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Design of Laparoscopic Executive Instruments for Robots

Veronika Atanasova-Georgieva

Robotized and Mechatronics Intelligent Systems
Institute of Robotics, Bulgarian Academy of Sciences
1113 Sofia, Bulgaria
E-mail: iwanowa.w@abv.bg

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Abstract: *The main objective of this work is focused on improving some technical deficiencies of existing laparoscopic executive instruments to robots. For this reason two main problems have been overtaken: i) to perform a kinematic-structural analysis of existing executive instruments by structural and kinematic criteria, to estimate their engineering characteristics, motivating the need to develop new ones and ii) to develop functionally operating model of an executive tool, with simplified kinematics of actuation of end-effectors, with higher reliability and easier support of the sterility of the instrument. In contrast to daVinchi robot system which includes structures with three orthogonal rotations this study describes other decision with combination of perpendicular and parallel rotations* ($R \perp R \parallel R$)*. The design is simplified, no additional transmission mechanisms of the executive links are required, which in turn facilitates the process of control of the device and proved higher reliability.*

Keywords: *Robot-assisted surgery, Laparoscopic instruments, Minimally-invasive surgery.*

Introduction

In general, minimally-invasive surgery is an alternative to open surgery where tiny instruments are inserted into the abdomen through small skin incisions in order to perform surgical procedures. Major advantages of this type of surgery to the patient are short hospital stay, timely return to work, and less pain and scarring after the surgery. For a long time robotic systems are applied in the surgical rooms for minimal invasive surgical interventions. Robot-assisted surgery has been achieved in various fields of minimal invasive surgery in appendectomy, cardiology, laparoscopy, etc., by the daVinci surgical system (Intuitive Surgical Incorporation, USA, http://www.intuitivesurgical.com), Zeus system by Computer Motion (http://www.computermotion.com). Many surgical procedures have been performed until now applying traditional laparoscopic technique today may be performed more quickly and easily by the daVinci. Intelligent control can filter hand tremor and increase accuracy by motion scaling. Instruments can have more degrees of freedom yielding higher dexterity. The main benefits for the patients are: shorter hospital stay – a majority of patients are discharged on the same day or 1-day after the procedure, less pain, less risk of infections.

The improvement of the assistance functions of the robotic systems for operational activity is connected with the development of new and improvement of the qualities of the existing tools, their automatic positioning, gripping and cutting with controlled forces [7], as well as increasing the security of all actions.

In this work, some design issues laparoscopic executive instruments to robots are discussed. First, the structure of the available mechanisms for the instruments are analyzed and the design of an instrument for robot is described.

In the world practice many tools for robotic laparoscopic surgery have been developed and used, which are justified by the need of the surgeons. From an engineering point of view, both kinematic and force characteristics of the tools is necessary to be systematized and estimated.

At the present stage, there are significant achievements, both for hand executive tools and those that are driven by robots. No systematic studies have been performed on the functional actions and the accompanying movements, and on the mechanical structures that provide them. The present work sets the beginning of systematic research of mechanisms suitable for grasping respectively cutting and manipulating (orienting) instruments in laparoscopic surgery, based on the functional actions they are intended to perform.

The performance of robotic laparoscopic surgery is accompanied by executive and auxiliary instruments. The second group includes devices for illumination of the manipulating object, for manipulation and visual observation (video camera) and for the implementation of free access-removal of organs that not to manipulation to the organ. They have their own specific features and requirements, but are not the subject of this study. Manual executive tools are also not an object of this work.

The main results achieved according to the literature and surgical needs [1, 2, 5, 9, 11, 16] can be systematized as follows:

1. At present, there is a wide variety of instruments for robotic laparoscopic surgery. They are designed to perform a targeted functional task, and along with the main task (grasping, cutting, etc.), three local orientation movements are provided. Thus, most often the total number of controlled movements is four (Intuitive Surgical Incorporation, USA, http://www.intuitivesurgical.com).
2. There are tools with depends movements, that must be conceder in programming.
3. End-effectors have different sizes, determined by the dimensions of the manipulated objects.
4. Solid-rigid links are used, which is generally justified, but there are cases in which flexibility can be used as a convenience.
5. The operation of the instruments is carried out by means of indirect video observation, visual observation for initial contact and execution of the action. This is logical from the point of view of all human activity, but from an engineering point of view processes can be optimized in the presence of measurement.
6. Laparoscopic surgery has evolved in many directions and, naturally, executive instruments will also follow these trends. It is difficult to predict all these areas, but one of them will undoubtedly be to improve the performance characteristics of the main functional purpose, which will assist the medical team to achieve higher quality.

In our view, the most effective results would be achieved by looking for developments in the following areas:

1. Systematization of the known instruments by structural and kinematic possibilities and, in the presence of those with better qualities, to make models, which, after full experimental studies, seek their practical realization.
2. Considering that the objects on which they are executed and manipulated are flexible, it should be expected that some features of the instruments could be improved if flexible (visibly deformable) were used instead of rigid end-effectors.
3. Visual contact is irreplaceable, but if accompanied by tactile (for the beginning of the contact) and force (for some actions) would helpful for the doctors in some actions.

4. An essential point for the quality of manipulation performance is the information the operator receives (feedback), especially for tools that allow for measuring forces.
5. Introducing measurement of certain parameters would be extremely important, both in terms of improving their performance and the operation itself.

