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An Experimental Module with Force Feedback Capabilities for Robot System

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Abstract: Laparoscopic surgery is very popular medical intervention for diagnoses and treatment of same abdominal diseases. The task of the surgeon is to gripping, moving, and cutting of tissues, organs and execute diagnosis. The main problem which is associated with this surgical procedure is the lack of tactile sense – it is due to the specifics of the operation and construction of the instrument. It is very important for surgeons to be able to touch and feel the tissue/organs/ while operating because of the sense is the primary source of information that guides the surgeon during surgery. Despite problems, the applying of laparoscopy is increasing and this leads to development of innovative techniques, tools and methods for the elimination of disadvantage. This work is one effort for improving some technical side of laparoscopic surgery as designing an experimental module with force feedback capabilities. In contrast to other robot-assisted systems which included instruments for manipulations and observations, this study presents a designed model for surgical robots that includes different applications. Two main problems are decided related to designing and produced an original construction of an experimental module with force feedback capabilities for robot systems and it is realized hardware and program resources for control and monitoring of this module. A significant advantage of the proposed program solution is the graphical visualization of measuring and comparing the results.

Keywords: *Robot system; surgical robotics, surgery, laparoscopic instrument, control system*

1. Introduction

Laparoscopic surgery is very popular medical intervention for diagnoses and treatment of same abdominal diseases (Fig. 1).

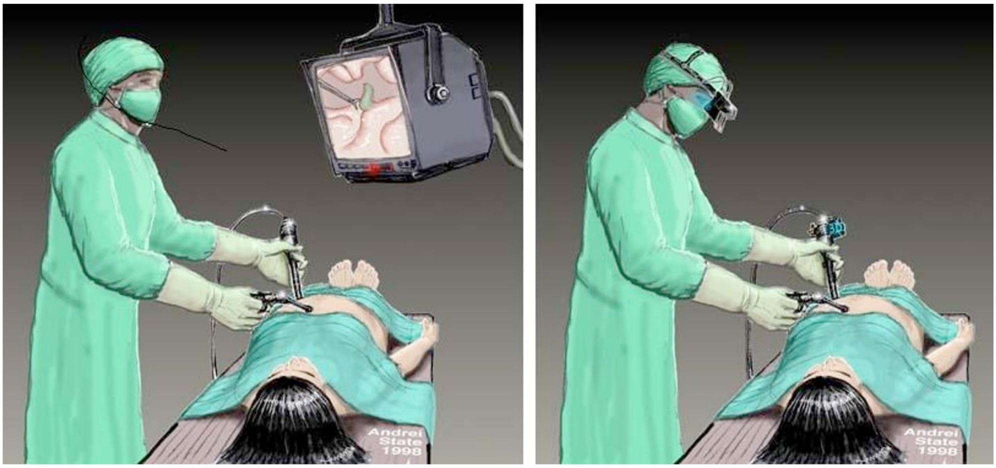

Fig. 1. Laparoscopic intervention

The task of the surgeon is to gripping, moving, and cutting of tissues, organs and makes diagnosis. The main problem which is associated with this surgical procedure is the lack of tactile sense – it is due to the specifics of the operation and construction of the instrument. It is very important for surgeons to be able to touch and feel the tissue/organs/ while operating because of the sense is the primary source of information that guides the surgeon during surgery. Despite problems, the applying of laparoscopy is increasing and this leads to development of innovative techniques, tools and methods for the elimination of disadvantage. This work is one effort of improving some technical side of laparoscopy surgery.

The interventions are performed using long thin tools that are inserted through a trocar in the human body (Fig. 2).

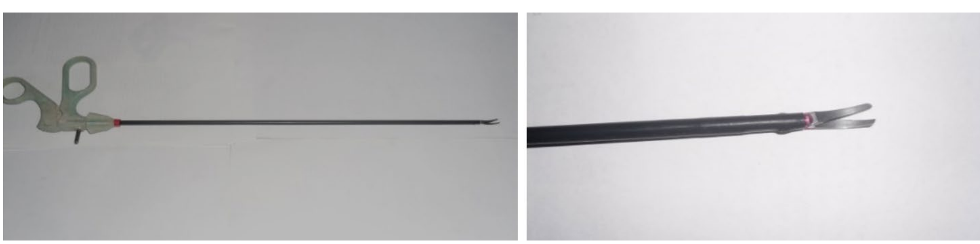

Fig. 2. Laparoscopic instrument

The surgeon orients the instruments by laparoscopic images displayed on a monitor. Environment is unstructured (highly dynamic). Applied forces are in a wide range in depends on the age of patient, previous disease etc. The space is narrow (limited). Unless in bloodless surgery the tools are handled and manoeuvre in such way that the surgeon must adapt to the specifics of the instruments. Guiding such an instrument is difficult, requires a lot of practice and skills. Typically for everyone instrument which is applied for laparoscopic surgery is a long shaft with rigid end-effectors and similar construction.

Conventional laparoscopic instruments lack own actuation and modularity, previously developed novel instruments are large and no tri-directional force measurement. They have a limited dexterity – only 4 DOFs because of the trocar who limits the number of free movements, and arbitrary orientation of instrument tip 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 lack own actuation and modularity, limited dexterity, and tri-directional force measurement are typically problems here. Possible movements of the surgical tool in the abdominal cavity are shown in the Fig. 3.

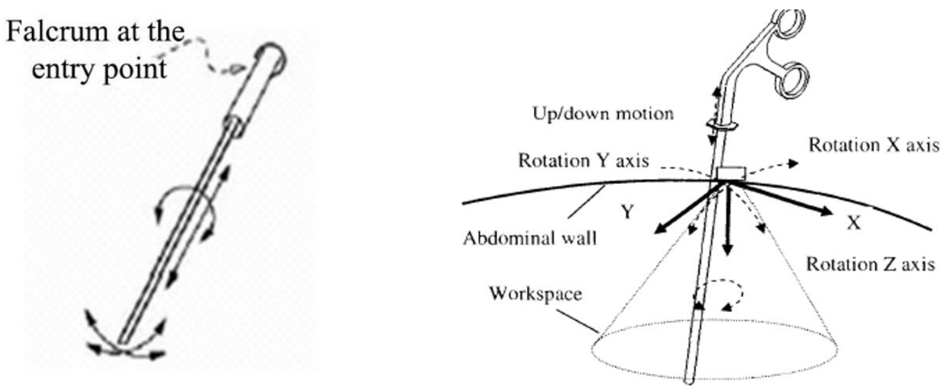

Fig. 3. Movements of the surgical tool in the abdominal cavity

The introduction of robots in surgical area will considerably enhance the surgical skills. Various laparoscopic interventions that could not be performed by standard operations can be performed with robot-assisted systems. Intelligent control can filter hand tremor and increase accuracy by motion scaling. Robotic instruments possess more degrees of freedom yielding higher dexterity. The surgeon will be able to perform surgical procedures more efficiently, accurately and with fewer fatigues. Robotics application of new surgical instruments (e.g., laser systems, microtools, radiation devices) are proposed which cannot be applyed in conventional laparoscopic surgery, in order to demonstrate their benefits in surgical treatment.

How robotics can help surgery? Some problems which Robotics solves in surgery:

- Precision of the tool position and orientation into pre- and intra-operative imagine;
- Following of complex, accurate directions;
- Elimination of the problem hand –eye coordination;
- Elimination of risk;

- Ergonomic position for the surgeon;
- Elimination the need for a third hand during the surgical procedure;

Intelligent robot control can filter hand tremor and increase accuracy by motion scaling.

The main results achieved according to the literature [1-6] can be summarized as follows:

1. There are currently a large variety of robotic laparoscopic surgical instruments available at this stage. They are designed to perform a targeted functional task, and in addition to the main action (gripping, cutting, etc.), three local orienting movements are provided. So most often the total number of controlled movements is four-exist and more.

