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CONTROL SYSTEM AND SOFWARE PACKAGE FOR AN EXPERIMENTAL MODULE FOR ROBOTS APPLIED IN LAPAROSCOPYC SURGERY

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Abstract: *The main target of everyone engineering work associated with minimally-invasive surgery is to provide adequate tool-tissue force information to the surgeons so that they can regain the "sense of touch" that has been lost through laparoscopic surgery. In contrast to daVinchi robots by Intuitive Surgical Incorporation which instruments are designed for manipulation and video observation our institute developed family tools with additional functions. Therefore, two main problems were solved: i) an original construction of an adequate experimental module for robots was designed and produced, in which two force sensors was incorporated to provide tool-tissue information (some of which were described and discussed in a previous work), and ii) hardware and program resources for control and monitoring of this module were achieved, this being the object of this work. The computer program includes information about various measurements of the tip tool-contact surface interactions and data obtained from the experimental module that is used to find the difference between data from previous measurement and information received in real time. Another signification advantage of the proposed program solution is the graphical visualization of the measurements and comparison of the results. Therefore, the surgeon can give the adequate command to force interaction between the instrument and tissue. For verification of the functionality and working capacity of the experimental module with force feedback capabilities of robots, different experiments with the designed control system were conducted.*

Key words: *control, robots, user-friendly software, program resources, force sensors, laparoscopic surgery, minimally-invasive surgery.*

1. INTRODUCTION

For adequate control of everyone instrument and device is very important to have interactive user-friendly software providing a graphical environment for designing, testing, editing and downloading control sequences. The adequate software will give examples of the various commands and techniques. Also, analysis at an early stage of the design process, and on a system that interfaces directly to an unstructured environment, exposes certain issues relevant to the application of current hazard analysis methods. The range of property program commands will allow the user to control output or input devices, such as motors, actuators, sensors and lamps which are connected to the microcontroller. It is possible to switch devices on or off in sequences using: timing, counting, repetition, and decisions based on signals from sensors and actuators that are connected to the microcontroller.

From all mentioned above, the construction design of an electronic interface board and program resources of the experimental module with force capabilities were realized. In contrast to *daVinchi* robots by Intuitive Surgical Incorporation-USA [1, 2] and *Zeus* by Computer Motion [3] whose instruments are designed for manipulation and video observation we offer family of intelligent tools for robots with application in laparoscopic surgery, which includs four types of instruments – for diagnosis [4, 5], manipulation [6], therapy and video observation. By developing novel specialized instruments, it had to be created more compact, simple, cheaper and easier robotic instruments than ever. Alos, it had to be developed novel smart instruments for robotic surgical systems and capability of irregular shape object manipulation, such as stones, organs, tissues, etc.

Each instrument is divided into three sections:

- control block (electronic interface board);
- handle of the tools incorporating 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.

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The hardware and program resources for control and monitoring of the experimental module with force capabilities are subjects 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 data obtained from the experimental module, which is used to find the difference between previous measurement and received information in real time. Another signification advantage of the proposed program solution is the graphical visualization of the measurements and result comparison. Therefore, the surgeon can submit the adequate command to force interaction between the instrument and tissue.

The paper is organized as follows: section 2 includes hardware of a control system for an experimental module with force capabilities. Section 3 describes language, program resources and ability to force control and its adjustment in requested range. In section 4 some experimental results are shown. Finally, section 5 concludes the paper giving some points at the intentions to future researches.

2. CONSTRUCTION OF ELECTRONIC INTERFACE BOARD OF EXPERIMENTAL MODULE WITH FORCE CAPABILITIES

It was designed and produced an original construction of an adequate experimental module including two force sensors to provide tool-tissue information to the surgeon (which was described and discussed at previous work). In Fig 1 the experimental module with force capabilities is shown. The main elements of the experimental instrument are a handle and an electronic interface board (control block).

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

The instrument can be divided into handle, shaft and modular jaws for grip and manipulation of irregular objects. The main element of tool is the handle, which incorporates a linear stepper motor by PrimoPal China [7], a position sensor and two force sensors by Honeywell USA [8].

A hybrid stepper motor PHL35-47-4S05 by PrimoPal China was used, 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. In Fig. 2 a hybrid stepper motor PHL35-47-4S05 by PrimoPal China is shown.

