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FAMILY TOOLS FOR ROBOT-ASSISTED LAPAROSCOPY

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Abstract: *Laparoscopic surgery rapidly evolves as minimally invasive surgery. The lack of the tactile sense is the most important disadvantage associated with laparoscopy because it limits surgeon abilities to diagnoses and treatment some surgical problems. The introduction of robots in minimally invasive surgery will considerably enhance the accuracy of medical interventions. But investigations of current robot instruments are indicated to have some technological deficiencies the main of which are lack of tactile sense. Research in the area of laparoscopic tools with force measurement capabilities has led to significant advancements over the past several years. Researchers have retrofitted conventional laparoscopic instruments with force and position sensors, developed novel laparoscopic tool with sensors incorporated into their design, and have also developed entire robotic surgical systems with force sensing/reflection capabilities. Several researchers have also incorporated a direct sensing method for tissue characterization through pressure measurement normal to the surface of the jaws. These methods are expensive, none sterilizable and not modular which make them difficult to incorporate into laparoscopic tools. To avoid cardinal problems in direct force measurements in bloodless surgery a mechanical construction was produced where two force sensors by Honeywell USA were incorporated. Our work focuses on design of novel surgical instrument for laparoscopic Cholecystectomy with force feedback control and sensors which are incorporated in handle of tool. The paper shows also some variants of rigid and elastic links for irregular objects manipulations.*

Key words: *end effectors, haptics, surgical robots, instruments, laparoscopy.*

1. INTRODUCTION

Gallbladder removal is one of the most commonly performed surgical procedures. Frequently, Gallbladder surgery is performed laparoscopically. The medical name for this procedure is Laparoscopic Cholecystectomy. Laparoscopic surgery required specialized instruments to handle and manipulation of solid and elastic small objects. Precision, stability and safety are the decisive criteria for instruments used in laparoscopy but, sensitive and easy control of the instrument is a basic requirement for successful patient outcomes [1]. The main problem in Laparoscopic Cholecystectomy, the most common performed laparoscopic procedure, is that the conventional surgical instruments are too bulky to be used in microsurgery but the lack of the tactile sense is maybe the most important problem associated with laparoscopic surgery. This problem is result from the instruments construction – Fig 1 and character of operation.

Despite the lack of the tactile sense, the application of laparoscopic interventions is increasing, and this, in turn, leads to demands for better laparoscopic techniques, methods and tools. The introduction of robots in minimally invasive surgery (MIS) such as *daVinchi* [2] and *Zeus* [3] will considerably enhance the accuracy of medical interventions. Many surgical procedures performed using traditional laparoscopic technique can be performed more quickly and easily with Robot-assisted Systems. Intelligent control can filter hand tremor and in-

Fig. 1. Laparoscopic instrument.

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crease accuracy by motion scaling. Robotic instruments can have more degrees of freedom yielding higher dexterity. Current *daVinchi* instruments are indicated to have some technological deficiencies the main of which is the different dimension of grasping force ant the surgeon lacks tactile feedback. This problem can be solved by introducing small force sensors that enable force interaction to the surgeons. The sterility is as well difficult for the variety of plays. The strings are easily wearable and require constant replacement. We intend to introduce modularity, hermetically and easy and convenient sterilization of the new developed instruments. Another important problem of *daVinchi* end-effectors is that they are too expensive. By developing novel specialized robots instruments we have created more compact, simple, cheaper and easier robotic instruments than ever. We have developed novel smart instruments for robotic surgical systems and capability of irregular shape objects manipulation. The use of the force feedback instruments will help the surgeon to accurately execute laparoscopic procedures. The expected result of novel end effectors is a radical improvement of the quality and efficiency of our healthcare.

Some requires are addressed to this instrument links when we designed them:

1. The instrument links have to have a small diameter –smaller than 10 mm, which can be inputted in the work area and at the same time, be extended to cover concretion larger than 10mm.

