Project of the assigning/executive manipulator to surgery

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The development of an interactive remote control of robots, of sensors and of view systems has enabled an expansion of potential area of modern surgery. Initiated by an army, the project of surgery in the field of battle has become a base of new domain of knowledge. It should be noticed that surgery executed by robots as minimally invasive surgery could be more precise and less incriminating for patient then using classical methods.

The topic of the research described in this elaboration is the project of the haptic device with 6 degrees of freedom intended for the work with feedback-force control. The kinematic scheme is based on a partially decoupled parallelogram mechanism POLMAN 3×2. It means that it has 3 arms, each consists of parallelogram and quadrilateral transmission-carrying mechanism. The displacement of any degree of freedom has a very little influence on other degrees of freedom. Very important problem for ergonomic and surgery precision is a signal communication between the two sides, so it can give a feeling of real touching of an operated tissue by a doctor.

Keywords and phrases: robots, manipulator, surgery, haptic, 6 dof, parallel robot, force feedback, laparoscopic surgery.

Introduction

From the beginning of the medicine treatement, scientists have been thinking how to help patients more effectively and cause less pain. First step has been made in 1981 when Kurt Semm from the Universitats Frauenklinik in Germany performed the first laparoscopic appendectomy. This method has a lot of advantages. Firstly, smaller incision, which reduces pain, shortens recovery time and reduces risk of acquiring infections. Secondly, reduced haemorrhaging and less analgesics needed. From the other hand, laparoscopy is impossible to perform in the cases when the precision is required and access is difficult. Additionally, special tools and qualified personnel are needed. The surgery is very exhausting for doctors because it requires to stay in the same position for a long time. In 1994 problem with a camera has been solved by Computer Motion. AESOP 1000 was the first laparoscopic robot. This version was used to hold and stabilize view system, position could be changed using control panel. Next model, 2000 and 3000 were controlled using voice. After the success of AESOP view platform scientists started preparing full robotic system for surgery. In September 2nd, 1998 first heart bypass using robot Da Vinci has been performed. After it in October 1999 the first world's surgical robotics beating heart coronary using Zeus was performed. Both of the robots have advanced systems reducing vibrations and increase precision, 3D view systems and ergonomic workspace for a doctor. Surgery performed with this technique reduces pain and shortens recovery time because it does not need to cut sternum, only four 1 cm incisions. Both of them have the same disadvantage, there is no force-feedback from the operated patient body. Doctor does not feel the touch of instrument, so does not know if he cuts muscles, bones or something different. So it might cause unnecessary damage.

Kinematically decoupled parallel mechanism with six DOF

The first design of parallel manipulator for the use as an assigning/executing manipulator for surgery is shown in Fig. 1. As the base frame of the manipulator, the modified Stewart platform has been applied. It guarantees appropriate durability and high stiffness of the model.