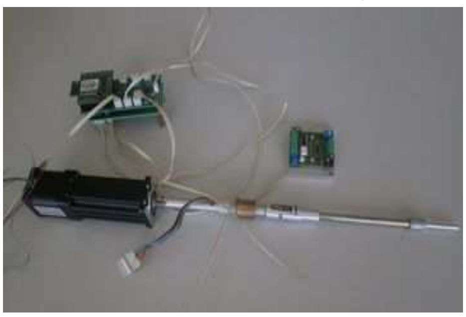
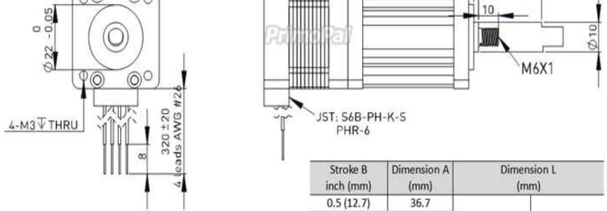


Fig. 1. An experimental module with force capabilities.

Figure 3 shows the characteristics of the hybrid stepper motor PHL35-47-4S05.

Laparoscopic intelligent instruments require an appropriate force sensor, which measures 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 were used, which are very appropriate for medical applications (the force sensors are shown in Fig. 4). FSS sensor allows to very precisely measure the gripping force in the requisite operating range from 0 to 1500 g. Another important function is that this sensor fixes the moment of contact of the jaw to organs/ tissues/ blood vessels respectively, the time being extended.

Fig. 2. A hybrid stepper motor PHL35-47-4S05 by PrimoPal China.



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

Fig. 4. FSS sensor 1500NSB by Honeywel.

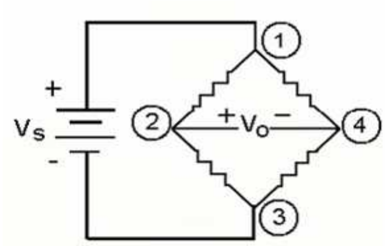


Fig. 5. Excitation Schematic – 5 Vdc Typ., 6 Vdc max**.**

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.

2.2 Electronics interfaces board foran 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.

In designing the hardware for control of the experimental force module two basic requirements were taken into account: 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 which incorporatesd: i) microcontroller JN5148-01- M00 [9], 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.

Control module is shown in Fig 6. Main element of Control Block is a microcontroller JN5148-01-M00. The microcontroller works as a network device in local wireless system and a processor for control with different simultaneously incorporated modules. This microcontroller provides a comprehensive solution with large memory, high CPU and radio performance and all RF components included. 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.

Figure 7 shows the microcontroller JN5148-01-M00.

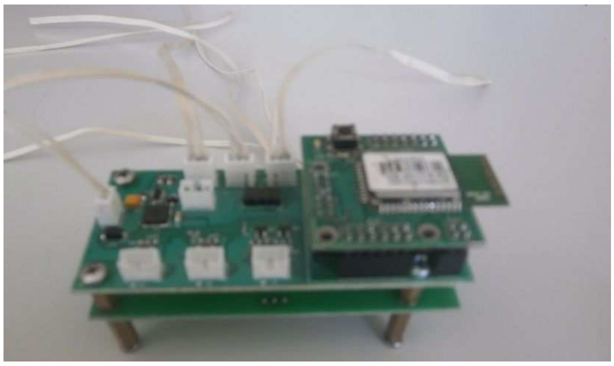


Fig. 6. Control module.