2. To be fitting for manipulation of irregular and variable-shaped objects.

3. To be fitting for manipulation of solid and elastic small objects.

4. The operating links of the instruments are of size 3, 5 and 10 mm.

5. Instrument tip should be completely open from 25 to 30 mm- movement of the output.

6. Links are of opened at an angle of 55 to 65 degrees.

When are designed novel surgical instruments for laparoscopy it has to solve two main problems:

- Tactile force feedback for reliable handling and possibility to force regulation;
- Force has to be control in definite range.

Development of family tactile force feedback is in its initial stage and accordingly with current laparoscopic instruments also novel laparoscopic end effectors are supplemented.

2. TACTILE FORCE FEEDBACK IN LAPAROSCOPIC TOOLS

In open conventional surgery the surgeon interacts directly with organs/tissues/tumors. Unless in bloodless surgery the tools are handled and maneuvered in such way that surgeon must adapt to the instruments. Guiding such an instrument is difficult, requires a lot of practice and lack of tactile force feedback. The lack of the tactile sense is maybe the most important disadvantage associated with laparoscopy, because it limits the surgeon's abilities to examine and palpate internal organs. An example is detection of tumors. Since they tend to be harder than the surrounding tissue, tactile feedback can indicate the presence, size and exact location of a tumor, thereby enhancing the chances of performing successful diagnosis and surgery. There is a similar problem with stones and sometimes not possible detection them. Also cutting and grasping are similar movements of surgical fingers. Sometimes the surgeon does not distinguish. The tactile sense in laparoscopy increases the chances of performing successful diagnosis and surgery and solves a lot of problems in laparoscopy. Therefore one future direction of surgical robots is integration with Haptics devices (tactile force feedback devices**)**. Robot-assisted laparoscopic systems with tactile force capabilities will be enhanced the realism in these systems, and the tactile sense together with the visual information will be transferred to the surgeons. The application of haptic devices into operation rooms allows surgeons to experience a sensation of touch and force feedback when there are an interaction between tool's tip and organs' patients Haptic systems ensure the surgeon's hand and eye to work together. Haptic devices integrate the capabilities computer systems and the surgeon's abilities.

Research in the area of laparoscopic tools with force measurement capabilities has led to significant advancements over the past several years. Researchers have retrofitted conventional laparoscopic instruments with force and position sensors, developed novel laparoscopic tool with sensors incorporated into their design, and have also developed entire robotic surgical systems with force sensing/reflection capabilities.

Instruments force control can be realized by two approaches-direct and indirect sensing methods. Several researchers have also incorporated a direct sensing method for tissue characterization through pressure measurement normal to the surface of the jaws [5]. In medicine and especially for laparoscopy these methods are expensive, non-sterilizable, and not modular, which make them difficult to incorporate into laparoscopic tools.

To avoid cardinal problems of direct force measurement the force sensors are incorporated into handle of the tools as intermediate link between the linear actuator and interchangeable jaws.

The Haptics Control System consists: Haptics control device which is direct connected with surgeon fingers and a smart instrument which interacts with a patient.

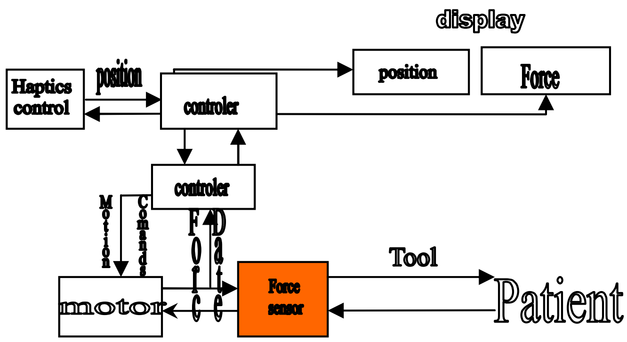

Fig. 2. Scheme of tactile force feedback in laparoscopy.

