Proceedings in MANUFACTURING SYSTEMS
Proceedings in Manufacturing Systems, Volume 8, Issue 2, 2013 ISSN 2067-9238

FAMILY TOOLS FOR ROBOT-ASSISTED SURGERY

Veronika IVANOVA[1,*], Krassimira KOLEVA[2], Radko MIHAILOV[3], Iossif BENIOZEF[4]

1) PhD, Department of Robotized executive mechanisms and Intelligent Systems, Institute of Systems Engineering and Robotics
Bulgarian Academy of Sciences, Sofia, Bulgaria
2) Assistant, Department of Technical Mechanics, Technical University of Varna, Varna, Bulgaria
3) Assoc. Professor, College of Technology to The Technical University o fVarna, Dobrich, Bulgaria
4) Engineer, Department of Robotized executive mechanisms and Intelligent Systems Institute of Systems Engineering and Robotics
Bulgarian Academy of Sciences, Sofia, Bulgaria

Abstract: *Medical technology trends to the design and development of novel type of executive tools and accessories, allowing improving the performance of medical staff and increasing quality of care for patients. Amongst them, laparoscopic surgery is very popular medical intervention for diagnoses and treatment some abdominal problems and diseases. However***,** *the lack of tactile sense is the cardinal disadvantage associated with laparoscopy, because it limits the surgeon abilities. In this context the main objective of the work is to investigation of current laparoscopic instruments and robot assisted systems, and design novel type family tools for robot-assisted surgery with better technical characteristics, and incorporation of force sensors in construction of instruments for restore sense of touch and recognizing the presence of contact at end –effectors with organs tissues and stones during surgical procedures. Thus it is improving some technical side of these laparoscopic instruments. Also this paper shows common examples for tool-object force interaction at different type end -effectors. To avoid cardinal disadvantage on existing direct sensing control methods for tissue characterization, different approaches* is *proposed. For this purpose an original instrument with two force sensors by Honeywell Company, position sensor and linear driving mechanism implemented there was designed and produced. This laparoscopic tool is main component in haptics control system for tissues characterization. During the designing process of family tools for robot-assisted surgery following main problems have to be overtaken: i) presence of tactile force feedback, ii) ability to force control and its regulation in requested range.*

Key words: *robotics, mechatronics, robot-assisted surgery, laparoscopic instruments, tactile sense, haptic device*

1. INTRODUCTION AND OVERVIEW OF ROBOTIC TECHNOLOGIES IN LAPAROSCOPY

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. This problem results from construction of the instrument and specifics of the surgery. Unless in bloodless surgery, the tools are handled and maneuvered in such way that the surgeon must adapt to the specifics of the instruments. Guiding such an instrument is difficult, requiring a lot of practice and skills. Typically for every instrument which is applied for laparoscopic surgery it is a long shaft with rigid end-effectors and similar construction. Conventional laparoscopic instruments lack actuation and modularity, previously developed novel instruments are large and three-directional force measurement. They have a limited dexterity; only four degrees of freedom because of the troacar limited number of free movements, and arbitrary orientation of instrument being not possible. Reduction in motion reversal as result from fulcrum at entry point. This means that the necessary point-organ in the abdominal cavity can be achieved only with a fixed orientation of the tool. Friction at air tight trocar decreases the sensitive.

The introduction of robots in minimally invasive surgery such as *daVinchi* [1] and *Zeus* [2] considerably enhances the accuracy of medical interventions. Intelligent robot control can filter hand tremor increasing accuracy by motion scaling. But investigations of current robot instruments [3] are indicated to have some technological deficiencies, the main of which being the lack of tactile sense. The sterilization is also difficult for the variety of uses. The strings are easily wearable and require constant replacement. The *daVinchi* instruments cannot be preprogrammed. Robot-instruments must be technical improvements**.** Another important problem of the *daVinchi* instruments is that they are too expensive.

