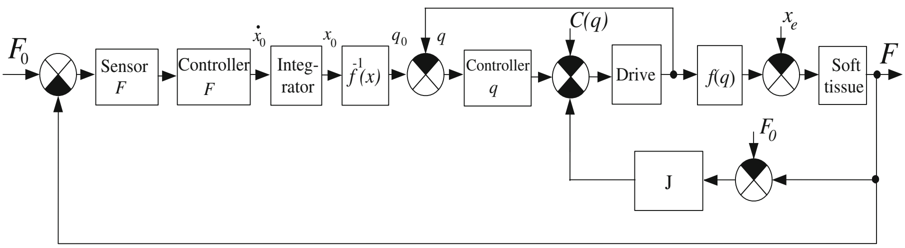

Fig. 2. Scheme of system of training by demonstration in view of ST deforming

The system of training force points, containing only one force component F_z, measured by one-component force sensor along the tool axis robot, directed perpendicular to the surface of the ST is a special case of the spatial training by demonstration system [5].

Indeed, $\{A_i; F_z\} = \{(x, y, z, o, a, t, F_z)^T\}$ is a set of force points and Fz is the programmed force. In the case of training by demonstration the continuous trajectory consists of force points, including six force components measured by a 6-component force sensor.

$\{A_i; F\} = \{(x, y, z, o, a, t, F_x, F_y, F_z, M_x, M_y, M_z)^T\}$ is a set of force points trained by demonstration and F is assigned manually. So, we have $A^{F_z} \subset A^F$.

Most experimental studies have been performed [2] with the robot, equipped with a system for training force points. The results of these studies relate to a certain degree to systems of trained manual demonstration.

The second control phase is the reproduction of recorded values of displacements and forces by the robot. The simplest system is positional reproduction which tracks the trained interpolated trajectory (Fig. 3). The assigned force F_0 is transferred by trained force points or trained by demonstration of the continuous trajectory $X = f(X_0, F_0)$ [3]. Real forces are not measured, because positional robot drives have high stiffness.

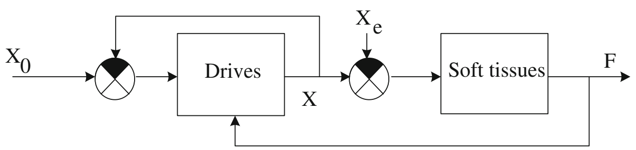

Fig. 3. Scheme of stiff position robot interacting with ST

If the robot software provides the calculation of robot displacements after polling the force sensor [2], then at limited time constant of drives only slow speed robot displacements at a small step that is necessary to ensure the accuracy are possible (see Fig. 4). Parallel position/force control supposes independent control of the robot movements along the assigned trajectory X0 and assigned forces F0 [13]. This control is necessary to support the assigned force at small ST movements, e.g., at patient breathing.

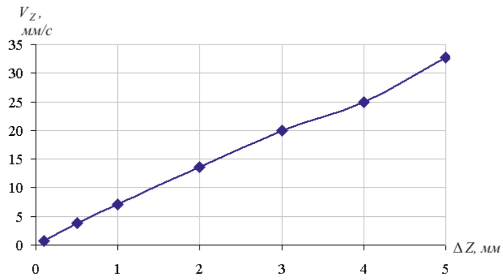

Fig. 4. The dependence of robot displacement speed on the step

The proposed apparatus operates according to the parallel position/force control principle, and therefore some drives, e.g., the six drives of angular robot track trained positional trajectory, and a separate one, e.g. the 7th force linear drive fixed on the flange, track the evolution of force F_{0z} along the tool axis (Fig. 4).

The movement of robot, providing the necessary deforming of the ST, is composed of the positional displacement drive x_1 and the displacement of the force module x_2 (Fig. 5).