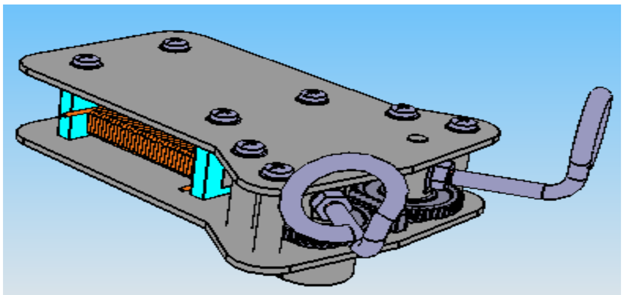

Fig. 3. Haptics control device.

The main components at this scheme are Haptics control device Figure 3 which is in contact with the surgeon and instrument which interacts with the patient. When surgeon moves the handle of haptics device his movements are translated in digital signals and controller performs signal processing. The Controller determines control signals to the laparoscopic instrument. Our decision for Haptics control in Laparoscopic surgery is given by Fig. 2.

2.1. Force sensor for sensing control

Laparoscopic Haptics systems require an appropriate force sensor which measurements the interaction between instrument tip and organs/tumors/tissues/stones and returns information to the operator' fingers**.** To avoid cardinal disadvantages of the direct force measurement of interaction between the laparoscopic instrument jaws and organs/tumors/tissues/stones was produced a mechanical construction where are incorporated 2 force sensors by Honeywell USA [6] which are situated opposite each other. Force sensors FSS1500NSB by Company Honeywell USA are very appropriate for medical application. FSS sensor allows to very precise measurement of gripping force in the requisite operating range from 0 to 1500 g and due to their linear - in its convenient conversion constant voltage. Another important function of this sensor is to fix the moment of contact of the jaw to organs/ tissues/ blood vessels respectively, the time was extended. The components are as folows: 1 – corpus; 2 – measurement head; 3, 4 – Ball-bearings.

The new construction of axial, bi-directional active force sensor is designed to provide realistic haptic feeling for a surgeon as he touches a real object. Figure 4 shows the force sensor. The force sensor is inserted into the handle of the laparoscopic instrument as intermediate link between the linear actuator and interchangeable jaws used for the implementation of the laparoscopic operations. Force is measured by the force sensor transmitted through haptic interface on the fingers of the surgeon forces of interaction between the laparoscopic instrument

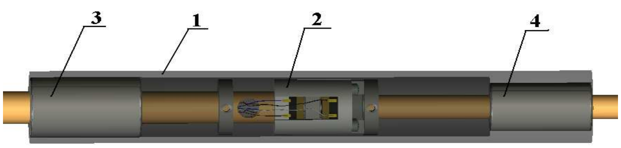

Fig. 4. Axial, bi-directional active force sensor.

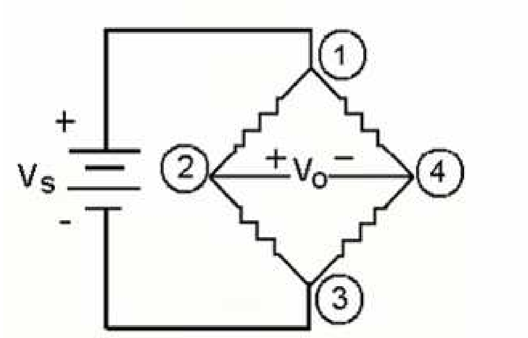

Fig. 5. Excitation Schematics – Excitation 5 Vdc Typ., 6 Vdc max**.**

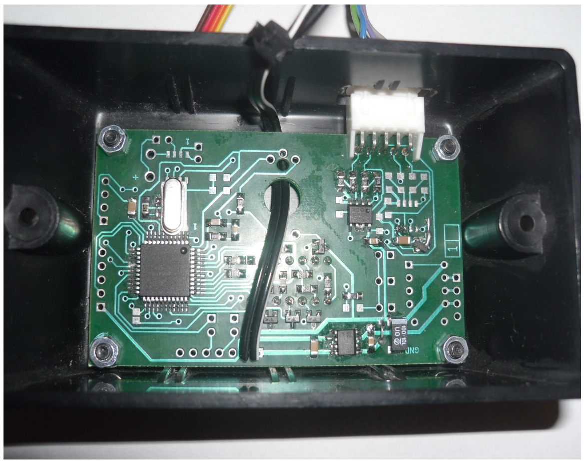

Fig. 6. Control module for the laparoscopic device.