2. There are tools that have motion dependencies that need to be considered in programming.

3. The end effectors have different sizes determined by the sizes of the manipulated objects.

4. Solid-rigid links are used which are generally suitable, but there are cases where 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 and supported technics will also follow these trends [7]. 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.

Future directions of surgical robots to be smaller, less expensive, easier to operate, and should seamlessly integrate emerging technologies from a number of different fields. The best solution, but technically the most challenging to be make in that way the surgeons to be able to touch and feel the tissue/organs/ stones while operating-sensing device must be integrating with robot systems. Every one of this benefits will enable continued progress in surgical instrumentation and, ultimately, surgical care and patient outcome.

From all mentioned above in this work it is offered an experimental module for robot systems which poses complex functions (diagnosis, therapy, manipulation and observation) and has application in laparoscopic surgery. A construction design of an electronic interface board and program resources of the experimental module with force capabilities is realized also. In contrast to daVinchi robots by Intuitive Surgical Incorporation-USA [8] and Zeus by Computer Motion [9] which instruments are designed for manipulation and imaging we offer family intelligent tools for robots with application in laparoscopic surgery which included four types of instruments – for diagnosis [10-11], manipulation [12], therapy and observation. By developing novel specialized instruments, it has to be created more compact, simple, cheaper and easier robotic instruments than ever. It has to be developed novel smart instruments for robotic surgical systems and capability of irregular shape objects manipulation such as stones, organs, tissues etc.

Each instrument is divided into three sections:

- Control block (electronic interface board);
- Handle of the tools where is incorporated a block with embedded force sensors, a linear stepper motor and a position sensor.

Different designed end effectors which are fixed to the end of the tools.

The basic structure of the advanced robot system for diagnosis and therapy in laparoscopy is shown in Fig. 4.

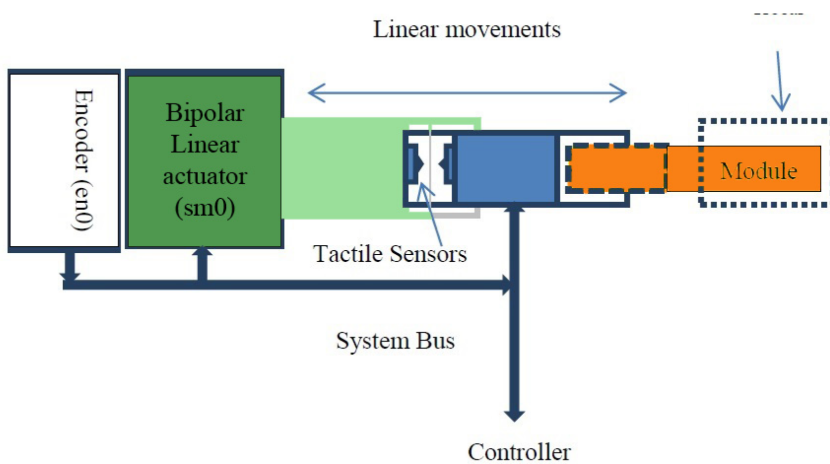

Fig. 4. A basic structure of the advanced robot system for diagnosis and therapy for laparoscopic surgery

The design of each instrument for the robot system consists of a force feedback sensor, a position sensor, a linear motor, and signals processing system. In handle of the mechatronics device a linear actuator works in combination with sensors providing positional feedback. Therefore, an absolute encoder, is implemented which is coupled to the shaft of the actuator. As a result of the high measuring resolution of his output feedback signals the proper accuracy of the tip translational positioning is ensured. In construction of handle mechatronics device is also incorporated an axial bi-direction force sensor. The sensor is intended for use as intermediate link between the linear actuator and tool's jaws. This force sensor aids as the tactile sense, and the tactile information is sent to the surgeon's fingers via a tactile feedback device to provide him with a feeling of the shape, hardness, or size of tissues grasped with the instrument. The force interaction is very precise measured in the requisite operating range from 0 to 1500 g and due to sensor linear – in its convenient conversion constant voltage. Another important function of this device is to fix the moment of contact of the jaw to organs/ tissues/ blood vessels respectively, the time was extended.

In Fig. 5 an experimental module of an advanced robot system with application in laparoscopic surgery is shown.

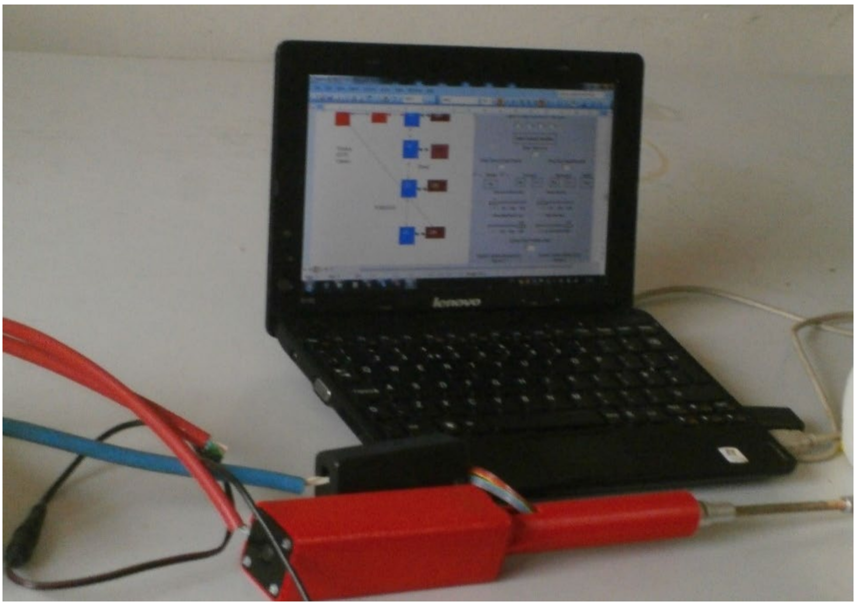

Fig. 5. An experimental module of an advanced robot system with application of laparoscopic surgery

The hardware and program resources for control and monitoring of the experimental module with force capabilities are an object of this paper. The computer program is designed to control of four laparoscopic instruments which can work together or individually, but it is only realized for one. The computer program includes information about various models of tissue. Software (program resources) consists of various commands for manipulation of the instrument (insertion and retraction of the tool, start and stop machine) with contact surfaces, and date obtained from the experimental module which is used to find the difference between previous measuring and received information in real time too. Another signification advantage of the proposed program solution is the graphical visualization of the measuring and comparing the results. Therefore, the surgeon can submit the adequate command to force interaction between the instrument and tissue.

The work is organized as follow: Section 2 includes design of intelligent instruments for an advanced robot system in application of laparoscopic surgery. Section 3 includes Hardware of a control system for an experimental module for the robot system. Section 4 describes language, program resources and ability to force control and its regulation in requested range. In section 5 are shown some experimental results. Finally, section 6 concludes the paper and points at the intentions to future work.

2. Design and construction of an experimental module for robot system.

Before designing process of the experimental module with force sensor incorporation, the required force range has to be specified. Investigation and information of the tool-tissues forces interactions during a laparoscopic intervention are insufficient; Some research works are focused on the forces which are applied from the surgeon on the tools [13-14], It is very important date during designing surgical training simulators. Information represented in [15] is very important. It includes only the data about needle-tissues force interactions. Therefore, it is accepted that the force regulation has to be in range 0-1500 grams for the experiments.

An experimental module with sensitive capabilities is designed to detect the different biomechanical characteristics of the tissues and compare the result with the previously collected information. It is measuring the force responses of mechanical micro- actions set up with different profiles of passive manipulator modules applied to the tissues.