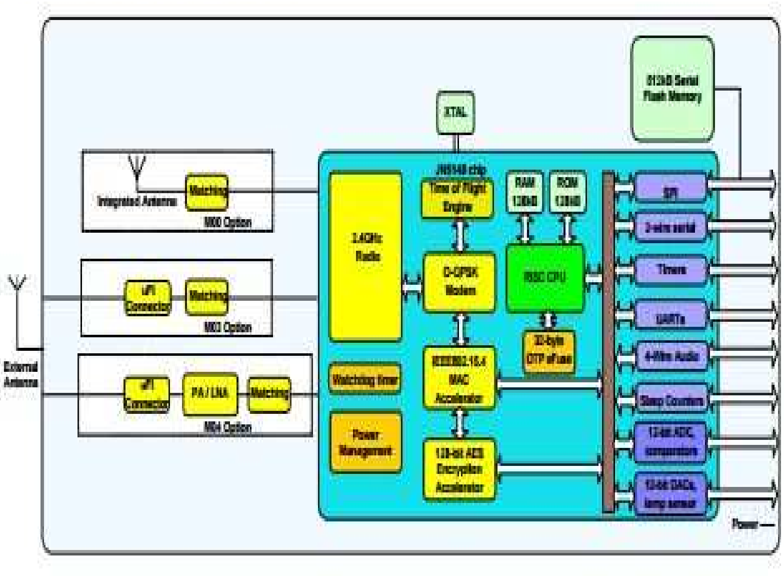


Fig. 7. Module block diagram of microcontroller JN5148-01-M00.

3. 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 data for ensure the necessary accuracy of the measurements of the force in requested range.

In accordance with the listed requirements the necessary for the purposes of the measurements software programs were developed using TCL-TK language [10]. In previous work, TCL/TK language for different applications was used [11−14].

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, and 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.

3.1. TCL-TK language for purpose of the experiments

As most suitable for the experiments with the designed and produced instrumental module for robots were chosen work with Tools Common Language /Tools Kit language (TCL/TK). TCL/TK is a compilation of program libraries of functions which are written and compiled in advanced C++. It consists of two parts − TCL and TK.

TCL/TK is a scripting language allowing the developers abilities for simple accessing 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 − C-like procedure oriented language, used for standard algorithms programming; ii) TK consisting in operators' forming requests to the operating system for system resources accessing and setting corresponding resource parameters.

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

The program demonstrates the operation of the tool by searching for contact point, detecting the presence or absence of contact at the tip of the tool with a surface, measuring the interaction force of the tool with a given surface. The obtained results are visualized in a graphical form and save in a database. The results are compared with other such 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 measurements, etc.

The program is designed for four instruments, but it is only realized for only one. The first step is to select the instrument that 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 or 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 done 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 program menu, which is displayed on the screen after its execution, is described further (Fig. 8).

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 a continuous sequence of steps in the specified direction is accomplished, 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.