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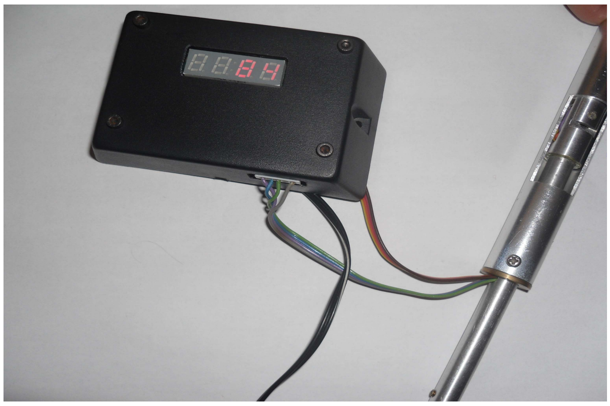

Fig. 7. Electronics and Bi-direction force sensor.

and object in the implementation of the laparoscopic manipulation, creating in him a sense of real tactile interaction with the object- organs/ tissues/ blood vessels.

The range of the force sensor is 0 to 1500 grams with sensitivity of 0.12 mV/gram.

Figure 5 shows the Excitation Schematics of the force sensors.

Figures 6 and 7 show control module for the laparoscopic device.

Optimal control is defined as the optimization of certain predefined performance indices. Sometimes, parametric objective functions may be applied, for example, the linear quadratic optimal regulator problem where two weighting matrices need to be defined. Many optimal

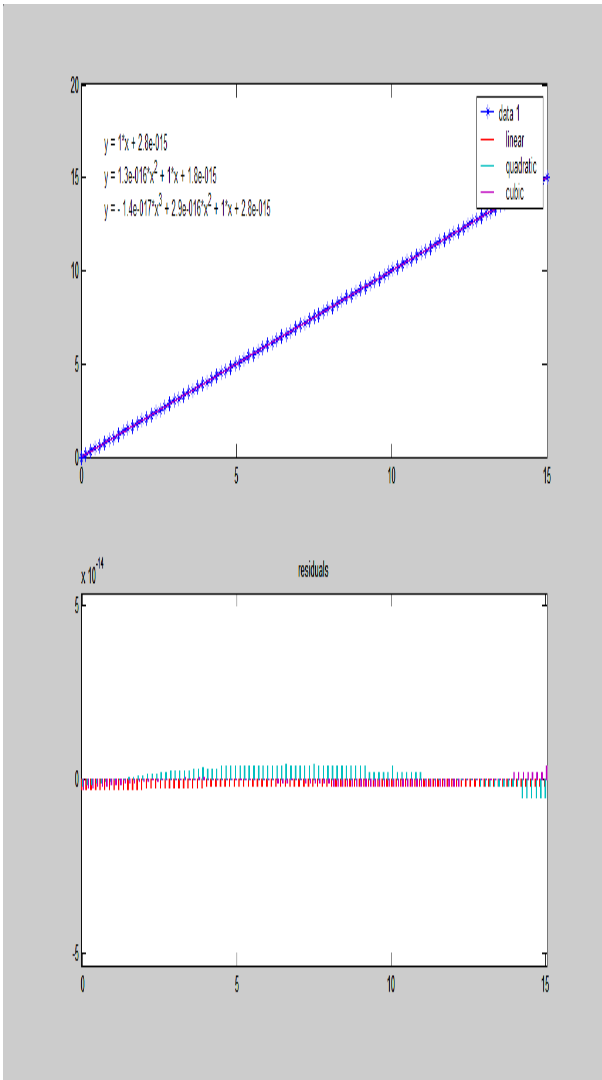

Fig. 8. Example for System with *P* Force control regulator for novel laparoscopic tool.

control problems can be conversed in to conventional optimization problems by the powerful tools provided in MATLAB interface. Theoretical control solutions often neglected considerations on implementation of the controller. The following example (Fig. 8) is designed to illustrate the application of testing model of *P* – control for the family tools for laparoscopic surgery when no noise. Linear, quadratic and cubic methods are applied.