Surgical robots can be conditionally divided into robots for assistant (for navigation of laparoscopic camera),

---

[*] Corresponding author: Akad Geoegi Bonchev Str. Bl. 2, 1113 Sofia, Bulgaria;
Tel.: +359 887 920 816;
Fax: +359 2 2 870 33 61
E-mail addresses: *iwanowa.wl@abv.bg* (V. Ivanova), *krassimirakoleva@abv.bg(* K.Koleva); *dtc_dobrich@tu-varna.bg* (R.Mihajlov); *josefben@abv.bg* (I. Beniozef)

robots for main procedures (for cutting, grasping and moving of tissues, organs) and both of them.

In laparoscopic surgery assistant handles the laparoscope depending commands received from surgeon. This method is inefficient because sometimes the assistant interprets wrongly the commands. Introduction of robots in surgical rooms has solved these problems. Clinical tests over robot navigator systems show many advantages over conventional navigation of the laparoscopic camera.

The lack of tactile sense in surgeon arm still does not solve problem in conventional surgery and in robot-assisted surgery. The best solution, but technically the most challenging, is that in which the surgeons are able to touch and feel the tissue/organs/ stones while operating-sensing device must be integrated with robot systems. The robotic systems have to be integrated with haptics control device to improve some technical sides of the laparoscopic surgery and radical improvements to the quality and efficiency of our healthcare.

Many works [4 and 5] have focused on the development of robotic surgical systems and instruments with force sensing/reflection capabilities. Robotics application of new surgical instruments (e.g., laser systems, micro-tools, radiation devices) are proposed, which cannot be applied in conventional laparoscopic surgery, in order to demonstrate their benefits in surgical treatment.

The problem associated with tactile sense still does not solve therefore the lack of suitable instruments capable of measuring the manipulation forces inside the abdomen of the patient and the lack of interfaces for conveying this force in a comprehensible way to the fingers of the surgeon. For better results in minimally invasive surgery, it is necessary to overcome this disadvantage. Robot-assisted laparoscopic systems with tactile force capabilities will enhance the realism in these systems, and the tactile sense and 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 is an interaction between tool tip and patients' organs. Haptic systems ensure the surgeon's hand and eye to work together. Haptic devices integrate the capabilities computer systems and the surgeon's abilities.

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 [6]. Thre are algorithms involving directly position and applied force (hybrid position/force control; hybrid impedance control) and methods involving directly applied force feedback(explicit force control). In medicine and especially in laparoscopy these methods are expensive, non-sterilizable, and not modular, making them difficult to incorporate into laparoscopic tools. Indirect force sensing technique includes force control via motion, without explicit closure of force feedback). Other methods are based on the relation between position and applied force (stiffness control by position only; stiffness control by force feedback correction; damping control). Also we can find methods applying the relation between velocities and force (impedance control and admittance control). Both direct and indirect control approaches showed their effectiveness but also some disadvantages.

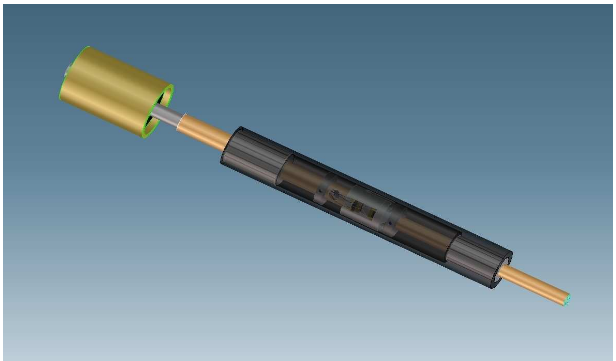


Fig 1. Designed tool for robot-assisted surgery.

To avoid cardinal disadvantage in direct sensing methods in reference to the price, modularity, sterility and to respond to the medical requirements that techniques do not upset function of the patient, electronics must be outside of the abdomen. For that reasons, it was designed and produced an original tool for robot-assisted surgery which is shown on Fig. 1. Two force sensors, position sensor and driving mechanism are implemented. It was designed elastic and rigid end-effectors for different procedures.

In contrast to the direct sensing methods where the sensors are incorporated into jaws of the tools [7], [8], this construction with sensors is inserted into the handle of the laparoscopic instrument. In this way novel decision is better than other as allow low price, interchangeable jaws, sterility and to respond medical requirements (electronics is outside of human body which is very important condition for medical technologies). Thereby it is possible to receive the information about the applied force with an innovative sensing method. This innovative method is intermediated between the direct and indirect sensing methods for tissues characterization as overcome their disadvantages, since in laparoscopic surgery it is very important for surgeons to be able to touch and feel the tissue/organs/ vessels stones while operating as since the sense of touch are one of the primary sources of information that guides the surgeon during surgery.