Based on this analysis, this work aims to design of functionally-operating model of laparoscopic executive tools for robots with improved engineering characteristics.

In order to achieve the main objective the following tasks need to be decided:

1. To make a kinematic-structural analysis of existing executive instruments by structural and kinematic criteria, to estimate their engineering characteristics, motivating the need to develop new ones.
2. To develop a functionally operating model of executive tools, with simplified kinematics of actuation of end-effectors, with higher reliability and easier support of the sterility of the instrument.

Possible solutions of suitable structures for gripping and manipulating of objects in laparoscopic surgery are examined in order to improve the engineering characteristics of laparoscopic executive instruments and the implementation of new constructions of instruments. System research is a prerequisite for informed choice in the design and achievement of the best technical indicators.

An analysis of mechanisms structures in instruments for laparoscopic surgery

Basic functional activities performed by laparoscopic executive tools

The actions that are referred to the performance of laparoscopic operations are extremely many and their priorities are defined and strictly performed by the medical teams. In this case, when they are referring to actions that require manipulative movements through specialized tools [2]. They may include:

- Visualization (illumination and movement of a mini video camera into the body of patients) of the manipulated objects and at the place where the controlled action is performed;
- Gripping with positional fixation of the object in order to be manipulated, without uncontrolled;
- Gripping (clamping) in order to isolate and temporarily disconnect the object during manipulation with it;
- Clamping-press blood vessels to hold up bleeding damage;
- Position and orientation of the object that can provide the most appropriate conditions for manipulation;
- Removable (elimination) of abrasions includes cutting (mechanical, with electro-coagulation or by laser) and restore the functioning of the organs after the invasion (stitching).

These activities do not cover the full range of manipulations for the surgical procedures. They contain only the part that need to provide instrumental mechanical movements. The drive of the instruments is realized directly by the surgeons or through controlled motor devices, as the macro movements are provided by specialized robots. Robots, including surgical robots, have two types of control – program and / or human operator (tele-control).

Instrument end-effectors movements

The human body is a typical example of an unstructured and dynamically changing environment. In such cases, complex spatial movements are required, which are often separated and performed by more than one instrument. The requirements to minimize the size of the instruments also impose specific restrictions. Kinematic completeness is associated with functional action realized by the movements of executive links, i.e., it is necessary to provide spatial movements that allow for quality implementation of the target action. The movements can be divided in two groups gripping respectively cutting and manipulating (orienting). The gripping movements are divided into spatial – they have more than two executive links and elementary ones – most often into two (three) executive links. The elementary (rotation, translation and general plane) gripping movements also include the cutting movements, although from another point of view, they are a kind of manipulation. This grouping is appropriate because they are performed by the same type of movement in another form of executive end-effectors.

Manipulating (orienting) movements must provide the operating team with the opportunity for full monitoring and decision-making for adequate action. It is known that full orientation is carried out through three elementary movements, most often rotations. In some cases, one or two are sufficient. The movements the laparoscope for the visualization of the surgical area also belong to this group.

When it comes to video observation of objects and the place of performance of the target action, the end-effectors is a miniature webcam with light source which is applied for object and place monitoring. Carbon dioxide is used for providing of better conditions for monitoring and freedom of actions.

The total required mechanical movements of the end-effector (executive links) can and most often are obtained from a combination of sequential and/or parallel (simultaneous) execution of elementary movements (rotation, translation). The combination of the types of elementary motions and their mutual arrangement of the axes, at a given total number, is the object of structural synthesis.

Irregular objects manipulations when mechanical characteristics are variable

For the systematic analysis of gripping devices, the type of movement of the executive links is decisive. As is known, movements can be spatial and planar. To date, in laparoscopic instrument, the executive links (usually two) perform plane movements (most often rotation). It is possible to use translation, which creates certain conveniences in the working range and improves the contact interaction with the objects, and general plane movement (intermediate characteristic in relation to rotation and translation). Another characteristic of the movements of the executive links, related to the gripping, is related to the autonomous drive of each executive links or simultaneously. In the first case, the grip can be performed in the entire working range without or with minimal displacement, while in the second – without displacement only if the object is located symmetrically with respect to the executive links.

Fig. 1 shows some of the possible schemes of executive links where the initial movement is linear, realized by handle or a control motor device.

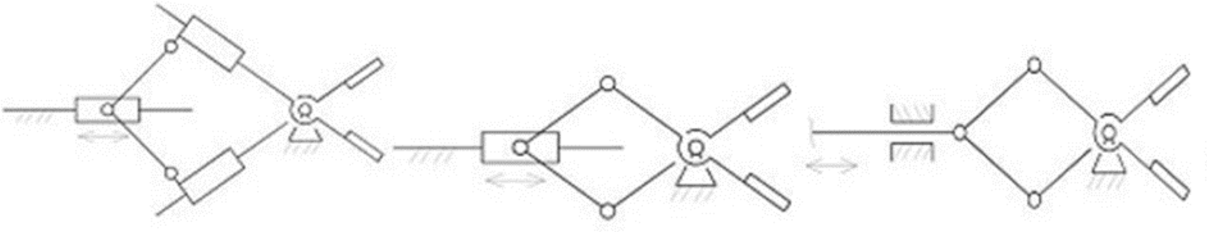


Fig. 1 Major possible actuation schemes of end-effectors in symmetrical gripping (cutting) as the initial movement is linear

Some widely used structures of the mechanisms are shown in [13, 14]. Others publications [4, 12] describe in details the structures of the mechanisms that allow actuating of executive links for these class movements of the executive links.