Controlled by a built-in microcontroller for realizing translational movements at a programmed speed, the device provides positioning of the manipulator module at the test point with an accuracy of 2 microns and uses its built-in tactile sensor for measurement as well as feedback for detecting the contact area with the tint. The Controller determines control signals to the laparoscopic instrument for implementation of the necessary commands.

$$F_{real} = f(F_{output}) \tag{1}$$

$$F_{input} - F_{feedback} = \Delta F_{input} \tag{2}$$

The force applied by the surgeon depends on the force of interaction tool-tissue (1). The difference between the force applied by the surgeon and force feedback received from the laparoscopic tool during the jaws –tissue interaction giving the required value adjustment of force (2).

A complex active module

This is a complex module with built-in motors, sensors for reading and positioning control (encoders) and mechanical structures that perform tissue manipulation (laparoscopic interventions). The module includes two stepper motors (sm1, sm2) with encoders (en1, en2) to them. The motors and encoders are built into two coaxial cylindrical structures – the second inserted in the first and performing rotation in it (formed by a motor sm1, mounted stationary in the first, as. of the inner cylinder relative to the outer). A stepper motor (sm2) (with screw and nut) and an encoder (en2) are installed in the internal cylindrical structure. The nut performs only linear longitudinal movements on the screw, as its rotational movement is blocked by two stops, formed by two parallel axes, passing through holes in it and fixed at both ends to the inner cylindrical structure. Two symmetrical crank mechanisms are attached to the nut and the outer end of the cylindrical structure, each of which consists of two elbows hinged to each other, the beginning of the first being hinged to the nut and the end of the second hinged to the outer end of the cylinder. The second elbow after the point of attachment forms one jaw of the tool grip. The movement of the nut on the screw determines a change in the angle between the two jaws of the grip and forms a force moment between them.

Three degrees of freedom of grip of the tool are realized:

- Translation (of the whole module performed by the main linear actuator sm0);
- Rotation (of the inner cylindrical structure) caused by the movements of a stepper motor sm1, fixed to the outer cylinder;
- Rotation of the grip jaws around the points of attachment to the end of the inner cylinder (caused by the linear movement of the nut and the operation of the symmetrical crank mechanisms driven by the rotational movement of sm2).

A complex active module is shown in Fig. 6.

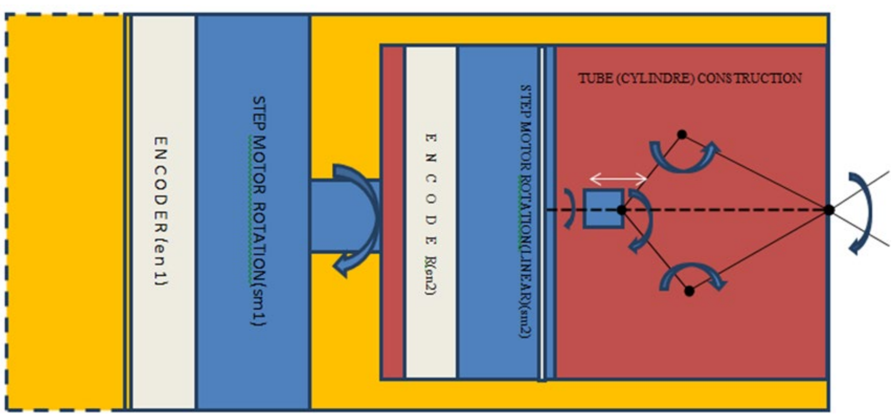

Fig. 6. A complex active module.

In cases where the last two movements are missing, the tactile sensors can read the values of the forces applied in the slider of the linear actuator sm0. This is because the motors (sm1, sm2) in this case form a holding force and do not receive step commands. As a result, the structure "hardens" and the forces applied to the grip jaws and oriented parallel to the slider of the sm0 are applied to its tactile sensors and can be measured by them.

If L_1 is the length of the first arm of the crank mechanism and L_2 of its second arm, then between the length of the distance from the joint on the nut and the joint at the end of the inner cylinder L, and the angle α between the jaws of the module grip, the dependence is in force.

$$L=L_2\cos(\alpha/2)+\sqrt{(L_1^2-L_2^2\,sin^2(\alpha/2))} \tag{3}$$

When $\alpha = 0$ then $L=L_1 + L_2$

If it is the start position of the linear motor, then in order to obtain an angle α between the jaws it is necessary to realize the displacement of the nut at a distance:

$$\Delta L=L_1+L_2 - (L_2\cos(\alpha/2)+\sqrt{(L_1^2-L_2^2\,sin^2(\alpha/2))}) \tag{4}$$

Another implementation of this module is possible by using a ball screw pair. In this case there is no need to block the rotational movement of the nut and respectively the two parallel axes. The hinged connections to the nut and to the end of the inner cylinder are common to both crank mechanisms. The dependences of the angle between the jaws and the distance L between the end points of the bearing of the mechanisms described above are preserved. This solution provides higher efficiency and positioning accuracy, but is significantly more expensive due to the more sophisticated technology for making ball screw pairs.

An instrument for diagnosis

The designed instrument for diagnosis poses a wide range of force capabilities measuring (0-1500 grams) both in insertion and retraction of the instrument for implementing different types of end-effectors. It was recognized the presence of the tools –surface force interactions and the lack of these. The instrument is designed to provide the surgeon with a feeling of the shape, hardness, or size of tissues grasped with the instrument.

An instrument for diagnosis

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Fig. 7. Cone-Shaped end-effector.

The cone axis symmetry matches the axis of the linear actuator slider. As is shown on Fig. 8, when the slider is moved in one micro- step with a length L, each point of the tissue contacting the surface of the cone moves orthogonally to the tangential plane of the cone at that point at a distance $Lsin\alpha$.

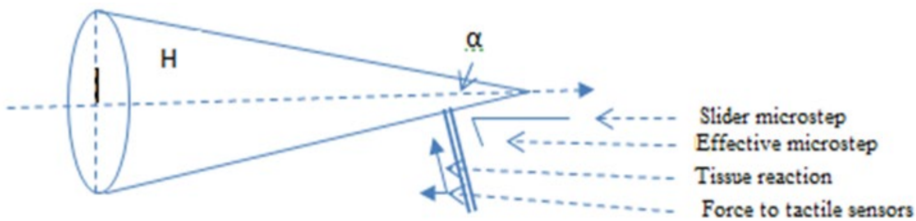


Fig. 8. Local tissue reaction of Slider micro step.

As a result of the displacement of the contact point a local reaction of the tissue forming an anti-force directed towards the orthogonal occurs. The sum of the projections of these forces along the cylinder axis forms a resultant force measured by the tactile sensor located in the body of the linear actuator slider. The Cone-Shaped end- effector is very useful for tissue structure research and diagnosis. Its main advantages are:

- Circular symmetry ensuring the inclusion in the set of contact points of all points of the cone surface located on the circle obtained from the cross-section at the position of a contact point;
- Each contact point remains in contact until the end of the movement of the linear actuator slider;
- The linear actuator slider performs a sequence of micro steps of the same length, after each of which the stepping motor "retention mode" is performed and tactile sensor measurements;
- Each micro step of the slider forces the formation of effective displacement at all contact points, having a length $L \sin\alpha$, where L is the length of the micro step and α is the angle between the cone axis and the forming it line. As α is smaller the accuracy of diagnosis increases.

An instrument for manipulation

The instruments for manipulations with force feedback capabilities and application in laparoscopic surgery are shown in Fig. 9 and Fig. 10.