The results of this study may be useful both for the surgeon and patient thus improving some technical side of the laparoscopic instruments: higher patient safety by improving medical interventions and preventing errors during the laparoscopic procedures.

The remainder of the paper is organized as follows: Section 2 is focused on tool-object force interactions. Section 3 shows presence of tactile force feedback and ability to force control at family tools for robot assisted surgery. Section 4 includes example and result in MatLab surface. Section 5 offers possibility for future work.

2. TOOL-OBJECT FORCE INTERACTIONS AT DESIGNED END-EFFECTORS

Some areas of our life such as medicine require specialized instruments to handle and manipulation of solid and elastic small objects. Irregular object handling is differently than those with regular shapes. One reason is

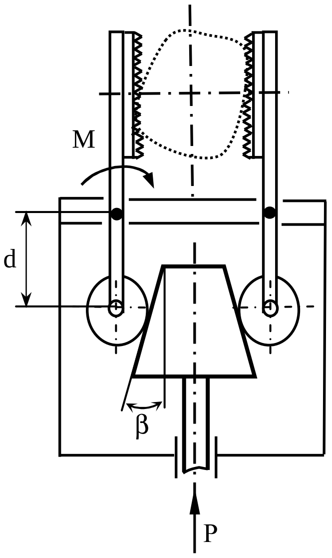


Fig. 2. Scheme of gripper which is driven by wedge mechanism.

higher link adaptation to the irregular object shape. In this case, the work area has also special requirements for these instruments. At previous work [9], some type end-effectors for irregularly shaped object manipulations such as gallbladder stones was synthesized. Precise control of tool-object interactions is the major component of surgical procedures. An inability to regulation of force interactions is associated with slipping in the case when the gripping force is lower and damage of the tissues, organs, blood vessels when the force interactions are higher. Nonlinearities in the kinematics of the linkages complicate computing the grasping force.

In laparoscopic surgery known instruments with two rigid links are mostly. It was designed laparoscopic tool with rigid links in the case when the force results from pneumatic cylinder. On Fig. 2 scheme of gripper which is droved by wedge mechanism is shown.

Then the force P is computing by equation:

$$P \cdot \eta = \frac{1}{b} \cdot \sum_{j=1}^{n} M_j \cdot \tan(\beta + \rho), \qquad (1)$$

where ρ is the angle account for the strength of the axes of linkages, n − number of jaws, b − distance from the centre to the axis of jaws, β − angle of the wedge.

For grippers with symmetrical situated jaws where $M_1 = M_2 = M$ the driving force is obtained by:

$$P \cdot \eta = \frac{1}{b} \cdot 2 \cdot M \cdot tg(\beta + \rho), \qquad (2)$$

when the jaws are droved by two symmetrical pneumatic cylinders, the force is obtained by :

$$P \cdot \eta = \frac{1}{b} \cdot M \cdot tg(\beta + \rho). \qquad (3)$$

According to the rule, the thickness is selected in reference to the constructional recommendations. For gripper with elastic cover-plates and elastic objects such as soft tissues, the point of contact is realized with surface which size is corresponding to the size of the manipulated objects.

On Figs. 3 and 4 designed rigid links for laparoscopic tools with elastic covered are shown.

Normal open position of this construction is given on Fig. 5.

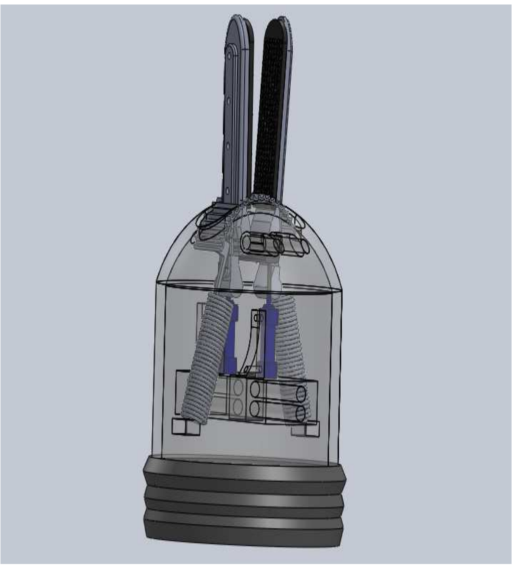


Fig. 3. Rigid links for family tools.