On Fig. 2 are shown some of the possible schemes of executive links where the controllable initial movement is rotational and realized by handle or a control motor device.

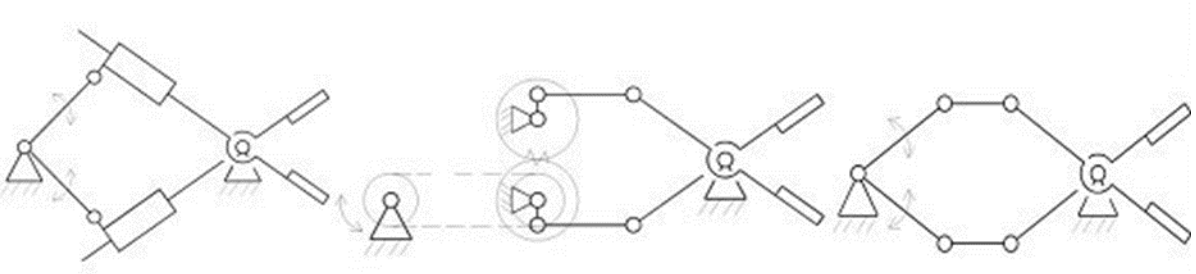


Fig. 2 Tree major possible actuation scheme of end-effectors in symmetrical gripping (cutting) with rotation initial movements.

In autonomous actuation the kinematical chains are the same but have two motor devices. On the Fig. 3 is shown autonomous actuation of executive end-effectors in gripping-cutting with two linear engines.

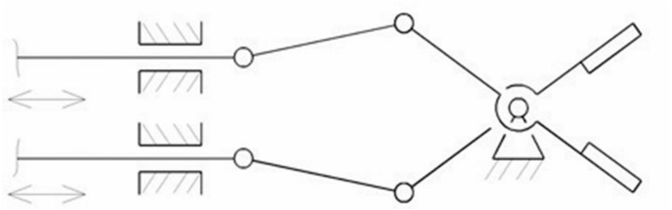


Fig. 3 Autonomous actuation of end-effectors with linear engines

On the Fig. 4 is shown autonomous actuation of executive end-effectors in gripping (cutting) with two rotary motor devices.

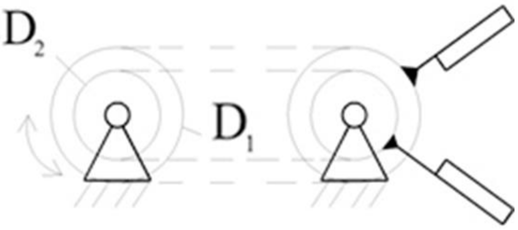


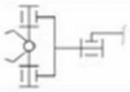
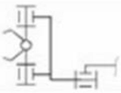
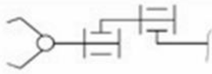
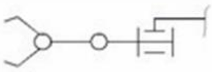
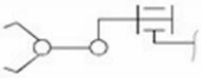
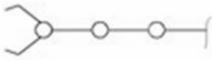
Fig. 4 Autonomous actuation of end-effectors with rotary engines

Orientation and positioning of objects to controlled manipulations

As is known, three rotations are most often used for the orientation of material objects, and in some cases one or two are sufficient. The case of one is trivial and concerns the arrangement with the gripping motion (parallel, perpendicular with intersection axes or cross-axes).

In two and three orienting motions, the arrangement of the axes is combined, as is known can be orthogonal (parallel and perpendicular with the intersection or cross of the axes) and non-orthogonal. Possible combinations of structures with two orthogonal rotations and illustrating schemes for interceptive and crossing axes are shown in Table 1.

Table 1. Possible combinations of structures with two orthogonal rotations

N	Possible combination of two orthogonal rotations	Interceptive axes	Cross axes
1	R ⊥ R ⊥ R		
2	R ⊥ R II R		
3	R II R ⊥ R		
4	R II R II R		

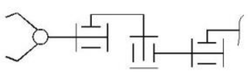
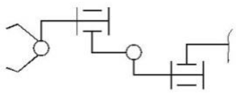
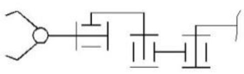
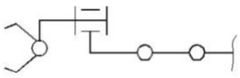
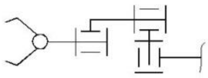
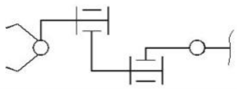
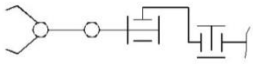
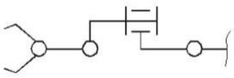
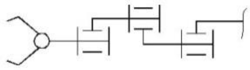
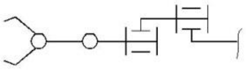
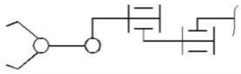
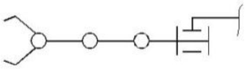
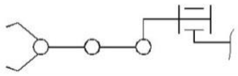
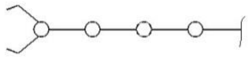
Two examples of non-orthogonal arrangement of the axes are shown in Fig. 5. It is accepted that the executive links for gripping (cutting) have autonomous movements.