We have X = [0: 0.1500:15.0000] – input data,

Y = [0:0.1500:15. 0000] – output data.

In that (ideal) case Output date has to equal to input date (Output Force has to equal to input Force).

3. FAMILY LAPAROSCOPIC INSTRUMENTS

World trend in medical technology is the development of a new type of tools and accessories, to improve the performance of medical staff and increase quality of care for patients! Two main streams on which the work in recent years, reducing the number of ports to access the patient's body and restoring visibility in the surgical arm or tactile feedback. Researchers plan to reduce the number of ports and their size, the working parts of instruments remains rigid. Universal tools have been developed with many degrees of freedom to manage enforcement units and the camera [8 and 9]. The main problems are a difficult control and coordination of movements, time delay, which is undesirable for surgery. Long thin tools with rigid jaws and lack of 3-dimensional image by feedback control from the place of medical treatment to remain major problems inherent in the tools developed so far in surgery. Flexible robotic nozzles which can reach to any point of the work area significantly increased maneuverability, thereby increasing the quality of execution of the procedure itself.

The incorporation of cameras for three dimensional monitoring tools in the work area is a great challenge for modern researchers. Also, the tool can be modified to control actuators whose interface is connected to a computer. Different programs can be written for various procedures performed by physicians.

3.1. Syntheses of elastic and rigid links for family tools for robot-assisted surgery.

Elastic links can be applied for manipulation of solid irregular shapes object such as gallbladder stones [9] which are shown on Fig 9. By now there are developed robots for a regular shapes object manipulation or regular sections. Rigid irregular shape objects can be handled by special and specialized robot gripers that through cinematic control when they perform a desired action by the operator. Universal grippers with a lot of degrees of freedom can be used also. The application of elastic deformations for handling of solid regular shape objects and small size is widespread [10, 11, and 12]. To increase range, and to satisfy the Force-deformation and other requirements to proceed to the synthesis of more complex structures where conventional relationships between the links are commuted with monolithic flexible with integrated actuators. The capabilities of these approaches to achieve significant displacements and hence a wider range of the catcher is very limited.

At this work are proposed the application of elastic links to handle solids irregular shape objects and the required force to grasp and adapt to the form obtained as a result of mechanical elastic deformation. In this case flexible links are those which, due to linear and transverse dimensions, material and allow mechanically induced significant releasable distortions (be extended to cover concretion larger than 10 mm). The choice of the deformation value must comply with the necessary force to hold other specific conditions, which are subject to special design.

The elastic links can be classified:

- The type of internal stress induced - bending, twisting and complex.

- Cross section of the link- continuously variable (continuous and / or discrete) and other forms. Fig 10

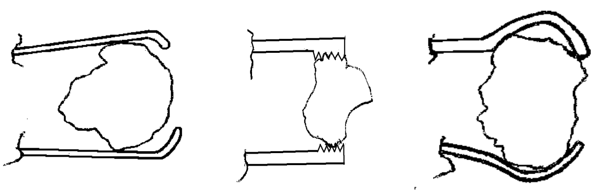

Fig. 9. Syntheses of elastic links for irregular shape objects.

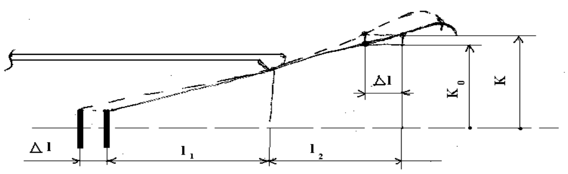

Fig. 10. Elastic link with normal open structure.

shows an elastic link with normal open structure. Where l the length of the link is, l_1 is the length of the elastic link before contact with object. l_2 is the length of elastic link when there is a contact with object.

