Smart parallel robots for massage

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Abstract. A new concept smart robots for massage with plane and spatial parallel mechanisms is shown. Plane and spatial parallel robots (PPR and SPR) are based on triangular and octahedral structures. Every one of sides of triangle and ribs of octahedron is linear drive. Ends of the adjacent linear drive are connected with by cylindrical (for triangle) and spherical (for octahedron) joints. As result PPR and SPR have three and twelve degrees of freedom, and they can adapt to body of patient and. Possibility of full automation some kinds massage by autonomous portable smart PPR and SPR is shown. The use of these robots will allow the masseur remotely via the Internet to serve several patients at the same time in real time. PPR and SPR are portable multifunctional smart robots for various rehabilitation applications. Both kinds parallel robots will be discussed in detail.

1. Introduction

It is known that a massage is now considered as one of the most effective non-drug methods of effective meaning of disease prevention, treatment, rehabilitation, removal of weariness. Among the body parts most widely massaged are the back, the chest, and the upper and lower limbs, including the knee and elbow joints, as well as the neck. In Figure 1 some applying massage to the back (a), and the upper (b, and c) and lower (d) extremities, including the elbow joint (c), and also to patients’ neck (e) are shown [1]. The masseur uses the following main approaches: vacuum cup massage (VCM), stroking and rubbing, lengthwise and transverse kneading of the upper and lower extremities, mobilization and manipulation at the elbow or knee joints, manipulation with vibration of limbs, manipulation by forced movement of the free part of the limb relative to the fixed part, etc. Because of the need for forceful actions on these body parts, the masseur undertakes prolonged physical loading during the working day, leading to fatigue and decreased productivity. Furthermore, only one patient and by two hands can be massaged at a time, decreasing the number of patients treated. Thus, automation of the process of massaging the muscle of the upper and lower extremities (MULE), including the elbow and knee joints, as well as the neck, is a relevant current task in rehabilitation medicine. The many current massage robotic technical devices (RTD) are intended for application of massage only to certain body parts, for example massage chairs, RTD for massage of the elbow, knee, and ankle joints and the neck, and RTD with anthropomorphic manipulators, etc. [2]. However, none of these is a universal RTD able to automate the massage procedure of all the body parts listed above. Currently, there are some types anthropomorphic robots, which can be used as prototypes for massage robots [3-7], for example, such as anthropomorphic one-armed robot with hand prosthesis and three active fingers (Fig. 2, a) [3] or two-armed robot with three active fingers (Fig. 2, b) [4], and also two-armed robot with four active fingers (Fig. 2, c) [5]. Using an RTD with one or two anthropomorphic manipulators, their movement trajectories can be specified by a control program not requiring the
direct involvement of the masseur. However, during the procedure, in contrast to the situation with the adaptive movements of a masseur, the patient’s body parts being massaged must be fixed relative to the basal system of coordinates of the anthropomorphic manipulator. In addition, the lack of a remote connection between the RTD and the masseur outside the massage room can lead not only to decreases in the efficacy of massage, but also to emergency situations threatening the patient’s health. Because of their size and weight, such RTD are not mobile or suitable for use in domestic or field conditions. Therefore, it is needed of modern portable smart massage robots, being able to work autonomously without the presence of the masseur [8].

Figure 1. Some examples of massage manipulations for the back (a), and the upper (b, and c) and lower (d) extremities, the elbow joint (b), and patients’ neck (e).

To overcome these drawbacks, I propose new concepts of adaptive self-moving robotize masseurs based on active triangle with 3 DOF called plane parallel robot (PPR) and active octahedron with 12 DOF called spatial parallel robot (SPR). The description of design principles of PPR and SPR as future smart base blocks for various rehabilitation and other robotic systems that can self-movement and self-reconfigure, and also its benefits with respect to anthropomorphic one/two-armed robots are presented below.

Figure 2. The anthropomorphic one-armed robot with hand prosthesis and three active fingers (a), two-armed robot with three active fingers (b), and two-armed robot with four active fingers (c).
2. Description of PPR
PPR is based on the 2D triangular parallel mechanism with high stiffness and light structure. In Figure 3 a structural scheme of PPR and some examples it’s using are shown. PPR is a smart portable robotized system, which can be used for the following applications:

- VCM to several patients simultaneously by several cups in the sitting or standing, for example by three cups on chest and three cups on back of patient at the same time.
- VCM of back and chest by sliding and stretching of skin at the same time the three cups.
- Controlled Self-VCM of inaccessible parts of back.
- Controlled Self-VCM at the home.
- The Triangle released extra time, which can be used to conduct other types of massage and, as a consequence, there is a possibility of increasing the number of patients served per shift.