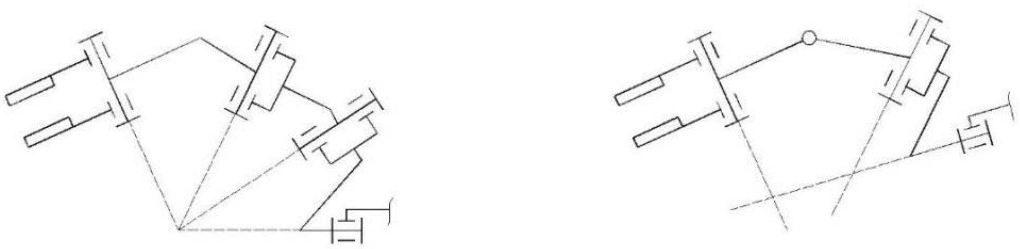
a) interceptive axes b) cross-axes

Fig. 5 Non-orthogonal axes with two orientation movements

Structures for gripping by rotation of the executive links and three rotational orienting movements are shown in Table 2. Possible combinations of arrangement are illustrated by exemplary schemes for interceptive and cross of the axes.

Table 2. Possible combinations of structures with tree orthogonal rotations

№	**Possible combination of tree orthogonal rotations**	**Perpendicular interceptive axes**	**Cross axes**
1	R ⊥ R ⊥ R ⊥ R		
2	R ⊥ R ⊥ R II R		
3	R ⊥ R II R ⊥ R		
4	R II R ⊥ R ⊥ R		
5	R ⊥ R II R II R		
6	R II R ⊥ R II R		
7	R II R II R ⊥ R		
8	R II R II R II R		



a) Interceptive axes b) Cross-axes

Fig. 6. Non orthogonal arrangement of the axes with tree orientation movements

Fig. 6 shows two examples of schemes of non-orthogonal arrangement of the axes in three orienting movements and autonomous drive of the end-effectors in gripping (cutting). The executive links own independent movements. As expected, they are not the only ones.

Constructive schemes of selected structures

When designing the constructive schemes, the functional application must be considering in order to provide the most conditions for implementation. Without such a preliminary analysis, the probability of choosing the most appropriate solution is random.

Fig. 7 shows a structural diagram of a tool for symmetrical gripping (cutting) and perpendicular rotation with interceptive of the axes. The tool is designed to be operated by the hand. The links are normally closed. The gripping force (cutting) is obtained by the spring. The scheme allows inversion of this action by changing the location of the spring.

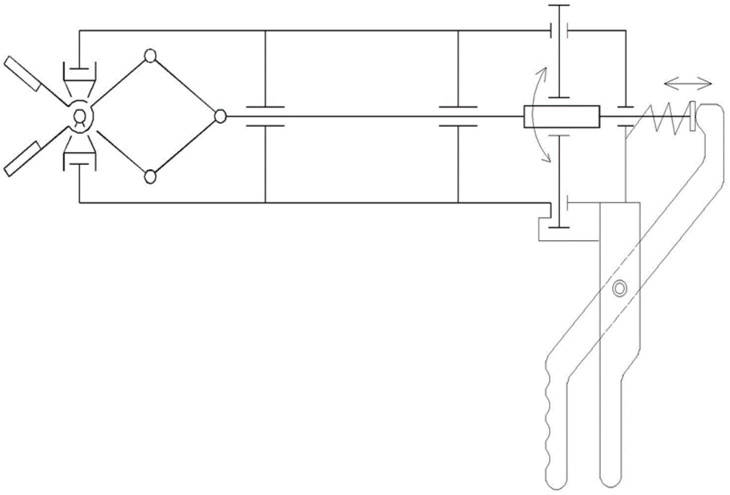
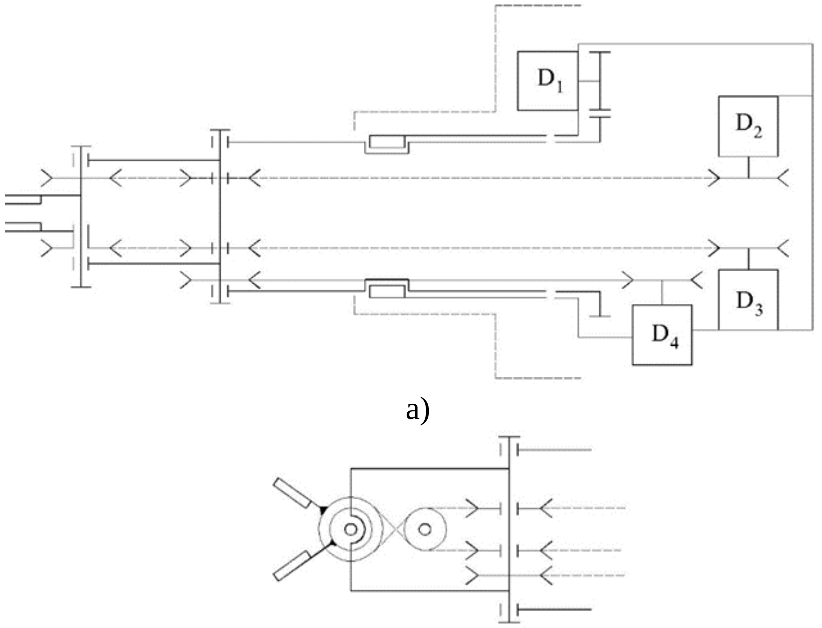