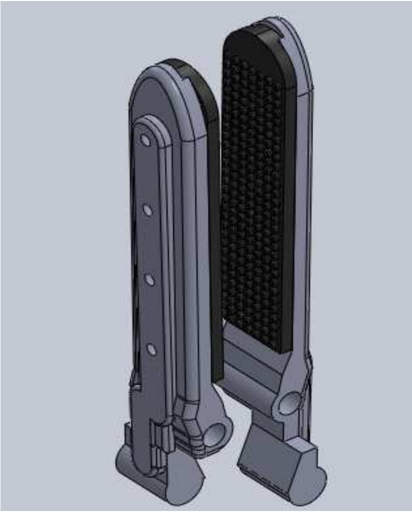


Fig. 4. Rigid links Pincers type.

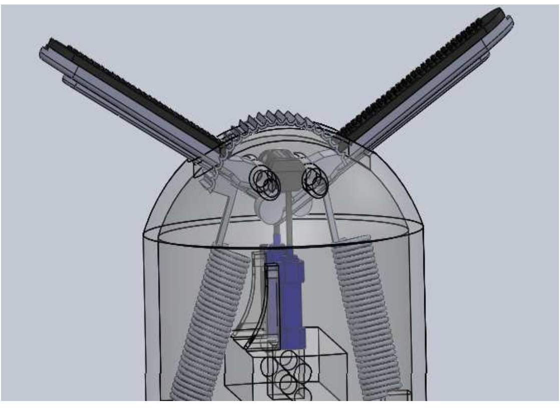


Fig. 5. Gripping with designed rigid links.

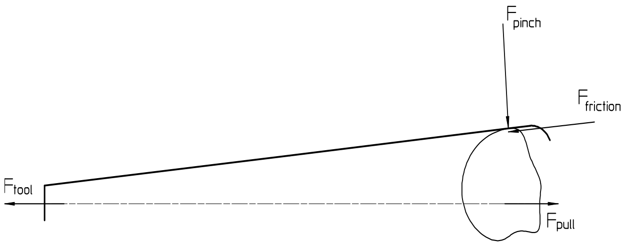


Fig. 6. Shematic representation of the synthesized end-effectors.

In this occasion end-effectors can be designed with a smooth surface or shaped profile. Alignment of forces-contact over surface allows keeping manipulated objects on the same conditions of gripping.

Fig. 6 shows schematic representation of the synthesed elastic end-effectors with normal open structure and force interactions.

Tool-object force interactions are realized with pinching force, puling force, friction force and force of the tool. Pinching force is equal on both sides of the end-effectors as result of symmetry. It was assumed that friction force is high enough and no slippage of the manipulated object during tool-object interaction occurs.

In an initial position there are no forces:

$$\sum F = 0\,. \tag{4}$$

If only pinching force is applied:

$$F_{pinch} = \frac{1}{2}\lambda F_t\,, \tag{5}$$

where λ is the force transmission coefficient and Ft is force of the tool.

When forces of pinching and pulling are applied together, the pulling force is equal to Force of tool and then we calculate Force of pinching from equation:

$$F_{pinch} = \frac{1}{2}\lambda(F_{pull} - F_t)\,. \tag{6}$$

3. PRESENCE OF TACTILE FORCE FEEDBACK AND ABILITY TO CONTROL FORCE IN LAPAROSCOPIC TOOLS

Previous works [10−12] presents our efforts for haptics system in laparoscopic surgery, which purpose were avoiding cardinal disadvantages in direct sensing methods in reference to price, sterility and modularity and to respond to the requirements of the medicine to techniques to not upset functions of the organism the electronics has to be outside. At the proposed scheme of force feedback control in laparoscopic surgery [13] main components are haptics control device which is in contact with the surgeon and laparoscopic instrument which interacts with the patient

When surgeon moves the handle of haptics control device, his movements are translated in digital signals and one controller performs signal processing. The Controller determines control signals to other controller and respectively to the laparoscopic instrument for implementation of the necessary commands.