A summary of the results we have the reduction of physical fatigue of the masseur, thereby increasing his productivity, and improving health at end his work shift.

PPR (Figure 3) has a massage device based on triangular parallel structure with cup 1 in each of a vertex. The vertices (A, B, and C) connect by joins ends of adjacent similar linear drives (LD) 2. Each of the LD 2 has a sensor of force (SF) 3, a sensor of displacement (SD) 4, and a sensor of velocity (SV) 5.

Figure 3. Scheme of PPR (a). A installation of PPR on the chest (b) and back (c) of patient and scheme of VCM; local VCM by PPR (d).

Each of cups 1 is connected by a tubing 6 with a system of air allotment (SAA) 7 and a sensor of pressure (SP) 8. Also SAA 7 and vacuum system (VS) 9 are connected with a system of control (SC) 10, which includes a computer 11. The inputs of computer 11 are connected with analog–digital converters (ADC) 12, 13, 14 and 15 of sensors 3, 4, 5, and 8. The outputs of computer 11 are connected digital-analog converters (DAC) 16 and amplifiers of power (AP) 17 with LD 2, SAA 7, and VS 9. SC 10 works in real-time.

VCM by PPR includes following operations. Massage device ABC installations on the chest (Figure 3, b) or the back (Figure 3, c), and cups 1 degas by VS 9 [1]. VS 9 and SAA 7 make two immovable cups 1 and one mobile cup 1 by turns.

In Figure 3 (b, and c) schemes of the VCM by PPR in various diseases are shown, for examples, spinal osteochondrosis (A), lumbago (A), pneumonia (B), bronchitis (B), myositis (C), sciatica (C), colitis (D), and hypertension (D) [1].

The movement of the cups1 on the surface of the patient’s body is carried out by appropriately changing the lengths of LD 2, controlled SD 4. Thus the required speed of the massage movements of the cups 1 on the patient’s body is provided by the speed control of axial movements of the linear drives 2 according to signals from the respective relative-velocity sensors 5. Geometric resistance of
the massage device ABC (Figure 3, b, c) allows you to define the coordinates of its vertices A, B, and C by SD 4 of the lengths of all LD 2 and control their movements similarly to the organization of spatial movements of the I-coordinate manipulator [9]. SV 5 allow to control the speed of movement of the sliding the cups 1 at this stage of massage in accordance with the valid values, defined for this type of massage movements and introduced to SC 10. It should be noted that all of the cups 1 in the course of their rearrangements through sliding motions on the massaged surface of the patient body, alternately become floating and unmoveable. Here in, the process of their permutation. In the massage device ABC one of the cup 1 closest to his move and the other two are roaming and unmoveable, respectively. While the maximum allowable air pressure sets in one roaming sliding cup 1, and in two fixed cups 1 – minimum allowable air pressure. After that, SC 10 is commanded to switch on the LD 2, is connected to the sliding cup 1 and produced a consistent change in their lengths at a given speed controlled by SV 5.

Using of PPR it’s also able to produce a local vacuum massage and the massage by sliding and stretching of the muscle tissue [1]. In Figure 3 (c) the scheme of their conduct is shown. Local vacuum massage is performed at a fixed on the patient's body cups 1 by the vacuum in the air up to a pressure whose value is in the range from the maximum pressure to the minimum pressure. For its implementation by commands from the control system in cups 1 with established frequency and amplitude of the pressure change from the minimum permissible to the maximum and Vice versa. Management of alternate higher and lower pressure is carried out using SAA 7 and VS 9 according to the commands from SC 10, formed as a result of processing the signals from SP 8. The distance corresponds to the maximum value of the amplitude in the conduct to local vibration by varying the pressure in the cups 1 (Figure 3).