Fig. 7 Construction scheme of a conventional instrument
for symmetrically gripping and perpendicular orientating movement



a)

b)

Fig. 8 An instrument scheme with autonomous control of the end-effectors
for gripping (cutting) and two orientating movements

A structural scheme of a tool with autonomous actuation of the executive links in gripping (cutting) and two perpendicular orienting movements with interceptive axes is shown on Fig. 8. The actuating is intended to be performed by four controllable rotary motors. The gripping (cutting) section of the tool can be with an axis parallel (Fig. 8a) or perpendicularly crossed (Fig. 8b) to the next orientation axis.

From the material described above, it can be seen that the R⊥R‖R structure and autonomous actuating of the kinematic chains, the engineering characteristics of the laparoscopic instruments can be improved, as the design is simplified, no additional transmission mechanisms of the executive links are required, which in turn facilitates the process of control of the device and proved higher reliability. Therefore, the next sections focuses on the design of a laparoscopic executive instrument with a R⊥R‖R structure.

A laparoscopic executive instrument with R⊥R‖R structure

The improvement of the assistance functions of the robotic systems for operational activity is connected with the development of new and improvement of the qualities of the existing tools, their automatic positioning, gripping and cutting with controlled forces, as well as increasing the security of all actions.

For the purposes of robotic laparoscopic surgery, the Endo Wrist Technology of Intuitive Surgical (USA) built into the tools of the daVinchi robot is widely used. The full range of the catalog contains structures with 4 and 7 degrees of freedom. The wrist with 4 degrees of freedom provides autonomous movement of the executive links. The disadvantage of this structure is the three mutually perpendicular rotations (R⊥R⊥R), which requires the use of additional rollers to drive the end-effectors. In the present work, a R⊥R‖R structure is proposed that avoids additional rollers. In the Endo Wrist, the motors are located in the base, which makes the movements after the first degree of freedom dependent. The described scheme dependent movements receive the third and fourth degrees of freedom, only when the wrist is folded. The proposed laparoscopic instrument has a simplified construction compared to the instruments of the robot daVinchi, without the need to use additional rollers to drive the actuators. This is beneficial both for ensuring higher reliability and for cleaning and maintaining the sterility of the instrument. The dependence of the movements is smaller and this simplifies the operation of the operator.

The instrument is designed for manipulation (grasping, holding, and moving) objects with irregular geometric shape in the field of minimally invasive surgery, mainly elastic (tissues, organs, blood vessels) [15] or rigid such as gallbladder stones. The general appearance of the instrument is shown on Fig. 9 and the constructive diagram of a laparoscopic instrument R⊥R‖R is shown on Fig. 10.

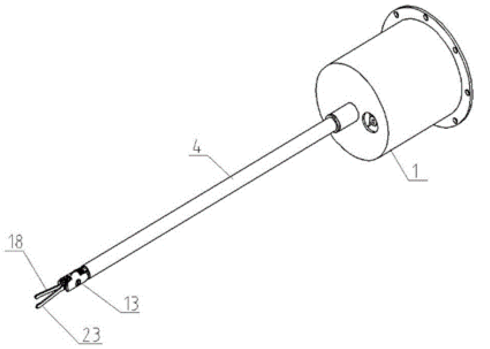


Fig. 9 A general appearance of the laparoscopic robotized instrument:
1 – basis; 4 – hollow tubular body; 13 – joint; 18 and 23 – executive links.

The main elements involved into the mechanical structure are the basis (1), where four electrical motors are fixed immovably, hollow tubular body (4) for transmitting motion to the two executive links (jaws) (18) and (23).