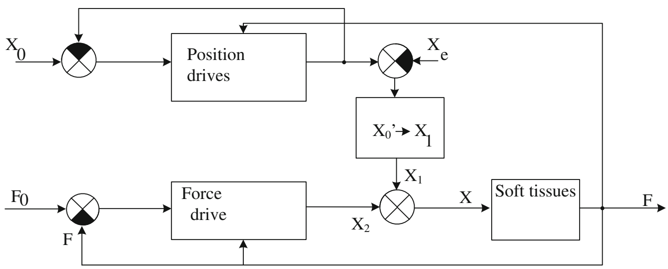

Fig. 5. Scheme of the system of parallel position/force control

4 Features of Robotic Systems for Restorative Medicine as Man - Machine Systems

A basic feature of the medical man-machine systems is the interaction of the robot and the operator with the human patient [5]. This characteristic allows us to create a combined control system for the simultaneous operation of the robot and the operator – masseur, and to create a system in which the robot as a massage chair is controlled by the patient only.

To implement the robotic system using the commercially available robots, the biomechatronic modules are used [4]. These modules offer the following functions: measurement of forces for position/force control systems, protection against overload, compliance control, measurement of muscle tone for biotechnical systems and tool change. Figure 6 shows the biomechatronic robot module with spring compensator and one-component force sensor [8].

Fig. 6. Biomechatronic module with one-component force induction sensor

Most of the experimental work has been carried out with the participation of a modernized robot RM-01, equipped with a one-component force sensor, enabling training of nodal force points [8]. To take into account the mobility of the patient from his breath [15], a new method that uses two interacting robots has been developed (Fig. 7). The first robot performs a positional function $z'_0(t) \approx A\sin 2\pi f$. The second robot provides an assigned force with force errors ε_F (f) = $(F\text{-}F_0)/F_0$.

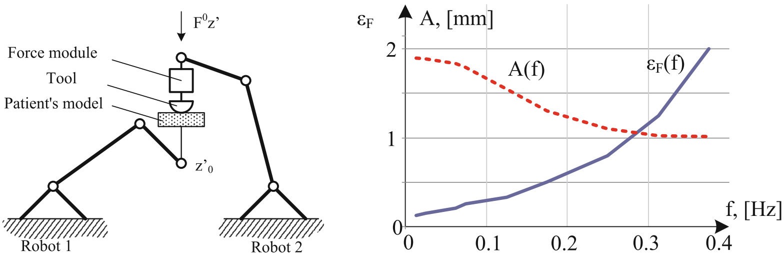

Fig. 7. Imitation of patient's breathing

The research allow to offer three project variants of robotic systems for the restorative medicine: with a one-component force sensor and positional reproduction; with a six-component force sensor, training by demonstration and positional reproduction; with a six-component force sensor, training by demonstration and force reproduction.

Priority of universal medical robots for the restorative medicine development belongs to Russia [14]. The development in the field of the restorative medicine robots can be taken into account because of proven achievements of robotics in surgery, where invasive actions such as transects and punctures are performed with the highest accuracy.

5 Development of Integrated Research and Industrial Structures for the Implementation and Production of Massage Robotics

The creation of medical devices and robotic systems, in particular for the restorative medicine and rehabilitation, is of considerable interest for practical medicine, as well as for developers, medical industry enterprises and higher technical educational institutions [7].

What reasons slow down the development of massage robotic systems? Are they technical, medical, organizational or economic? Currently there are no commercially available robots with 6-component force sensors, which are mounted on the end robot link. One of the explanations for the delay in development of massage robotics systems in comparison with surgical robotics and systems performing limb movements in the joints can be a prophylactic focus of the massage robotics in a promising future.

It is possible to combine the efforts of science, business and government in the realization of the priority directions of technological development of the economy in the form of integrated scientific and industrial structures, for example, the "Bio-Medical and Technical Cluster" [1]. It can be a significant contribution to solving the implementation task in the production of new innovative developments in the field of medical, in particular, massage robotics.

These developments allow enhancing the capabilities of all participants to expand international cooperation, commercialization, reducing costs and improving the efficiency of spending in all stages of the development and implementation of innovative robotic medical devices.