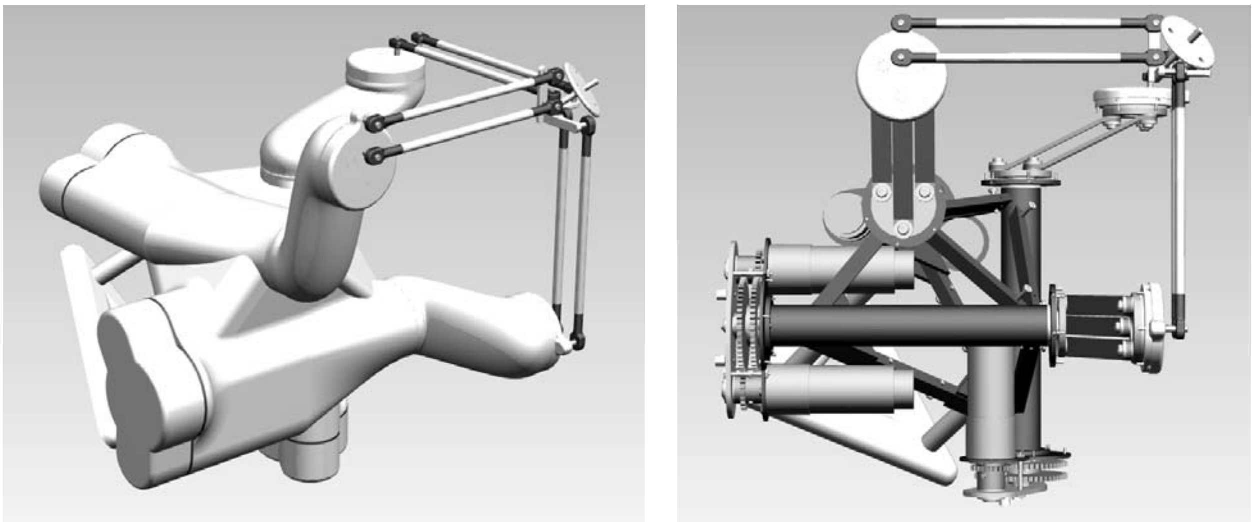

Fig. 1. First design of the proposed manipulator.

To drive the structure, 6 electric motors with planetary gearboxes fixed to the frame have been applied. The kinematic scheme is based on POLMAN 3×2. It has 3 arms, every one consists of parallelogram and quadrilateral transmission-carrying mechanism. Arms are jointed to one end element of the manipulator. The structure can be use as well as a robot or as a manipulator. It is worth noting, that each drive is responsible for execute motion of the different degree of freedom.

Kinematic structure

For easy feedback force control low correlation between degrees of freedom is important. If we want to realize some specific "simple motions" for example straight line motion, they could be executed by simple linear combinations of common motions of drive units. All components of force and torque could be easily separable.

Minimal number o degrees of freedom to reconstruct a move of a body in the 3 dimensional workspace is 6. 3 translations and 3 rotations. For good precision of the structure, besides of motions and control, the most important is high structural stiffness in every direction.

The kinematic scheme proposed in this article is based on a partially decoupled mechanism POLMAN 3×2 (Fig. 2). It means that it has 3 arms, every one consists of parallelogram and quadrilateral transmission--carrying mechanism. Quadrilateral mechanism has a facility to transmit 360 deg rotation. The drives are built in the base so there have not influence on the inertia of the structure.

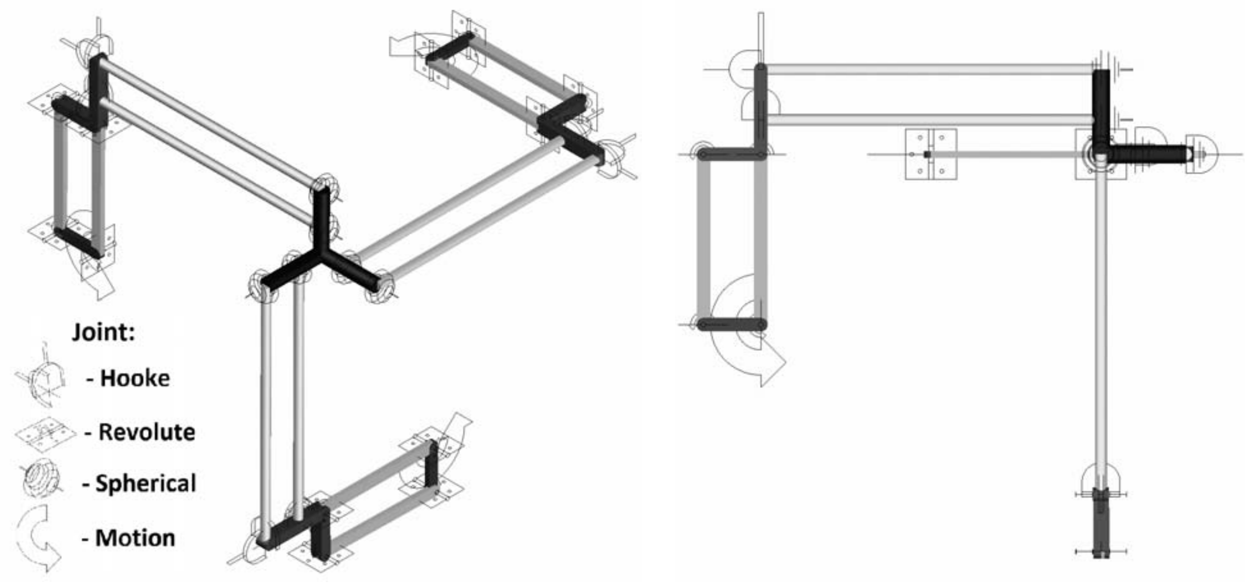

Fig. 2. Kinematic arrangement of the manipulator.