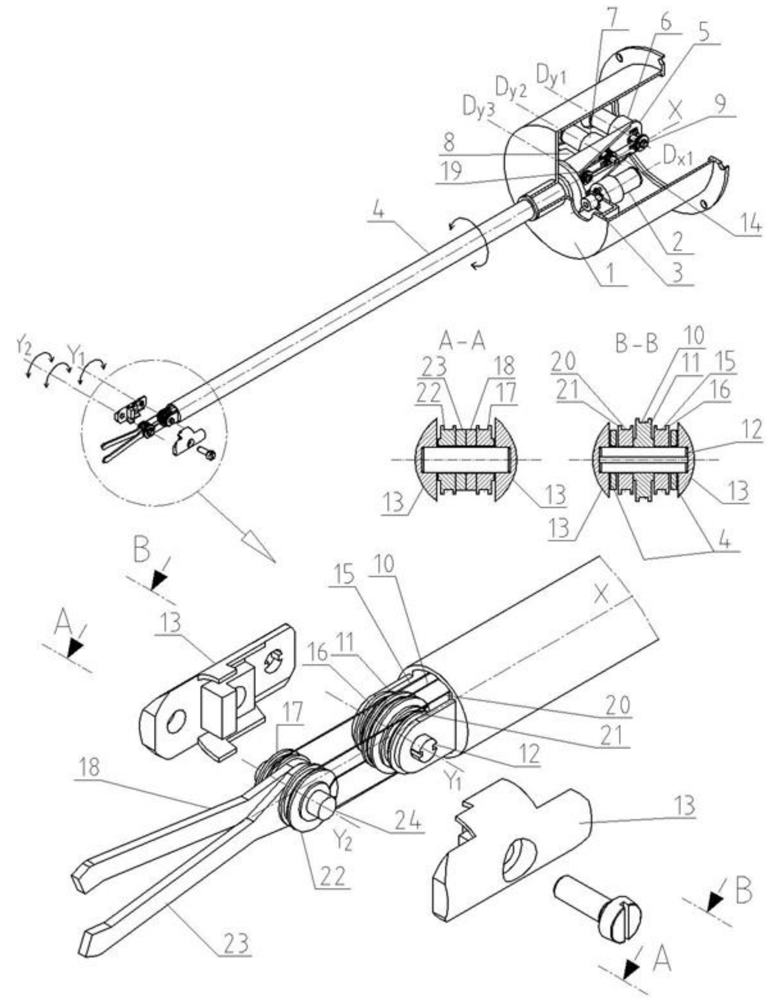


Fig. 10 Constructive diagram of a laparoscopic instrument with $R \perp R \parallel R$ structure:
1 – basis; 2 – electrical motor; 3 – transmitting mechanisms; 4 – hollow tubular body;
5 – console; 6-8 – electrical motors; 9-12 – fibred mechanisms; 13 – joint;
14-17 and 19-22 – fibred mechanisms; 18 and 23 – executive links.

Principle of the work

Laparoscopic instrument includes a base (1) to which a motor (2) is fixedly mounted, which drives by means of a transmission mechanism (3) a hollow tubular body (4) mounted in the base (1), to a unit (4) the bracket is fixedly attached (5) on which the motors (6), (7) and (8) are mounted, the motor (6) is driven by a fibred mechanism (9), (10), (11) and (12), the unit (13), the motor (7) drives by means of a threaded mechanism (14), (15), (16) and (17) the jaw (18), and the motor (8) drives by means of a fibred mechanism (19), (20), (21) and (22) jaw (23). The spools (9), (11), (14), (17), (19) and (22) have a side slot which passes through one flange and part of the pulley bed, and its purpose is to grip the thread to the pulley. The pulleys (16), (21) are mounted and can rotate freely around the shaft (12), which is fixedly connected to a unit (13) and the pulley (11) transmits rotational movement of the shaft (12) by means of slots or other known method. The pulleys (17) and (22) are mounted on the shaft (24) and transmit independent rotational motion to the jaws (18) and (23), respectively.

As a consequence of the limitations imposed by the operating environment – the manipulation is performed in a narrow working space in the human body-motors are situated at the base of the instrument, which is situated outside of the troacar, respectively, outside of the human body. The diameter of the hollow tubular body is 8 mm, since the diameter of the troacar, where the instrument is inserted is the standard size of 10-12 mm. The length is inserted is also standard 68 mm. Due to the limitations imposed by the environment and the human body according to the specificity of the intervention the instrument moves forward and back are limited to 100 mm.

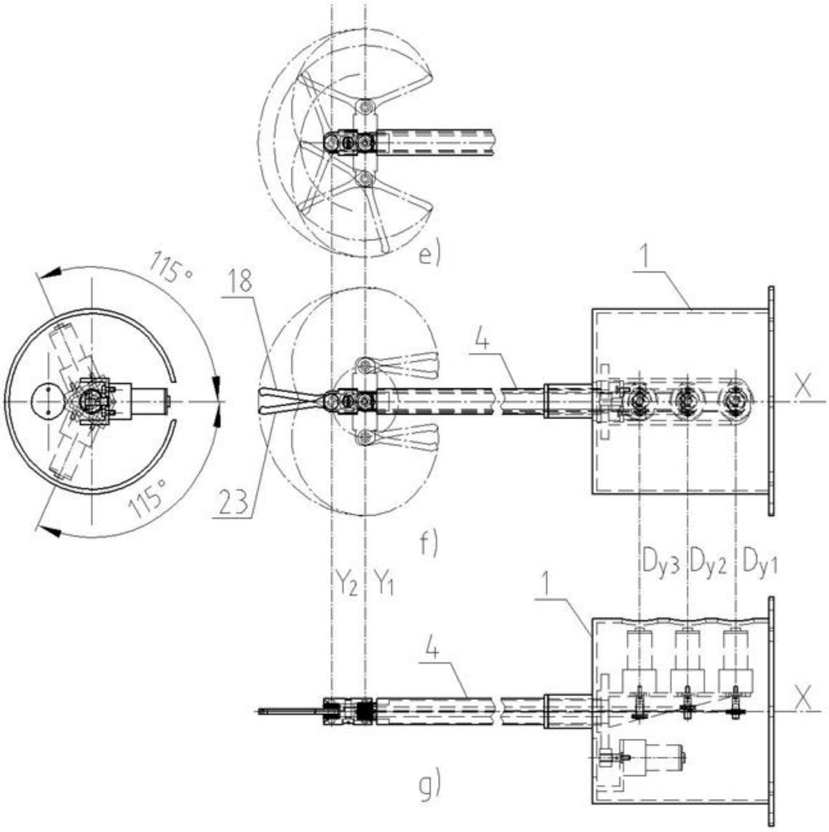


Fig. 11 Working area of the instrument at the initial, open and closed position

The possible movements of the laparoscopic robotized instrument in the working area are two. The angle of rotation, around the axis of the tool is 360 degrees. This movement is realized by one of the motors and the transmission mechanism. The length of the hollow tubular body (4) is 68 mm.