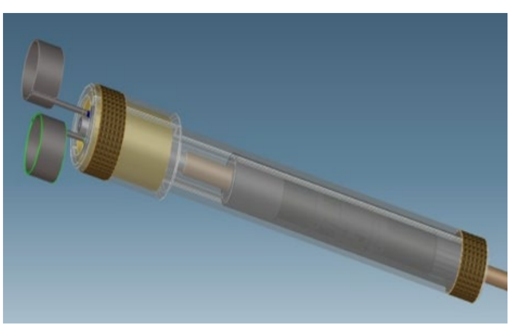


Fig. 9. An instrument for manipulation

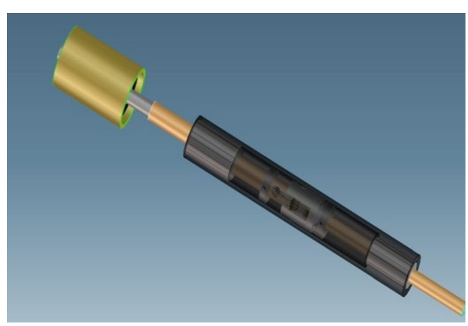
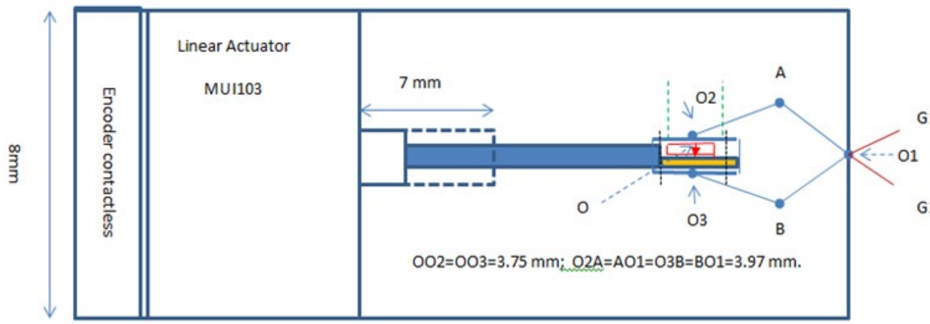


Fig. 10. An instrument for manipulation with force feedback capabilities

An instrument for a therapy (Fig. 11) is a sophisticated module that incorporates engines, sensors for positioning and control of encoders and mechanical structures that perform manipulation on tissues (laparoscopic interventions).



Linear Actuator Slider; Sensor FSS; Support; Jaws

Fig. 11. An instrument for therapy with application in laparoscopy

An instrument for observation

The tool is designed to monitor of important vital parameters during the operation, implemented as a wireless networking device designed to monitor patient status in real time. It is realized by making an ECG presented in digital form and sent wirelessly to the Controller Block of the laparoscopic instrument. This Controller analyses the received digital information by specifying parameters such as pulse, heart rate, blood pressure, body temperature, etc., measured in an area where the instrument probe is fixed.

An instrument for RF therapy

This module is designed for programmable irradiation of FEM into two ranges each with them having own accuracy (0 – 500 MHz and 20 – 8000 MHz). An instrument for RF local therapy is shown in Fig. 12.

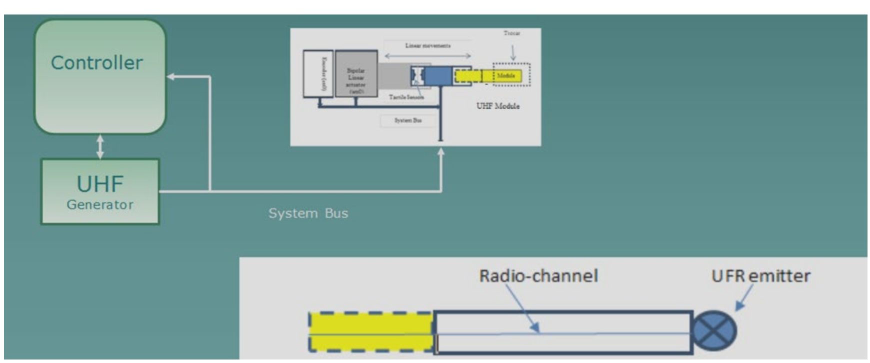
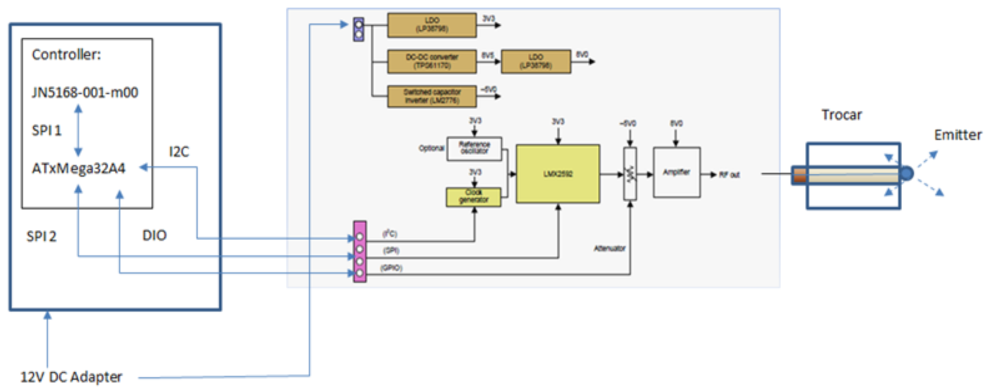


Fig. 12. An instrument for RF therapy

The irradiation is local. A programmed change in the intensity and frequency of the radio signal is a function of time. A basic idea is to transport the end of the tool where is embedded UFR emitter and therapy to be executed locally. It is possible to change of the intensity and frequency of the UHF radiation as a function of the time. The broadcast signal poses large range of intensities.



LMX2592 Wideband Frequency Synthesizer with Integrated VCO, Min f=20 MHz, Max f=9800 MHz, Texas Instrument. SPI.

AD9915 Clock generator 2.5 GSPS Direct Digital Synthesizer with 12-Bit DAC. Max f=1000 MHz, Analog Devices. I2C.

DIO Input/output signals for the devices control.

Fig. 13. An instrument for RF- therapy, including Controller, RF-generator and RF-emitting block.

The radio signal acts on the emitter, placed on the top of instrument, being in direct contact with the tissues. The signal attenuation is at 100% off outside of the sphere, with a radius of 1 mm and a centre of the tool (for UHF). The RF-generator is built on the base of programmable PLL generator LMX 2592, using programmable frequency reference source AD9915. Odd of them are being controlled by SPI and I2C from microcontroller ATxMega32A4, embedded in the main controller. The formed radio-signal is transmitted through wave-channel placed into the slider to the emitting block.

3. Hardware – Construction Design of the Electronics Interface Board of the Experimental Module with Force Capabilities

It is designed and produced an original construction of an adequate experimental module, where are incorporated two force sensors to provide tool-tissue information to the surgeon (which was described and discussed at previous work).

Fig. 14 shows the experimental module with force capabilities. The main elements of the experimental instrument are a handle and an electronics interface board (control block).

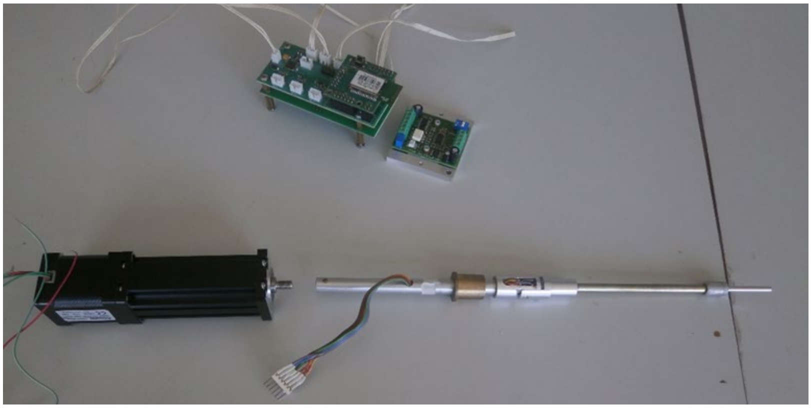


Fig. 14. An experimental module with force capabilities.

3.1. Handle of the experimental module with force capabilities for laparoscopic surgery

The instrument can be dividing on a handle, shaft and modular jaws for grasping and manipulation of irregular objects. The main element of tool is the handle where are incorporated a linear stepper motor by PrimoPal China [16], a position sensor and 2 force sensors by Honeywell USA [17].