For measuring purpose, two force sensors are implemented opposite each other into the handle of tool, in contrast to the direct force measurement method, where the force sensors are incorporated into the jaws of the tools. The instrument can be dividing on a handle, shaft and modular jaws for grasping and manipulation of irregular objects in the process of laparoscopic surgery. The basic component of this instrument is the handle where a position sensor, linear motor and force sensors are incorporated,. We applied force sensors FSS 1500NSB by Honeywell Company [14] whose technical parameters are given by Honeywell Company and shown on Table 1.

The force applied by the surgeon depends on the force of interaction tool-tissue (7).The difference between the force applied by the surgeon and force feedback received from the laparoscopic tool during the jaws –tissue interaction is giving the required value adjustment of force (8).

$$F_{real} = f\left(F_{output}\right), \tag{7}$$

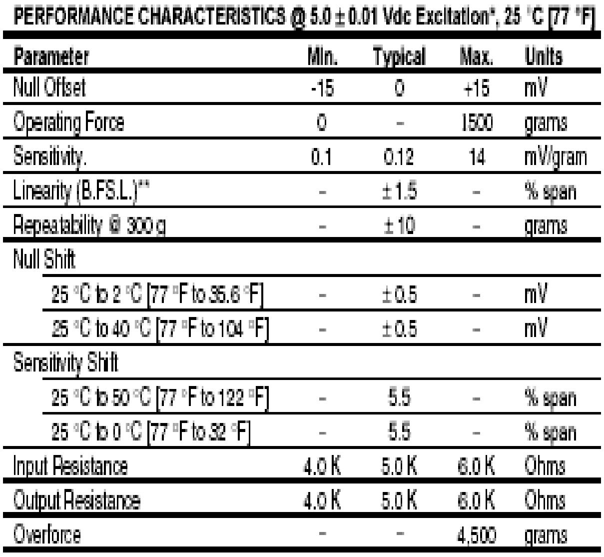
$$F_{input} - F_{feedback} = \Delta F_{input}\,. \tag{8}$$

It was designed and produced a control module for sensitive control of laparoscopic tool. The control module includes channels for other controllers which can be implemented as a part of major system. The electronic control module reads and convent input and output force into digital date and transfer this date to other control digital device.

In this electronic module two channels for low profile force sensors are implemented. Analogue-digital converter converts the measuring force in necessary range. Digital converter is used to digitalize measured analogue output signal from the sensor in real time. Direct control of the applied force on the sensors is observed over local display. Different channels are applied to transfer of

Table 1

Technical parameters of FSS1500NSB by Honeywell Company



PERFORMANCE CHARACTERISTICS @ 5.0 ± 0.01 Vdc Excitation*, 25 °C [77 °F]

Parameter	Min.	Typical	Max.	Units
Null Offset	-15	0	+15	mV
Operating Force	0	-	1500	grams
Sensitivity.	0.1	0.12	14	mV/gram
Linearity (B.FS.L.)**	-	±1.5	-	% span
Repeatability @ 300 g	-	±10	-	grams
Null Shift				
25 °C to 2 °C [77 °F to 35.6 °F]	-	±0.5	-	mV
25 °C to 40 °C [77 °F to 104 °F]	-	±0.5	-	mV
Sensitivity Shift				
25 °C to 50 °C [77 °F to 122 °F]	-	5.5	-	% span
25 °C to 0 °C [77 °F to 32 °F]	-	5.5	-	% span
Input Resistance	4.0 K	5.0 K	6.0 K	Ohms
Output Resistance	4.0 K	5.0 K	6.0 K	Ohms
Overforce	-	-	4,500	grams