The jaws (two executive links) of the instrument are fully open at the rotation angle of 120 degrees depending on the position. It allows moving only one of the links. The movement of the jaws (18) and (23) is implemented by the motors and the wiring mechanisms. The length of the executive links is 6-8 mm by the limitations and specifics of the working area, respectively, the human body. On the Fig. 12 various possible options for opening at the jaws and turning in the joint of the instrument are shown.

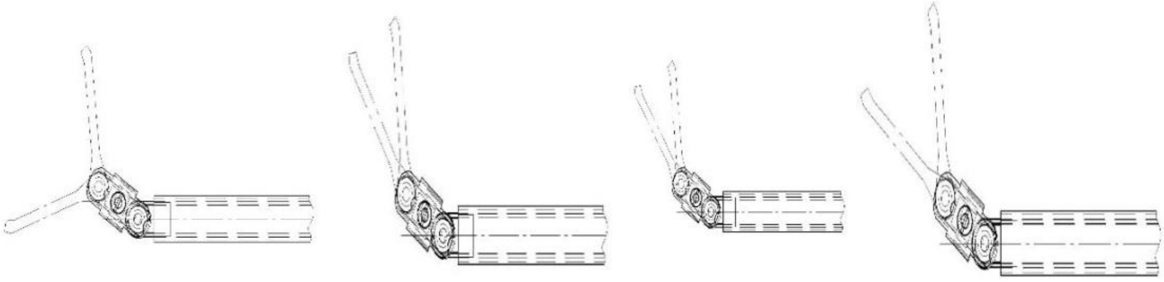


Fig. 12 Various possible options for opening at the jaws
and turning in the joint of the instrument

Determination of the transfer functions between motors and actuators of the instrument

The desirable working area of the designed instrument depends on the linear sizes (l_2, l_3, l_4) and limitations of the joints (angles of rotations) ($q_{1\min} \le q_1 \le q_{1\max}$, $q_{2\min} \le q_2 \le q_{2\max}$).

The values of q_3 and q_4 depend on the type of intervention (gripping, moving, cutting, clamping), which is often symmetrical to the two executive links and the kinematic chains are identical but with autonomous drive. The action is performed by controllable movement of one jaw relative to the other during the manipulation without moving the object. Uncontrolled movement occurs when the jaws are driven (opened, closed) by one motor and the object is not symmetrically located relative to the two jaws.

The direct kinematical problem is used to control the action in remote control (by the leading doctor of the operation). Moreover, to refine the action, a systematic position error in the operating position can be entered in the control unit.

Moving at the working area is realized by the motors. The transmitting mechanisms corresponded with the motors and executive links. This relation can be written by Eq. (1):

$$\dot{\phi} = J\dot{q}, \tag{1}$$

where $\dot{\phi} = [\dot{\phi}_1, \dot{\phi}_2, \dot{\phi}_3]^{\mathrm{T}}$ is a vector of the angular velocities of the executive link; J is Jacobs matrix; $\dot{q} = [\dot{q}_1, \dot{q}_2, \dot{q}_3]^{\mathrm{T}}$ is the vector of angular velocities in the robot's joints. For the concrete example Eq. (1) can be written as:

$$\begin{vmatrix} \dot{\phi}_1 \\ \dot{\phi}_2 \\ \dot{\phi}_3 \\ \dot{\phi}_4 \end{vmatrix} = \begin{bmatrix} \frac{\partial \phi_1}{\partial q_1} & 0 & 0 & 0 \\ 0 & \frac{\partial \phi_2}{\partial q_2} & \frac{\partial \phi_2}{\partial q_3} & \frac{\partial \phi_2}{\partial q_4} \\ 0 & 0 & \frac{\partial \phi_3}{\partial q_3} & 0 \\ 0 & 0 & 0 & \frac{\partial \phi_4}{\partial q_4} \end{bmatrix} \cdot \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_4 \end{bmatrix} \tag{2}$$

There is a need to determine the optimal area for movement of the tool, using qualitative indicators. These indicators are based on the Jacobs matrix. As a result, the geometry of the tool can be optimized so that in a certain area the configurations will provide optimal movement from the point of view of kinematics. This is important when scaling movements, ie. with a larger "size" of movement by the operator (master) provides minimal movement of the robotic tool. With an optimal configuration (good quality indicator), these optimal configurations facilitate the control system.

Transmitting functions at the major diagonal $\frac{\partial \phi_i}{\partial q_i}$ ($i = 1 \div 4$) are

$$\frac{\partial \phi_i}{\partial q_i} = i_{pi} \times i_{ni}, \; i = 1 \div 4, \tag{3}$$

where i_{pi}, $i = 1 \div 4$, is the value of the gear reduction ratio of the respective chain (often and in this case they are identical i_{pi}, $i = 1 \div 4$; i_{ni}, $i = 1 \div 4$ is the value of the gear transmission ratio of the wire.