It is used a hybrid stepper motor PHL35-47-4S05 by PrimoPal China, covering a wide range of applications with a frame size of NEMA 8 to 42. Made of high quality cold roll sheet copper and anti-high temperature permanent magnet. This hybrid stepper motor has a complete design of high reliability, high accuracy, and featuring low noise, low vibration, low motor heating and smooth run. Besides conventional solutions, custom housing and winding, shaft modification, as well as encoder, brake, gearbox adders are also available to optimize the product's performance for different needs.

A hybrid stepper motor PHL35-47-4S05 by PrimoPal China company is shown in Fig. 15.

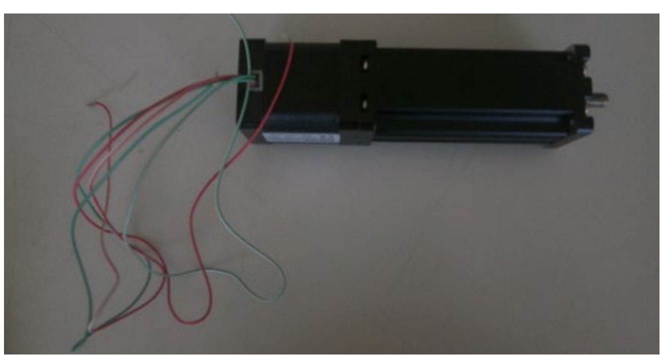
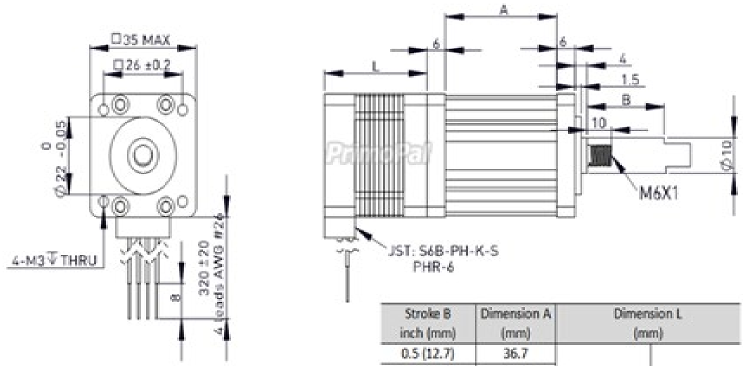


Fig. 15. A hybrid stepper motor PHL35-47-4S05 by PrimoPal China

The parameters of the used hybrid stepper motor PHL35-47-4S05 are given in Fig. 16.



Stroke B inch (mm)	Dimension A (mm)	Dimension L (mm)	
0.5 (12.7)	36.7	Single stack motor 35 mm	Double stack motor 47 mm
0.75 (19.05)	43.05		
1.0 (25.4)	49.4		
1.25 (31.8)	55.8		
1.5 (38.1)	62.1		
2.0 (50.8)	74.8		
2.5 (63.5)	87.5		

Fig. 16. Characteristics of the hybrid stepper motor PHL35-47-4S05 by PrimoPal China.

The experimental module with force feedback capabilities requires an appropriate force sensor which measurements the interaction between instrument tip and organs/tumours/tissues/stones and returns information to the operator' fingers. For purposes of the force experimental module two Force sensors FSS1500NSB by Company Honeywell USA are implemented into the construction which are very appropriate for medical application. The force sensors are shown in Fig. 17.

Fig. 17. FSS sensor 1500NSB by Honeywell.

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 range of the force sensor is 0 to 1500 grams with sensitivity of 0.12 mV/gram. Fig. 18 shows the excitation schematics of the force sensors.

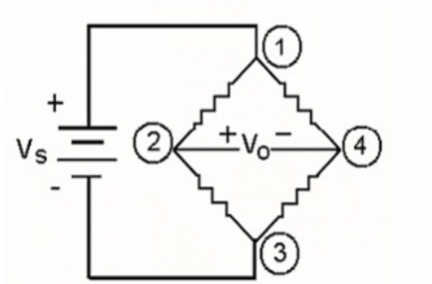


Fig. 18. Excitation Schematics – Excitation 5 Vdc Typ.,6 Vdc max

3.2 Electronics interfaces board for an experimental module with force capabilities

The purpose of the electronics of the experimental module with force capabilities is to:

- serve as an interface between experimental module and the computer that controls the experimental process;
- process and transform the generated by the computer signals for the experimental module ‘stepper motor into the appropriate electrical signals needed for the motor’s normal operation.
- ensure the necessary amplification, transformation and noise protection of the output signals of the sensors, necessary for some measurements and experiments connected with simulation of laparoscopic process.

When designing the hardware for control of the experimental force module it has to be decided two basic recommends: i) to measure force quick and precise and ii) to transfer measured data to the control system.

Hardware for control and monitoring of an experimental module with force capabilities consists of Control Block where are incorporated:

i) microcontrollers JN5168-001- M00 [18] and ATxMega32A4 [19];
ii) bi-connected coordinator to the instrument and the computer by wireless connection; and
iii) other electronics components necessary for the provision of the helping functions.

The module for control tasks is shown on the Fig. 19. Main element of Control A microcontroller JN5168-01-M00 is main element included in this module. The microcontroller has two basic functions – to works as a network device in local wireless system and to be a processor for control with different incorporated modules simultaneously. This microcontroller provides a comprehensive solution with large memory, high CPU and radio performance and all RF components included.

Fig. 19. A module for control tasks.

All that is required to develop and manufacture wireless control or sensing products is to connect a power supply and peripherals such as switches, actuators and sensors, considerably simplifying product development. The Module block diagram of microcontroller JN5148-01-M00 is on the Fig. 20.

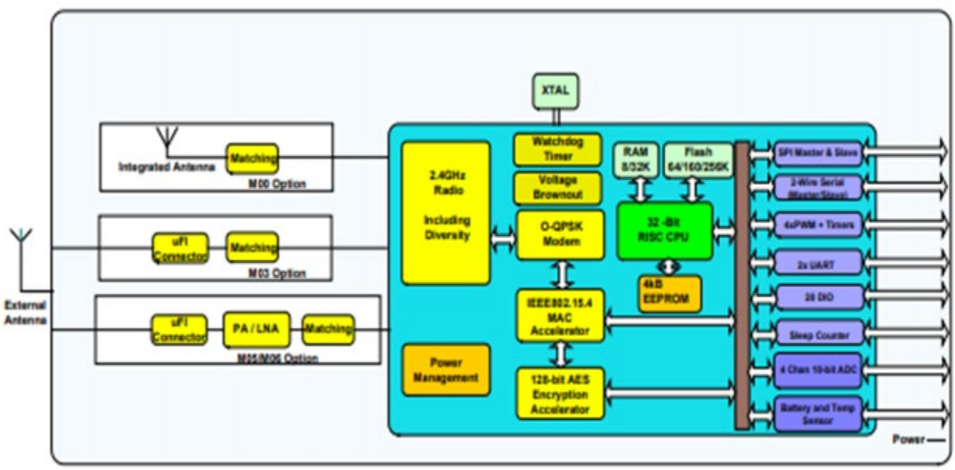


Fig. 20. Module block diagram of microcontroller JN5148-01-M00.

The control module includes as co-processor and microcontroller ATxMega32A4. In Fig. 21 is shown the Module block diagram of microcontroller ATxMega32A4. This microcontroller is responsible for the encoders data processing and radio- therapy controlling. JN5168-01-M00 and ATxMega32A4 ate connected between using on board SPI bus (primary). ATxMega32A4 is controlling the frequency generator module using embedded secondary SPI and I2C busses.