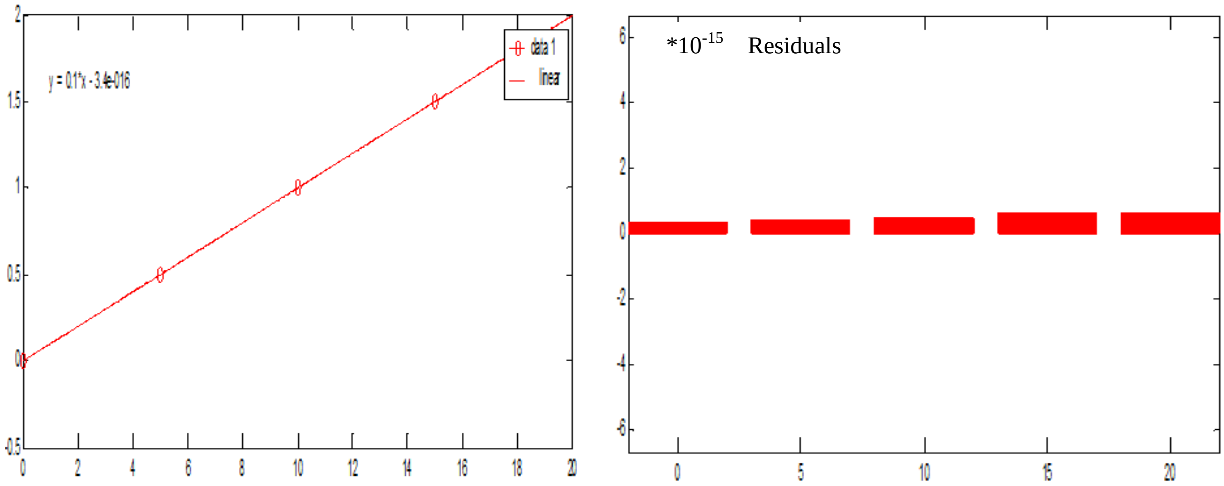


Fig. 7. Illustration of the application of testing model with PI-control for the laparoscopic tool.

measuring results to the control system of the haptics control system. The force sensors are supplied by a current generator.

The instrument works as smart transmitter when directly transfers measured data to the next control system. In this case, the calculation of the PI control is done in the control system of the laparoscopic robot works. Also it is possible the calculation mode. For that reason, the PI control is built in the program inside the control module. In this case, the control module generates a direct task for implementation. The module recognizes the direction of applied force and displays it on the front indication panel with its absolute value.

4. EXAMPLE AND RESULT FOR SENSITIVE FORCE CONTROL FOR FAMILY TOOLS FOR ROBOT-ASSISTED SURGERY

Many optimal control problems can be conversed in to conventional optimization problems by the powerful tools provided in MATLAB interface. The results of the calculation are displayed in MATLAB diagram. Two parameters are displayed in diagrams after processing input and output forces. To verify the simulation software simple simulation examples were calculated delivering plausible results.

The following example, which is shown on Fig. 7, is designed to illustrate the application of testing model of PI-control for the laparoscopic tool with axial bedirectional force sensor and linear driving mechanism when no noise. Linear method is applied here. In that (ideal) case output data has to equal to input data (output force has to equal to input force.

Linear regression model: $y = 0.1x - 3.4\text{e} - 0.16$

Residuals – 0

5. CONCLUSIONS AND FUTURE WORKS

Medical technology trends to the design and development of new type instruments to trauma reduction of patients and thus better healthcare. In this contest the study focuses on the design and development of family tools for robot-assisted surgery with better technical characteristics, and incorporation of force sensors in construction of instruments. Both direct and indirect control algorithms showed their effectiveness and also disadvantages. The problem associated with direct sensing methods is solved by an original way. To avoid disadvantage in reference to expensive, sterilizable and modularity novel instruments were designed and produced and force sensors by Honeywell Company, driving mechanism and position sensor were used. During designing process of the instruments, the following problems were solved: *i*) presence of tactile force feedback, and *ii*) ability for force control and its regulation in necessary range. 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.

Further tasks of this work are *i*) wider field of application and *ii*) increased sensitivity and accuracy of the family tools for robot-assisted surgery.