Synthesis of elastic links of irregularly shaped object manipulation can be realized by known structures with rigid sections are replaced with appropriately selected elastic and suitable forms of contact-selection and adaptation. Another case is when synthesis of new structures, moving elastic links as the result of elastic deformations. When the tool includes 3 elastic links the required driving force before the realization of contact with the object is:

$$F_d = 3R_n(\sin\alpha + \cos\alpha) \quad (1)$$

Where α is an angle of the elastic link; R_n is normal component of the reaction.

If we accept a rectangular cross-section of the elastic link, which at one end is bend the beam, the normal component of the reaction is calculated:

$$R_n = \frac{3EJ_z}{l^3}(l - l_0)\sin\alpha\,, \quad (2)$$

where E is Young's modulus (modulus of elasticity), which depends on the material of the elastic link is made. J_z is moment of inertia for the cross-section of the elastic link. .If we accept the beginning of contact with object the current value of $l = l_1$ the calculation of the normal component of the Force of gripping is associated with further movement of the link and additional deformation at the second contact point. At the beginning of contact with the object, the radial distance k_0 is calculated with**:**

$$k_0 = (l_1 + l_2)\sin\alpha + r\,. \quad (3)$$

At the end when the object is gripped reliability (in this case normal and frictional force are of the same value) the radial distance is calculated with following equation:

$$3\mu Fxv^n = F\alpha\,. \quad (4)$$

where F_α is the influence of the force upon the object (gravitational and inertial force $F_\alpha \neq m(g+a)$ the worst case is when the forces lie along the axes of the tool opposite to the driving force).

The gripping force Fxv^n is obtained from elastic deformation of the link; therefore the radial distance k is calculated:

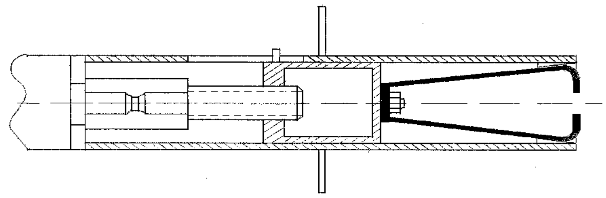

Fig. 11. Tool with 3 elastic links.

$$k = k_0 + \frac{m(g+a)l_2^3}{9\mu EJ_z}\,. \quad (5)$$

The ratio between the lengths l_1 and l_2 is changed, but in this case to a negligible value and we accept $l_1 = l_2$.

Driving force for 3 executive links equally deformed is calculated from:

$$F_d = 3\begin{bmatrix} R_n(\sin\alpha + \mu\cos\alpha) \\ + F_{hvn}(\sin(\alpha+\Delta\alpha) + \mu\cos(\alpha+\Delta\alpha)) \end{bmatrix}, \quad (6)$$

where for angle α is calculated:

$$\Delta\alpha = \arctan\left[\tfrac{K-K_0}{l_0}\right]. \quad (7)$$

If the driving force is produced by a screw mechanism converting rotational movement into linear, motor point of the screw is calculated from:

$$M_v = F_d \frac{d_{sr}}{2}\tan\gamma\,, \quad (8)$$

where γ is angle of inclination of a treading.

Engine torque at the presence of a reduction ratio of i_p is:

$$M_d = \frac{M_v}{i_p}\,. \quad (9)$$

Angular velocity of the engine is chosen according to the required speed of the gripping, according to available (produced) engines.

To provide a reliable holding of the object the edges of the tool are made round (Fig. 11). When it is possibly slip it has to be formed new contact points and force that restricts movement and promotes grip. If the object is not covered, it is appropriate to develop forms of contact parts in desired patterns hold for a group of objects.

In laparoscopic surgery are mostly known instruments with 2 rigid links. Figures 12 and 13 show a synthesis of an end –effector with 3 rigid links as a part of family tactile tools for laparoscopic surgery.