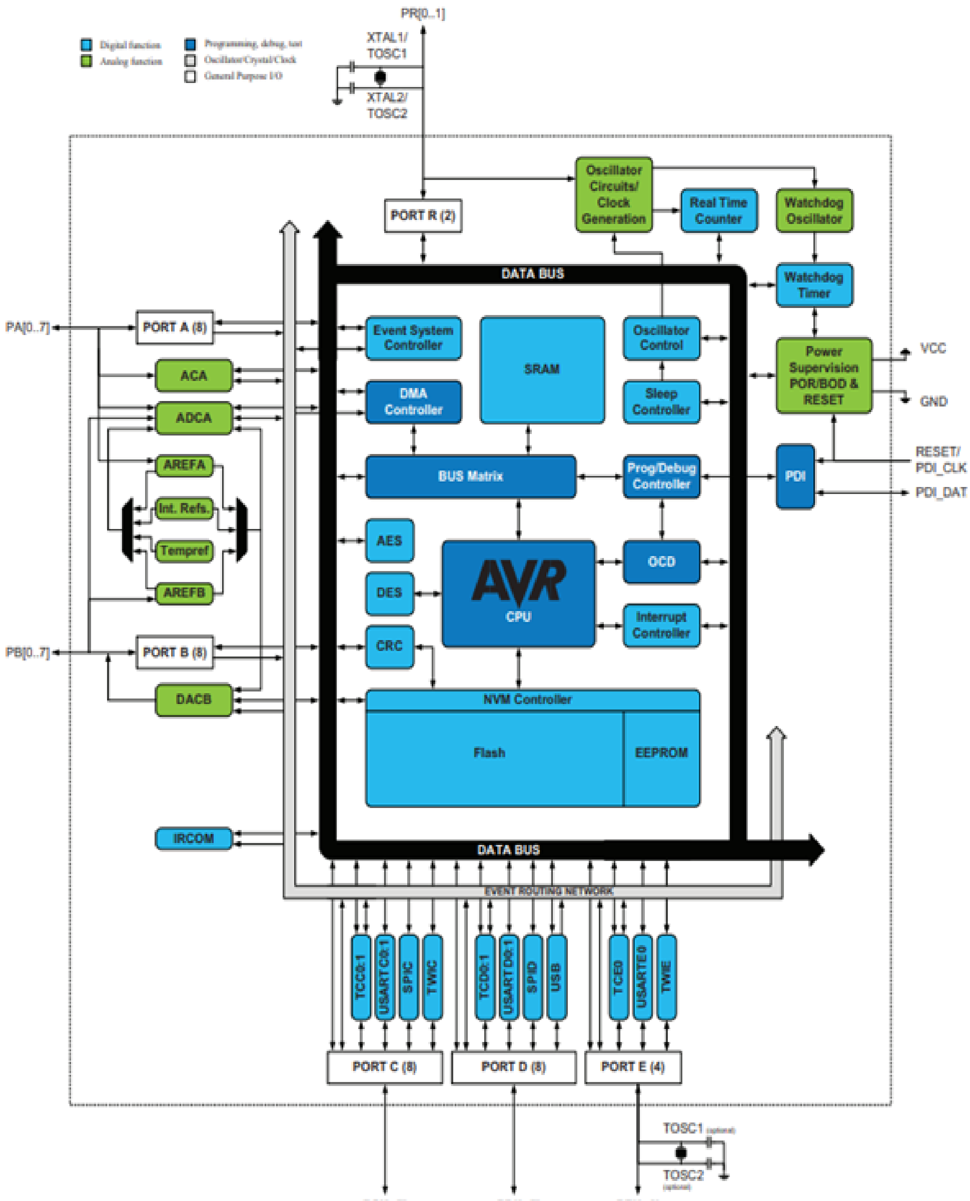


Fig. 21. Module block diagram of microcontroller ATxMega32A4

A block diagram of the control module is shown in Fig. 22.

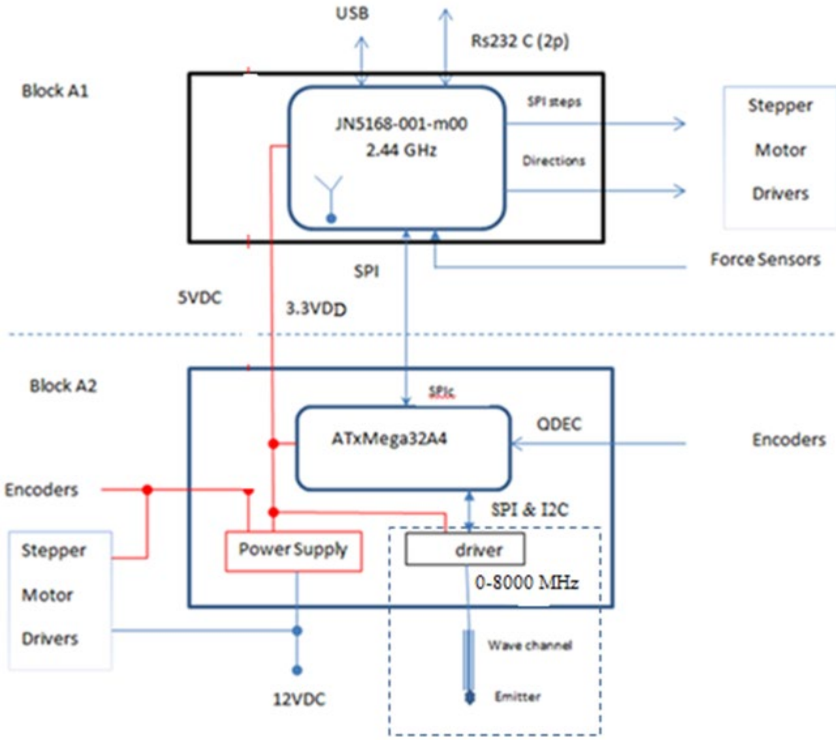


Fig. 22. Block diagram of Control module

4. Program Resources for Control and Monitoring of an Experimental Module with Force Capabilities.

From the way the managing software package is organized depends the movements, the work, the accuracy and the conduction of the experiments, the visually clear comprehensions of the receive results and the possibilities for their easy and unambiguous interpretation, comparison and analysis. Therefore, the managing software package has to be designed in such a way to permit some principal requirements as to realize the input of the date for ensure the necessary accuracy of the measurements of the force in requested range.

In conformance with the listed requirements the necessary for the purposes of the measurements software programs is developed using TCL-TK language [20, 21]. In previous work it is used TCL/TK language for different applications [22-25].

The TCL-TK program demonstrates the operation of the tool by searching for contact, detecting the presence or the lack of the tool-surface interaction, measuring the interaction force of the instrument with a given surface. The results obtained are visualized in a graphical form and save in a database. The results are compared with other results of the program results.

4.1. TCL-TK language for purpose of the experiments

As most suitable for the experiments with the designed and produced instrumental module for robots is chosen work with TCL/TK language or Tools Common language /tools kit. TCL/TK is a compilation of program libraries of functions which are written and compiled in advanced on C++. It consists of two parts – TCL and TK.

TCL/TK is a scripting language allowing the developers abilities for simple accessing to the resources of Operating system, in contrast to the “commercial” products VISUAL STUDIO and VISUAL BASIC of Microsoft. It is designed with “open source” GNU license and consists of two components:

i) TCL is C-like procedure oriented language, used for standard algorithms programming;
ii) TK consists operators forming requests to the operating system for system resources accessing and setting corresponded resource parameters.

4.2. Descriptions and the basic functions of the software package and the way it is used

The program demonstrates the operation of the experimental module by searching for contact point, detecting the presence or absence of contact at the top of the tool with a surface, measuring the interaction force of the tool with a given surface. The obtained results are visualized graphically and save in a database. The results are compared with other results of the program results.

The range of the commands allows the user or doctor to control the device and motors, actuators, sensor-force and position, which are connected to the microcontroller Some of basic program functions are Commands for Motion – Start and Stop machine, command for insertion and retraction linear of the tools, Mode-Automatic and manual, current step positions of the motor, save in samples or save in results, visualization and comparison of the measuring and etc.