Analysis of the structure

To obtain regular workspace (i.e. with constant orientation), for maximum changes of appropriate input angles, it has been simulated the 3D area, in which the--end element can be positioned. For arm length 148 mm and 74 mm and angular amplitude 58° workspace dimensions are 87 × 87 × 87 mm. It is more than enough for typical surgery.

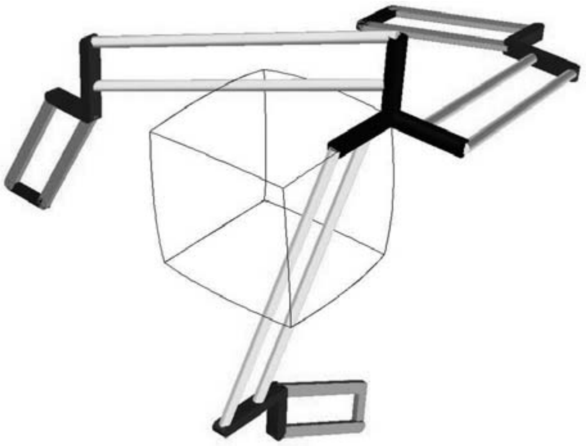

Fig. 3. Workspace of analyzed manipulator.

To show the correlation between displacements in 3D, it has been simulated the motion along one normal axis (x) with constant orientation of the manipulator's end--element (Fig. 4). The results of simulation shown in Figs. 3 and 4 illustrate that dependence between angular and translational displacement on the trajectory have quasilinear character. Angular amplitudes:
— on the normal directions (y, z) is equal 10.2°,
— on the parallel (x) 112°, displacement 120 mm

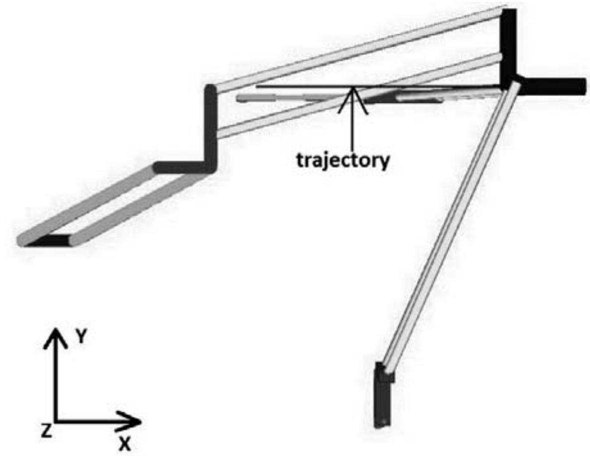

Fig. 4. Straight-line "trajectory 1" defined for kinematic investigations.

To show dependence between angular displacement between drives and end-element, the structure have been repositioned in direction perpendicular to the rotation plane (z axis) and then rotated (Fig. 5 and 6). The 90° rotation of an appropriate drive system (z axis) couse 73,34° of the end-element. The dependence have quasilinear character in the whole workspace. It is seen that it can simplify control process.