4. FUTURE WORK

Further developments should provide elaborated solutions to soft-tissue modeling and interaction with high application accuracy and human-machine interfaces. A computer program should include information about various models of tissue. The information obtained from sensors in the handle can be used to find the appropriate

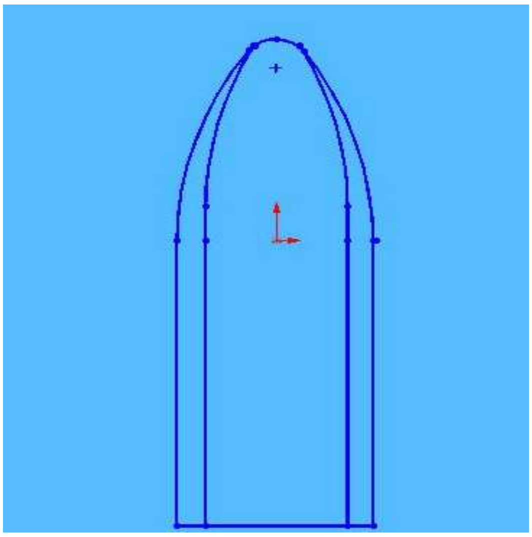

Fig. 12. End effector with 3 rigid links**.**

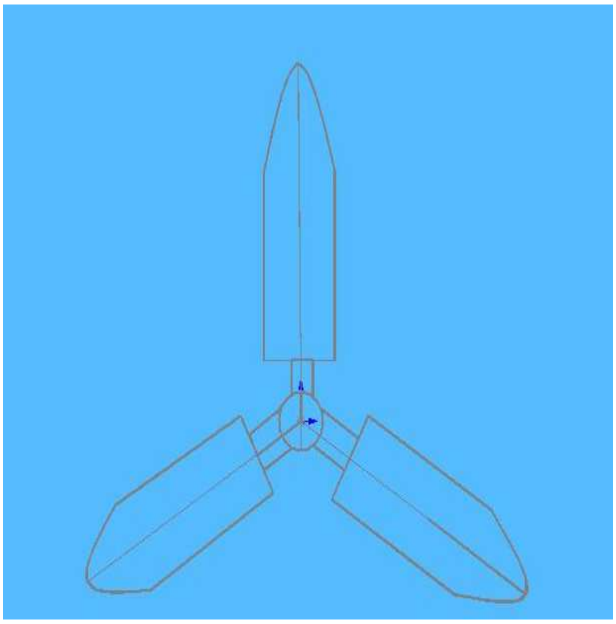

Fig. 13. Gripping with 3 rigid links.

tissue model and submitting the necessary command to force interaction between instrument and tissue. Some experiments with the modular synthesized elastic and rigid links (family tools for robot-assisted surgery) can be realized by the new method for sensitive control. The investigation can be made with materials of similar properties of human tissues and to compare results.

5. CONCLUSIONS

It is very important for surgeons to be able to touch and feel the tissue/organs/ stones while operating since the sense of touch is one of the primary sources of information that guides the surgeon during surgery. Current research is mainly focused on a problem in laparoscopic surgery. This problem was solved in an original way. Both direct and indirect control algorithms showed their effectiveness but and disadvantage. To avoid disadvantage of direct force measurement (expensive, non sterilizable and not modular method) a mechanical construction was produced where two force sensors by Honeywell Company were situated. The force sensor is inserted into the handle of the laparoscopic instrument as intermediate link between the linear actuator and interchangeable jaws. Syntheses of elastic and rigid links were done. The presented family tactile tools are an attempt to offer a solution that satisfies in some extent the complex requirements towards the robot-assisted microsurgery for tactile and force information. The main target of these instruments is to provide adequate tool-tissue force information to the surgeon so that he can regain the sense of touch that has been lost through laparoscopy. There are many areas in surgery where innovative techniques such as robotics, and methods where can make a difference for the better.

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