The program is designed for four instruments, but is only realized for one. The first point is to be selected which instrument has to work. The Fast Positioning button introduces a special mode to quickly search the working area.

Motion is a control program button with two alternative states: Start and Stop Motion of the instrument. It allows and prohibits the movements (insertion and retraction linear) of the laparoscopic instrument. Also the movements are forward and backward. According to the dimension of the step, the stepper motor respectively the instrument can work in four modes:

- a complete step;
- 1/2 step;
- 1/4 step;
- 1/8 step.

The choice of the mode of the motion is via micro-switches.

History includes all commands and rapports during the communication sessions. They are also duplicated in a file (archive.txt from Folder Laparoscopy) by selecting the Save button, located in the top row of the initial screen.

DTBS Samples and DTBS Results: DTBS Samples and DTBS Results are Graphical tools that provide the operator access to the files stored in the two databases for eventual visualization and benchmarking. They have the same organization and ways of working. Each one includes a list of filenames supported by the appropriate base at the current time, a sheet for locating a visible part of the list, and methods for selecting and positioning them in the lists, using several embedded program buttons

The main menu of the program which is displayed on the screen after its execution is as described below (see Fig. 23).

Fig. 23. Basic menu of the program

Mode is a control program button with two alternative states – auto and manual, which are basic function with two possibilities:

- Auto mode,
- Manual mode.

In Auto mode, Force buttons are enabled, and Step is disabled. Pressing Force button it is accomplished a continuous sequence of steps in the specified direction, taking into account the following limitations: when the linear actuator is positioned outside the work area, Force does not work; Force is running at the moment when the workspace is reached, the Mode state changes automatically from Auto to Manual.

Tension Low Limit for S1, Tension High Limit for S1, Step Limit 0 and Step Limit 1. These are four sliders enabling the operator to graphically input the control parameter values: a lower force threshold measured by S1 above which the instrument operating area is considered to be starting; upper limit of force measured with S1, at which (within the work area) it is forbidden to move forward; Permissible number of steps that can be performed during Fast Positioning; Fast Search – the number of steps that can be performed by the laparoscopic tool in the work area.

Analyses of the results consists of Automatic Control, Dynamic Measurement Graph and DTBS (DTBS Samples and DTBD Results). In order to record the results, the operator has to perform the command: "save in Result DTBS" or command: "Save in Sample DTBS". The user or physician can perform graphical processing and analysis of the research results by Graphical visualization of results too (see Fig. 24).

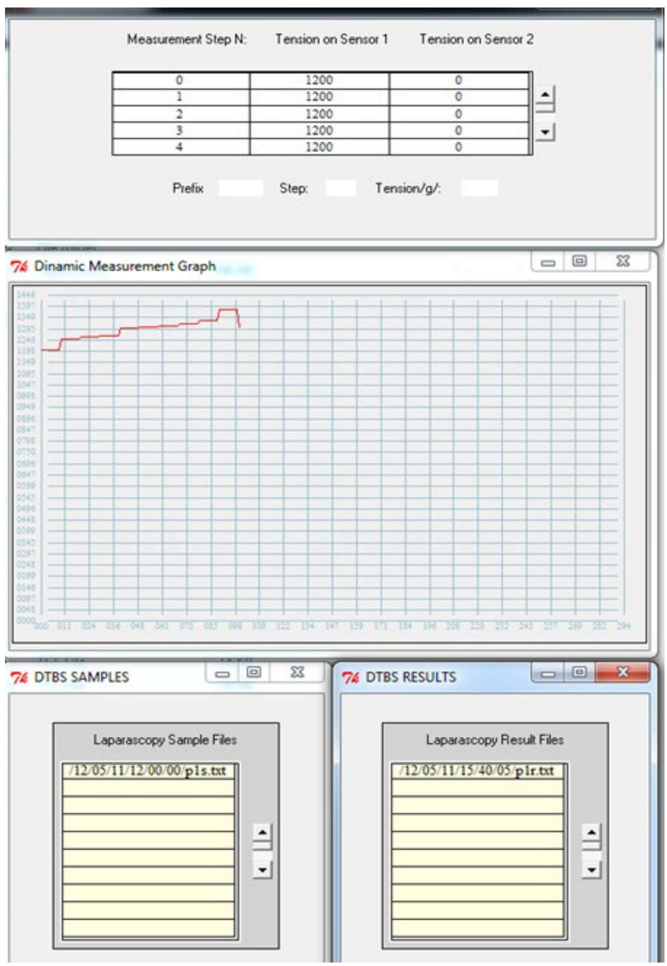


Fig. 24. Graphical visualization from the program

Working modes and networking

Every one module can function as autonomous or in a group of diverse instruments. In the first case, the surgeon can work the same way as traditional handhelds, but using the built-in touchscreen, which provides him with a lot of additional information and new possibilities. In the second case, the robotic laparoscopic tools can be managed by Operating Station using a wireless LAN as the primary information channel for command transmission and message reception. All instruments involved in the operation and the control program act as nodes on this network. Other autonomous wireless devices serving external sensors or connecting to external medical devices supporting the known wired interfaces may be involved in this LAN too.

Autonomous wireless modules

The autonomous wireless modules are designed to serve devices that are not directly involved in the laparoscopic operation but provide the conditions for successfully it conversion. These are microcontrollers with wireless communication capabilities and network connectivity that support external sensors measuring operational environment parameters, such as gas pressure, temperature, luminance, humidity, leakage, etc.

Another class autonomous wireless modules function as gateways between external medical devices and the wireless network, sending to the operator messages about the current state of the patient. In this way, it is possible to be maintained continuous information stream, on the basis of which the expert system, built into the control program to make adequate control decisions.

5. Experiments and analyses with the program TCL-TK

The purposes of carried out experiments with the realized experimental module with force capabilities are:

- Verify the functionality and working capacity of the experimental module with force feedback capabilities for robots;
- To evaluate practically whether the error introduced by the produced module during its normal operation is well within the required target of accuracy;
- To ensure that the error introduced during the carried out experiments and evaluation is negligibly small;
- To demonstrate the operation of the tool by searching for contact, detecting the presence or the lack of the tool-surface interaction;
- To measuring the force interactions of the instrument with a given surface.
- The following examples are made to illustrate the application of testing model. The experiments are conducted with a sample of memory material

and different end-effectors which are designed and produced for the propose of the experiments.

At a distance of about 2 mm from the wall inwards, the dissection is made and the tool is inserted. The step of the motor is 1/8 (6 microns) and the indicial force is 140 grams. The instrument searches the contact point with the surface, detecting the presence of the tool-surface interaction and measuring the force interaction of the tip tool with the given surface.

The result from the experiment is shown in Fig. 25, where the Force in grams is given on Y axes and the step of the motor is given on X axes.