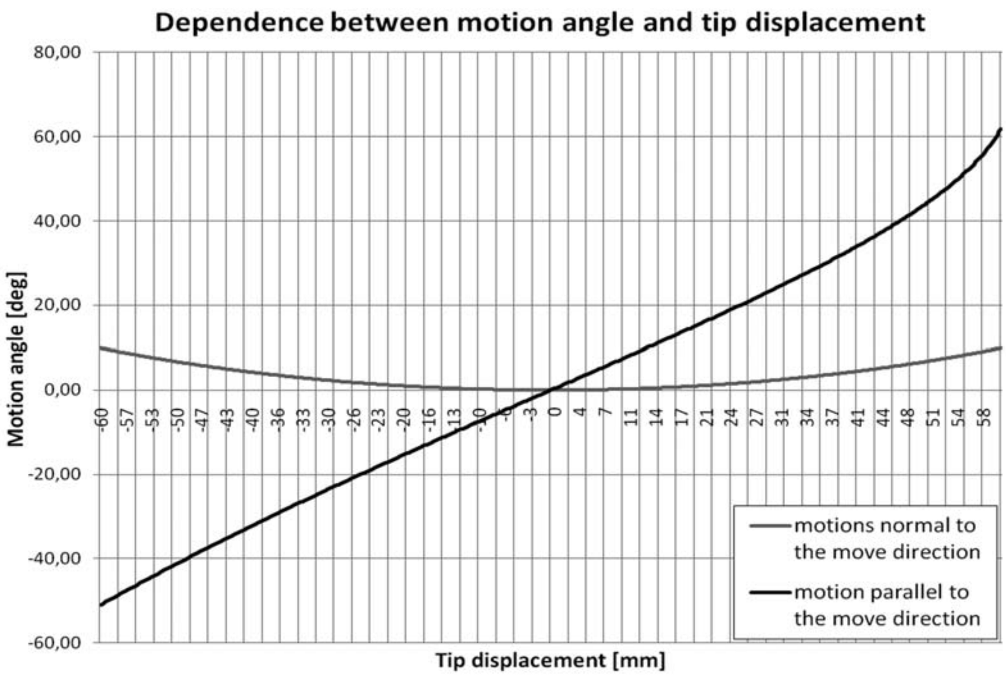

Fig. 5. Obtained kinematic characteristics for the straight--line "trajectory 1".

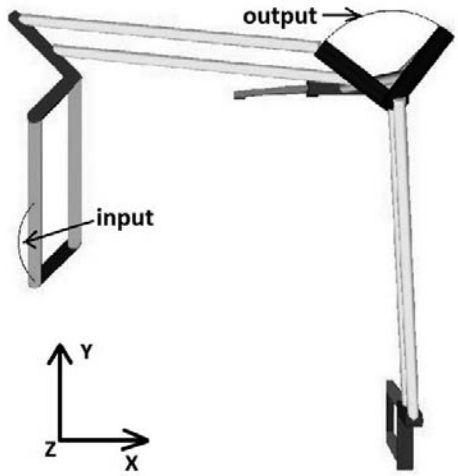

Fig. 6. Possible component of the end-element rotation--"trajectory 2.

simply copied (and very easy modified by using filters), so the same mechanism might be used as assigning and executive manipulator for medical surgery. For example it is very easy to realize the filter for elimination of the hands tremor (physical vibrations).

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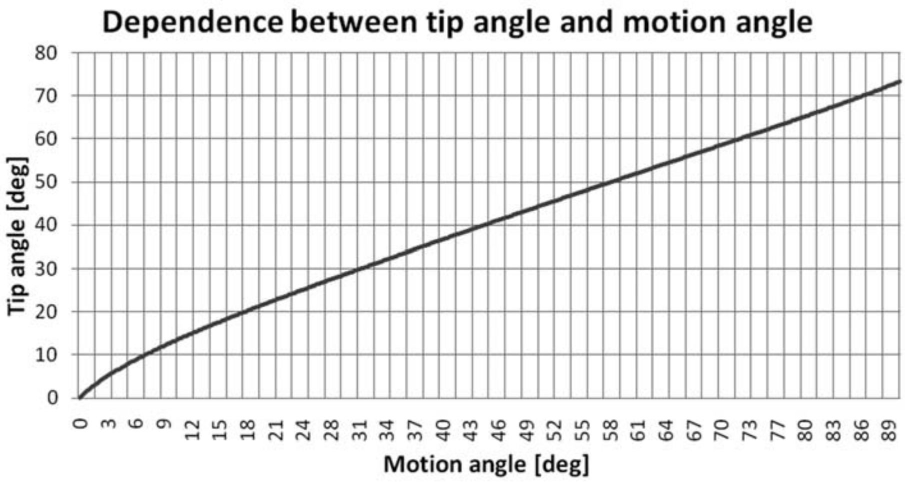

Fig. 7. Quasilinear characteristic of functional dependence between input and output angle for the "trajectory 2".