6 Conclusion

Currently the significant research results allow the development of robotics for preventive restorative medicine according to the principles of training by demonstration and reproduction of the training trajectory. Future investigations will be oriented toward the development of robots performing more fine massage techniques for the injured people, with consequences of cerebral palsy and stroke.

Combining the efforts of designers, producers of medical equipment and medical health institutions into integrated research and production structures in the form of clusters will allow extending the field of application of massage robotics, both on inpatient, health resort and outpatient phases of preventive medicine and rehabilitation.

Acknowledgements. The scientific work described in this paper was supported by Russian presidential grant № MK-5826.2016.8.

References

1. Gertsik, Y.: Organizational-economic stability and competitiveness of medical industry companies in integrated cluster. Russ. Econ. Internet J. **3**, 1–23 (2015)
2. Golovin, V., Arkhipov, M., Zhuravlev, V.: Force training for position/force control of massage robots. In: Rodić, A., Pisla, D., Bleuler, H. (eds.). MMS, vol. 20, pp. 95–107Springer, Heidelberg (2014). doi:10.1007/978-3-319-05431-5_7
3. Golovin, V., Arkhipov, M., Zhuravlev, V.: Position/force control of medical robot interacting with dynamic biological soft tissue. In: Ceccarelli, M., Glazunov, V.A. (eds.). MMS, vol. 22, pp. 303–310Springer, Heidelberg (2014). doi:10.1007/978-3-319-07058-2_34
4. Golovin, V., Arkhipov, M., Pavlovski, V.: Features of projection of robotic systems for restorative medicine. Mechatron. Autom. Control **16**, 664–671 (2015). № 10
5. Golovin, V., Arkhipov, M., Legotin, S., Kocherevskaya, L.: Expansion of ergonomics function in medical robotics. In: New Trends in Medical and Service Robots, Proceedings of 3rd International Workshop on Medical and Service Robots, pp. 207–218, Springer (2015)
6. Leskov, A., Golovin, V., Arkhipov, M., Kocherevskaya, L.: Training of robot to assigned geometric and force trajectories. In: Wenger, P., Chevallereau, C., Pisla, D., Bleuler, H., Rodić, A. (eds.). MMS, vol. 39, pp. 75–84Springer, Heidelberg (2016). doi:10.1007/978-3-319-30674-2_6
7. Razumov, A., Gavrusin, S., Gercik, Y., Makarova, M., Gercik, G.: Biomechanical and clinical aspects of medical robotic systems. REMEDIUM. J. Russ. Market Med. Med. Equip. № 11, 46–49 (2015)
8. Golovin, V., Zhuravlev, V., Arkhipov, M.: Robotics in Restorative Medicine. LAP LAMBERT Academic Publishing, GmbH & Co. KG, Saarbrücken (2012)
9. Eremushkin, M.: Massage from classics to exotics. Complete encyclopaedia of systems, species, techniques and methods. Eksmo (2012)
10. Leskov, A., Yushenko, A.: Modeling and analysis of robotic systems. Mechanical Engineering, Moscow (1992)
11. Sadovnichi, V., Goryacheva, I., et al.: Application of Mechanics Methods of Contact Interaction in the Diagnosis of Pathological States of Soft Biological Tissues. MSU, Moscow (2009)
12. Tavakoli, M., Patel, R., Moallem, M., Aziminejad, A.: Haptics for Teleoperated Surgical Robotic Systems. Monograph Series in the World Scientific Publishing under the title “New frontiers in robotics”. WSPC, Singapore (2003)
13. Vukobratovic, M., Surdilovic, D., Ecalo, Y., Kabic, D.: Dynamics and Robust Control of Robot — Environment Interaction. Monograph Series in the World Scientific Publishing under the title “New frontiers in robotics”. WSPC (2009)
14. Golovin, V., Samorukov, A.: Massage method and device for its implementation, Russian patent, № 2145833 (1998)
15. Breathing Physiology. http://medvuz.com/noz/ch10.php