Massage by sliding and stretching the muscle tissues is produced, while still fixed on the patient’s body cups 1 by discharging air to the minimum allowable pressure. It is possible to carry out this type of massage as alternate movement of the linear actuators, as the simultaneous movement of two or more linear actuators. After fixing the cups 1 on the massaged area of the body of the patient (Figure 3) at the position at which the length of LD 2 correspond to their average values, SC 10 is commanded to LD 2 on change its length at a predetermined value, after reaching which LD 2 is stopped and is switched on for reverse, increasing (decreasing) its length to a set value. The process is repeated at a given rate, the required number of cycles. The maximum change in length of LD 2 corresponds to a given vibration amplitude of the massage movements of compression-tension. Changing the length of LD 2 and the amplitude are controlled by SD 4 and the speed – with the help of SV 5. The efforts of the mechanical effects of cups 1 on muscle tissue of patient performing all types of massage are controlled by SF 3.

A summary of the results novel concept of portable smart mobile PPR for autonomously robotized VCM was created. In Figure 4 the pneumatic prototype of PPR (a) and VCM of back by pneumatic prototype of PPR (b) are shown.

Figure 4. Pneumatic prototype of PPR (a) and VCM of back by pneumatic prototype of PPR (b).
3. Description of SPR

SPR is based on spatial parallel mechanism with 12 DOF in the form of octahedron with variable geometry (OVG) 1, which has a high rigidity and low weight [9, 10]. Such robot versus hexapod has the larger workspace. Reference [11, 12] shows new functional capabilities of OVG 1. They were used us for creating smart adaptive SPR for automation process of massage of the upper and the lower limbs. The kinematic (a) and structural (b) schemes PPR are shown in Figure 5.

![Figure 5. Kinematic (a) and structural (b) schemes PPR; movement of OVG along arm (c), a geometry of grasping face (d) and pressing of arm (e), exoskeletons (f).](image)

All ribs of OVG 1 are executed as the rods with the linear drives (LD) 2 each of which has sensor of force (SF) 3, medial sensor of force (MSF) 4, sensor of displacement (SD) 5, and sensor of velocity (SV) 6. The ends of adjacent LD 2 are connected by the spherical joints in the tops 7 of OVG 1. The tops 7 contain the radial stops and the middles of the rods contain the clamps (on Figure 5 were not shown) each of which have sensor of temperature (ST) 8. OVG 1 is a spatial farm as soon as all LD 2 are turned off. All tops 7 have the sensors of spatial position (SSP) 9 which are integrated with the three-axial blocks of accelerometers (TABA) 10. The control system (CS) 11 includes: the neurocomputer (NC) 12, the software 13 and the digital-analogue integrated converters (DAIC) 14. The entrances of CS 11 are connected to exits of the analogue-digital integrated converter (ADIC) 15 for the force sensors 3 and 4, ADIC 16 for the relative linear movement sensors 5, ADIC 17 for SSP 9 with the three-axial blocks of the accelerometers 10, ADIC 18 for the relative velocity sensors 6, and ADIC 19 for the temperature sensors 8. Exits of CS 11 are connected to entrances of the software 13 and DAIC 14. The exits DAIC 14 are connected to the power amplifier 20 which is connected to each of LD 2.

OVG 1 may be used as a base element not only at the single-modular OVG 1, but also at the multi-modular ones. The radial stops and the clamps (on Figure 5 were not shown) provide the transmission of the efforts from linear drives toward the internal and external contact surfaces. SF 3, MSF 4 and ST 8 provide the operative control of these efforts and temperature in the contact places. SSP 9 with TABA 10 provide the operative control of the spatial position of tops 7 and of vibration along each of axes of rods with LD 2. SD 5 and SV 6 (observers of conditions) of LD 2 register their relative movements and velocities. Before using it we will have to place OVG 1 in inside or outside of the closed surface and then carry out the necessary movements depending on tasks. LD 2 and CS 11 fulfill the coordinated changes of the lengths of the ribs of OVG 1 herewith. As a result the tops 7 have got spatial movement concerning a base system of coordinates. A geometrical invariability of OVG 1 allows to define the spatial coordinates of all tops 7 as a result of the measurement of the lengths of all rods and to control their spatial movements similarly to the organization of spatial movements of the I-coordinate manipulator [9]. SSP 9 allow elevating a precision of these measurements herewith.
NC 12 and the software 13 provide the control of real time. SPR is based on the use of OVG 1 without mounting of SF 3 (Figure 5), ST 8 and the radial stops of the tops 7, and the claps of lateral sides of OVG 1. SPR may be used to do the massage of the upper extremities and the lower ones. The self-propelled of OVG 1 on the arm is shown in Figure 5 (c) and it includes the following stages:

- **Initial Stage or Position 0, I**: It is the placement of SPM on the arm (Figure 5, c). The rods AB, BC, AC, DE, EF, and DF are shortened by LD 2. These drives will be stopped by CS 11 from signals of SF 4 (Figure 5).
- **Stage 1 or Position I**: The rods DE, EF, and DF are lengthened by LD 2. These drives will be stopped by CS 11 from signals of SD 5.
- **Stage 2 or Position II**: The rods AD, AF, BD, BE, CE, and CF are lengthened by the linear drives 2. These drives will be stopped by CS from signals of SD 5.
- **Stage 3, 4 or Position III**: The rods DE, EF, and DF are shortened by LD 2. These drives will be stopped by CS 11 from signals of SF 4. The rods AB, BC, and AC are lengthened by the LD 2. These drives will be stopped by CS 11 from signals of SD 5.
- **Stage 5 or Position IV**: The rods AD, AF, BD, BE, CE, and CF are shortened by LD 2. These drives will be stopped by CS 11 from signals of SD 5.
- **Initial Stage or Position 1**: The rods AB, BC, AC, DE, EF, and DF are shortened by LD 2. These drives will be stopped by CS 11 from signals of SF 4. Position 1*: It is the initiation of next a cycle. The rods DE, EF, and DF are lengthened by LD 2. These drives will be stopped by CS 11 from signals of SF 4. The rods AD, AF, BD, BE, CE, and CF are shortened by LD 2. These drives will be stopped by CS 11 from signals of SD 5.

SPR has 12 DOF and it may therefore be used for massage operations such as stroking, friction, malaxation, and vibration on all surfaces of upper extremities and the lower ones. The interest of this concept is that it can be fully automated. ST 8 permit to measure the temperature of body. TABA 10 may be used not only for remote monitoring of the vibration influences, but also for the pulse. SPR may also be used for a limitation of an articular mobility and for a decrease of compressive (extending) load. The contact places may be changed to decrease stagnant effects.

OGV 1 (Figure 5, a) can connect together, forming some new mobile structures for various applications. For example two octahedral modules can be connected together, forming exoskeleton of the forearm with the elbow joint and that of the lower leg with the knee joint. These exoskeletons are shown in Figure 5 (f). They are based on the use of the octahedral modules without mounting of ST 8 and the radial stops of the tops 7, and the claps of lateral sides of OGV 1(Figure 5).

This concept possesses the following functional capabilities and the diagnostic ones:

- **Adaptation**: These exoskeletons can adapt to the arm (leg) with different sizes. The common side of two octahedral modules 1 can change sizes and it increases the workspace for the elbow (knee) joint.
- **Forced Movement**: These exoskeletons can be used for the forced movements of the forearm with the elbow joint and that of the lower leg with the knee joint in full compliance with the program of rehabilitation.
- **Force-Moment Measurements**: The force sensors 3, 4 may be used for the force-moment measurements of arm (leg).
- **Remote Monitoring**: It may be used with SD 5, and SV 6, SSP 9, TABA 10 for the monitoring of arm (leg) movements and vibration influences.

4. Conclusion
Any suitable self-propelled robots for autonomous VCM and for MULE, including massage of the elbow and knee joints, and neck haven’t found.

We presented the novel approach to the creation of smart self-propelled autonomous portable massage robot for VCM for back and chest, and for MULE, including massage of the elbow and knee joints, and neck based on original planar and spatial parallel mechanisms. The proposed novel concepts of
PPR and SPR can be used in physiotherapy offices, hospitals, rehabilitation, sports and Wellness centres, as well as at home to conduct autonomous self-massage hard to reach areas of the body. The use of these robots will allow you to automate the processes of VCM and MULE, including massage of the elbow and knee joints, and neck to improve its efficiency and reduce physical weariness and fatigue of therapist. Thus it’s possible additional installation of sensors at the vertices of PPR and SPR, e.g. ultrasound, which will allow you to extend the functionality of the massager moving. PPR and SPR could be used as future intelligent base blocks for various rehabilitation and other robotic systems that can self-propelled and self-reconfigure. Current objective is to design software and equip of PPR and SPR with reliable and miniature electronics, linear drives and communication hardware. Another future task is in applying of PPR and SPR towards on-line diagnostics of patient's health during the rehabilitation procedure.

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