To analyse the dependence between angular displacement of drives and translational displacements of the end--element of the manipulator, all appropriate cranks were rotated by 90°, while rotations drives were blocked in initial positions Fig. 8 and 9. Amplitude on end-element is equal 94 mm on x, y and z direction. Dependence have quasilinear character in the whole workspace similarly to rotations.

Conclusions

All simulations obtained by using the virtual model and verified using prototype confirm good properties of investigated mechanism structure. Because of this it can be proposed to apply as a "joystick" with force feedback. All six degrees of freedom are partially decoupled. It is very simple to control the manipulator and to realize the measure of forces, displacements, velocities and accelerations. Because motions of drives can be very

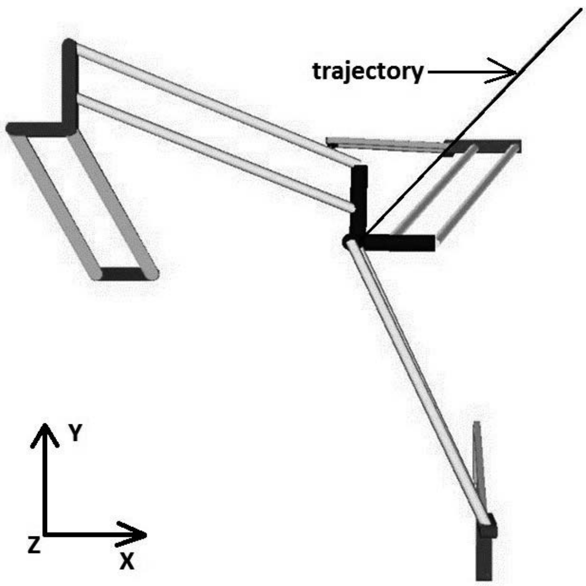

Fig. 8. Straight-line "trajectory 3" defined for kinematic investigations.

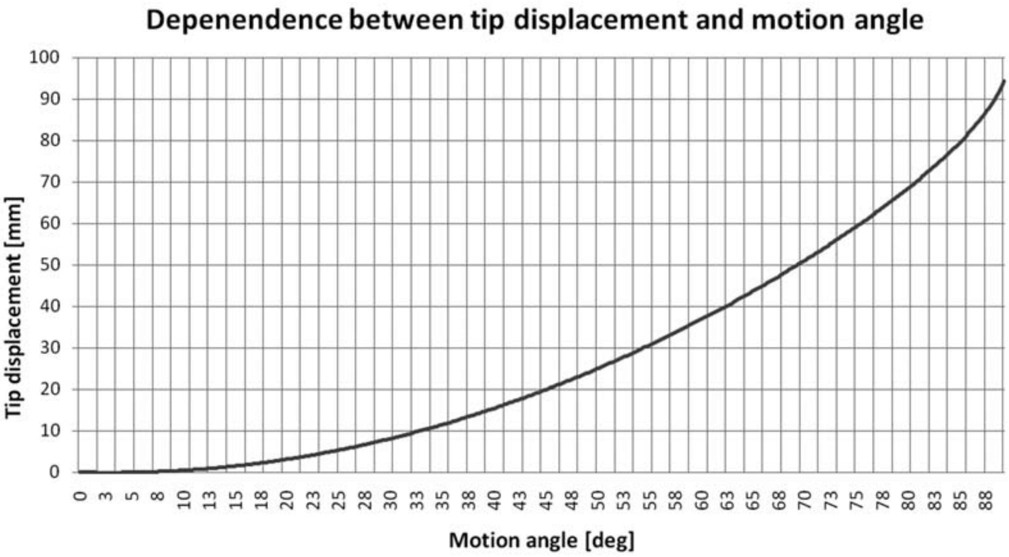

Fig. 9. Functional dependence between input angle of the driven crank and output displacement of the end-element for the "trajectory 3".

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