Theoretically further investigation should be focused on detailed computing of deformations and contact forces over the organs, tissues, blood vessels by Finite Elements Method. The work should include also implementation of the calculations in real-time control. Further developments may 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 tissues. The information obtained from sensors in the handle can be used to find the appropriate tissue model and submitt the necessary command to force interaction between instrument and tissue.

AKNOLIGMENTS: This work is supported by the project BG051PO001-3.3.005-0001 Science and Business, project co-funded by the European Social Fund trough the Operation Program Human Resources, D02-166/14.02.2013, P-6-02/13

REFERENCES

[1] IntuitiveSurgical.Inc `http://www.intuitivesurgical.com/`.
[2] Computermotion `http://www.computermotion.com/`.

[3] `http://www.intuitivesurgical.com/products/endowrist_instruments/Intuitive_Surgical_ins_cat.pdf`

[4] A.M Okamura, M.R. Cutcosky, *Featute Detection for haptic exploration with robotic fingers*, International Journal of Roboticss Research, vol. 20, no.12, 2001, pp. 925−938.

[5] T. Haidegger Balázs Benyó, Levente Kovács, Zoltán Benyó**,** *Force Sensing and Force Control for Surgical Robots***,** Proceedings of the 7th IFAC Symposium on Modelling and Control in Biomedical Systems, Aalborg, Denmark, August 12−14, 2009, pp. 413−418.

[6] G. Tholey, A. Pillarisetti, W. Green, J.P. Desai, *Laparoscopic Grasper*, Program for Robotics, Intelligent Sensing, and Mechatronics (PRISM) Laboratory, MEM Department, Drexel University, Philadelphia Proceedings of EuroHaptics 2004, Munich Germany, June 5−7, 2004, pp. 478−481.

[7] A.L, Trejos, R.V. Patel, M.D. Naish, *Force sensing and its application in minimally invasive surgery and therapy:* a survey, Proceedings of the Institution of Mechanical Engineers, Journal of Mechanical Engineering Science 224 (2010), pp. 1435–1454.

[8] J. Peirs, J. Clijnen, D. Reynaerts, H. Brussel, P. Herijgers, B. Corteville, S. Boone, *A micro optical force sensor for force feedback during minimally invasive robotic surgery***,** Elsevier, Sensors and Actuators A. 2004; 115: doi: 10.1016/j.sna.2004.04.057, pp. 447–455.

[9] V. Pavlov, V. Ivanova, *Handling of irregular shape objects by elastic links*, PRACTRO 2009–Sozopol, Bulgaria, 30 May−2 June.

[10] V. Ivanova, *Sensitivity of Mechatronics Laparoscopic Device*, Journal Mechanics of Machines (2007), Technical University Publishing House –Varna, Vol. XVI, No. 3, pp. 287−292.

[11] V. Ivanova *Laparoscopic device for restore sense of touch***,** Journal Mechanics of Machines, Technical University Publishing Hose (2012), Vol. 99, No. 4, pp. 46−50.

[12] V. Ivanova**,** K. Koleva, R. Mihailov, I. Beniozef, *Family tools for robot – assisted laparoscopy*, Proceedings in Manufacturing Systems, Romanian Academy Publishing House, Vol. 7 Issue 4, (2012), pp. 205−210.

[13] V. Ivanova, *Tools for haptics system in laparoscopic surgery*, Journal of Technical University Publication House-Sofia (2011), pp. 396-401.

[14] `http://www.honeywell.com/`

[15] P. R Ouyang, R.C Tjiptoprodjo., W. J Zhan., G. S Yang., *Micro-motion devices technology: The state of arts review*, Springer-Verlag London Limited 2007, DOI 10.1007/s00170-007-1109-6.

[16] O. Millet, P. Bernardoni., S. Regnier, Ph. Bidaud, D. Collard, L. Buchaillot**.,** *Micro gripper driven by scratch drived actuators coupled to an amplification mechanism*in, Transducers03, IEEE, ed., (Boston), 200,3 pp. 344−347.

[17] P. Bernardoni., Ph. Bidaud., C. Bidard, F. Gosselin, *A new compliant mechanisms design methodology based on flexible building blocks*, Smart Structure 2004, SPIE, ed., Modeling, Signal Processing, and Control, (San Diego), 2004.