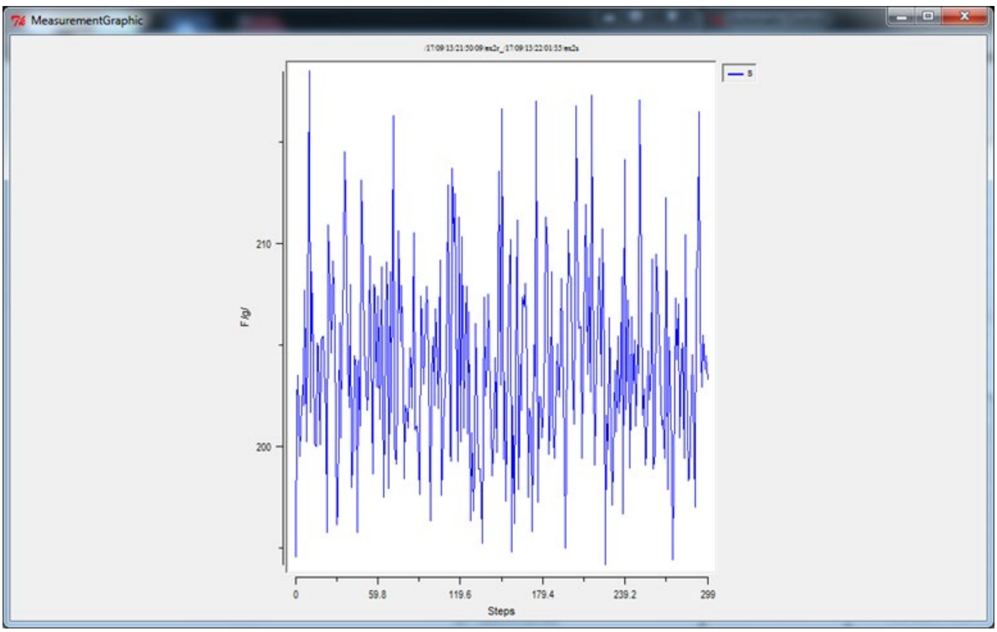


Fig. 25. Conducted Experiment with a piece of a sample of memory material

Under the same conditions measurements are made with the piece of rubber and a result file are obtained (Fig. 26).

The step of the motor is 1/8 and the indicial force which the instrument has to search is 140 grams. The instrument searches the contact point with the surface, detecting the presence of the tool-surface interaction and measuring the force interaction of the tip tool with the given surface (a piece of rubber).

The result from the experiment with a piece of rubber is shown in Fig. 26, where the Force in grams is given on the *Y* axes and the step of the motor is given on the *X* axes.

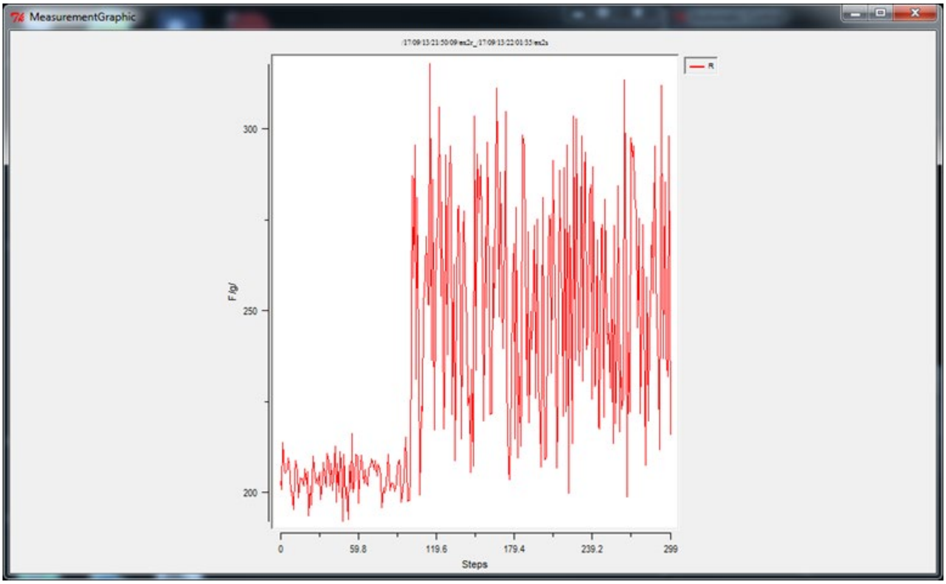


Fig. 26. Conducted Experiment with a piece of rubber

On Fig. 27 are selected results from first and second conducted experiment (the sample of memory material and a pies of rubber respectively). Where the Force in grams is given on the Y axes and the step of the motor is given on the X axes the same experiment is conducted with samples of other memory materials with similar properties. The results are approximately the same.

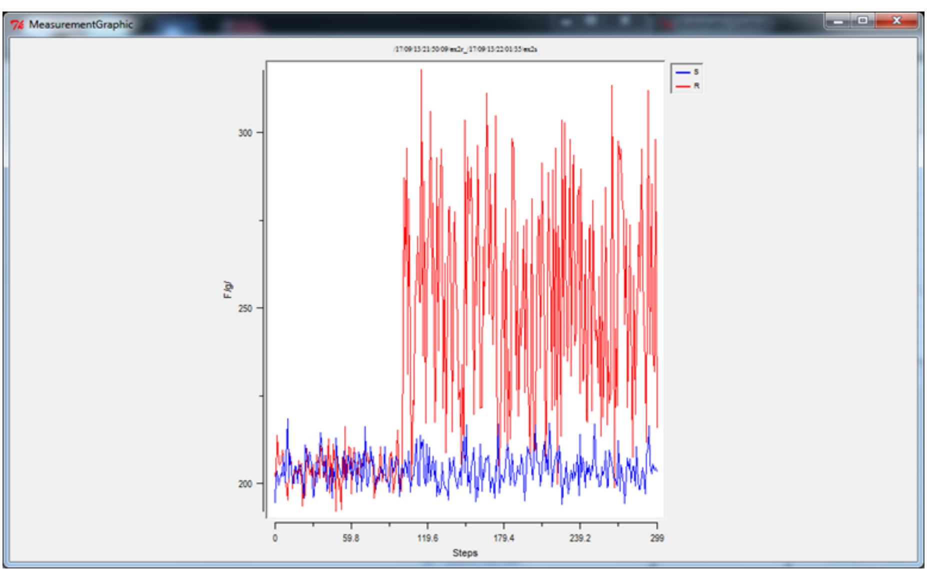


Fig. 27. Conducted Experiment with a sample of memory material and a pies of rubber – comparison results

The aim of the conducted experiment is to demonstrate the precision and functionality of the experimental module with force capabilities. The results from these, as well as all conducted experiments, show the exceptionally high accuracy of the measuring process (0.5%) for Automat and Manual modes of operation of the designed experimental force module in a wide range of forces (0-1500 grams) both in insertion and retraction of the instrument and implementing different types of end-effectors for those experiments. It was recognized the presence of the tools –surface force interactions and the lack of these.

Therefore, there are 2 errors – error of measuring of the force and error of the positions of the tool which depending on the motor.

- Measurement errors – accuracy of measurement is 1 gram-1/15% but performing averaging of 10 results we accepted that measurement error is 0.5%;
- Positioning errors of the linear actuator – assuming that a step is no missed, the error is 1 micro step ~ 6 microns and the at the length of the measured area is 300 microns, it is ~ 0.3%. But at the initial search, there may also be 1 micro step error, more true value of the error is about 0.6%.

The pictures are displayed in automatic scaling mode. The program looks for $max\ Y$ and $min\ Y$, then everyone value of the Y is displayed between Y max and Y min.

6. Conclusion

In laparoscopic surgery it is very important for surgeons to be able to touch and feel the tissue/organs/ stones while operating since the sense of touch are one of the primary sources of information that guides them during surgery. In contrast to commercial robot-assisted surgical systems such as daVinchi and Zeus in this study an experimental model with force capabilities and complex functions is presented. A design of intelligent instruments for an advanced robot system in application of laparoscopic surgery is presented. Hardware of a control system for an experimental module for the robot system are included to in this work. It is described language, program resources and ability to force control and its regulation in requested range The range of the commands allows the user or doctor to control the devices and motors, actuators, sensor – force and position, which are connected to the microcontroller Some experiments are conducted The purposes of carried out experiments with the realized experimental module with force capabilities is to verify the functionality and working capacity of this module.

Future work will include a novel Multifunctional Operation Station for control and monitoring of the experimental module for robot systems using Augmented Reality technology Augmented Reality – based design will allow more ergonomic remote instrument control in real time in contrast to conventional surgical instruments

As future directions it will explore the possibility to apply of Vuforia SDK to implement a complete Operating station with Augmented Reality including a visualization (training/advisory) terminal and a fully functional AR Operator Station. This system will be able to provide a remote control of laparoscopic instruments and supported medical devices

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