For the determination of i_{pi} it is applied the following kinematic scheme of the proposed model of the laparoscopic instrument, which is shown on Fig. 13.

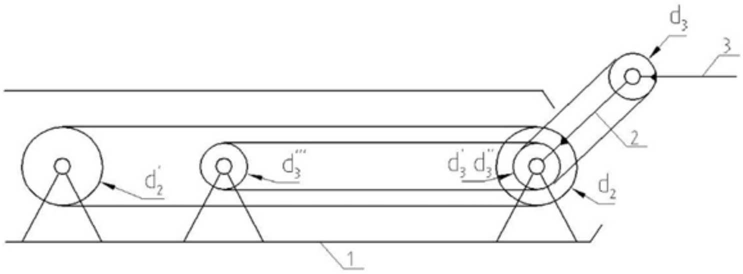


Fig. 13 Kinematic scheme of drive of units 2 and 3 (4)

The kinematic chains of the links 2 and 3 are only shown thereby kinematic chain to the link 4 as well 3.

The value of component (3) i_{pi} is obtained from Eq. (4):

$$i_{pi} = \frac{\varphi_i}{\psi_i} = a_i, \; i = 1 \div 4. \tag{4}$$

The gear transmission ratio of the wires are written by Eqs. (5.1), (5.2), (5.3) and (5.4).

$$i_{p1} = \frac{\psi_1}{q_1} = \frac{d_1}{d_1^{'}} \tag{5.1}$$

$$i_{p2} = \frac{\psi_2}{q_2} = \frac{d_2}{d_2^{'}} \tag{5.2}$$

$$i_{p3} = \frac{\psi_3}{q_3} = \frac{d_3}{d_3'} \tag{5.3}$$

$$i_{p4} = \frac{\psi_4}{q_4} = \frac{d_4}{d_4'} \tag{5.4}$$

The construction scheme and Eq. (2) show that movement of links 3 and 4 is result from controlled movement of the link 2. This movement must be appropriately controlled. For that reason it is necessary to determine the transfer functions $\frac{\partial \varphi_2}{\partial q_3}$, respectively, $\frac{\partial \varphi_2}{\partial q_4}$ which are obtained from Eq. (6):

$$\frac{\partial \varphi_2}{\partial q_i} = i_{21}^{di} = \frac{1}{1 - \frac{d_i}{d_i'}} = \frac{d_i'}{d_i' - d_i}; (i = 3,4)\,. \tag{6}$$

Angles of rotations of the executive links q_i, (i = 1÷4) when the angles of motors rotations φ_i, (i = 1÷4) are obtained from Eq. (7):

$$\begin{aligned} q_1 &= \alpha_1 \frac{d_1}{d_1'} \phi_1, \\ q_2 &= \alpha_2 \frac{d_2}{d_2'} \phi_2, \\ q_3 &= \alpha_3 \frac{d_3}{d_3'} \frac{d_3'}{d_3''} \phi_3 + \alpha_2 \frac{d_2}{d_2'} \left(\frac{d_3'}{d_3' - d_3} \right) \phi_2\,. \end{aligned} \tag{7}$$

The derived analytical dependences of the transmission functions make it possible to carry out calculation procedures for optimizing dimensions under the existing restrictive conditions, as well as to enter in the software for controlling the movement of the tool.

Some main results of the following developments [3, 17,] can be used in developing a program for the operation of this laparoscopic tool. Developments related to augmented reality are also of interest for future directions of work [8, 10, 18]. One such work is a Multifunctional Operating Station based on Augmented Reality developed in a laparoscopic diagnostic tool [19].

Conclusion

In this work, the possible solutions of mechanisms suitable for grasping and manipulating objects in laparoscopic surgery, which have an irregular and or variable geometric shape, are investigated. The study shows that one of the possible options for improving the engineering characteristics of the executive instruments is the application of the structure R$\perp$R$\|$R and autonomous drive of the kinematic chains, as it simplifies the design of the instrument, no additional transmission mechanisms are needed for actuating the actuators, which in turn facilitates the process of managing the entire device and favors to ensure higher reliability. As a result of this conclusion, the design of laparoscopic executive instruments, one of which is an instrument with a R$\perp$R$\|$R structure is designed. The proposed model avoids additional rollers and complicates the construction. The motors are incorporated into the tool and dependent movements receive the third and fourth degrees of freedom only when the wrist is folded. With direct kinematic problem and the Jakubs matrix, the geometry of the instrument can be optimized so that in a certain area the configurations provide optimal movement from the point of view of kinematics. This is important when scaling movements, i.e., with a larger movement of the operator's hands (master), minimal movements of the robotic tool are ensured. With an optimal configuration (good quality indicator), these optimal configurations facilitate the control system.

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Assist. Prof. Veronika Atanasova-Georgieva, Ph.D.
E-mail: iwanowa.w@abv.bg

Veronika Atanasova-Georgieva is an Assistant Professor at the Institute of Robotics – Bulgarian Academy of Sciences. She received her Ph.D. Degree in Robotics and Manipulators in 2020. Assist. Prof. Atanasova-Georgieva won the World Federation of Scientists Planetary Emergencies Grant – the prize of the competition for the most original scientific development for young scientist. Her main research interests include surgical robots, tactile instruments, haptic interface.