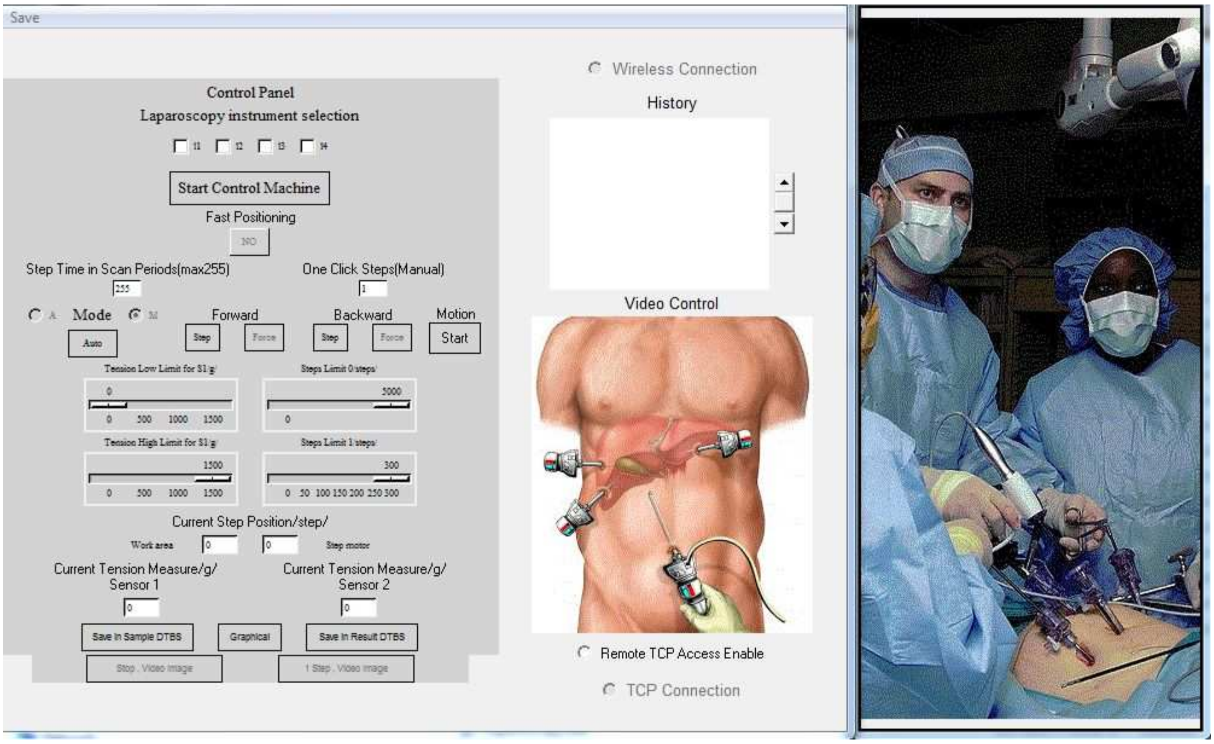


Fig. 8. Control panel.

Analysis of the results consists of Automatic Control, Dynamic Measurement Graph − DTBS (DTBS Samples and DTBD Results). In order to record the results, the operator has to perform the commands: "Save in Result DTBS" or "Save in Sample DTBS". The user or physician can perform graphical processing and analysis of the research results by Measurement Graphic (Fig. 9).

4. EXPERIMENTS AND ANALYSIS

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

- To 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 acceptable within the required target of accuracy;
- to ensure that the error introduced during the carried out experiments and evaluation was 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 measure the force interactions of the instrument with a given surface.

The following examples are made to illustrate the application of testing model. The experiments were conducted with a piece of Styrofoam and different end-effectors that were designed and produced.

At a distance of about 2 mm from the wall inwards, the dissection was made and the tool was 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 tool tip with the given surface. The result from the experiment is shown in the Fig 10, where the Force in

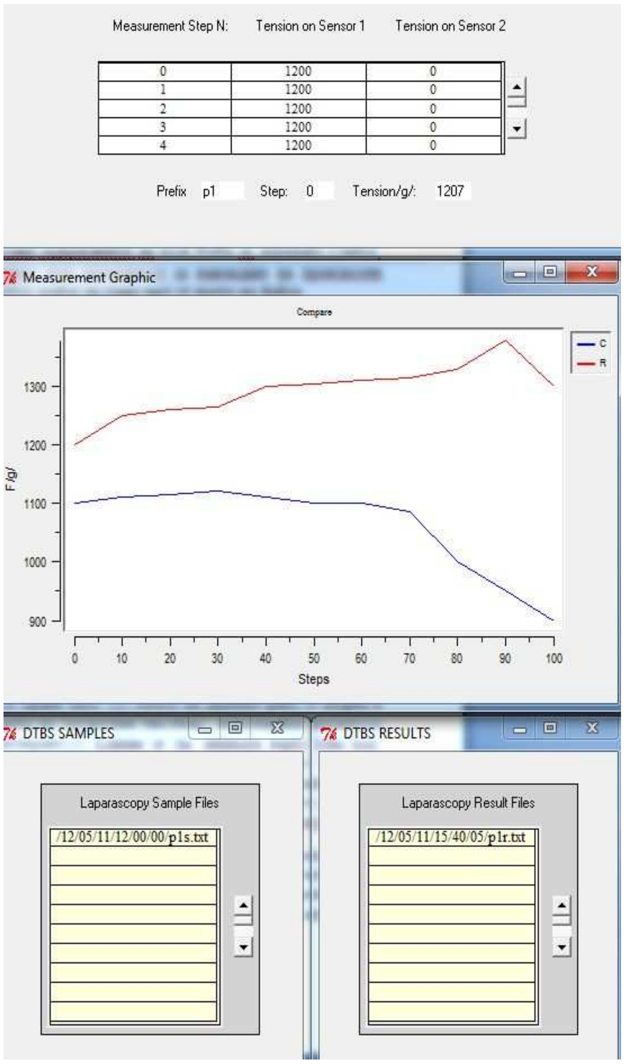


Fig. 9. Measurement Graphics from the program.

grams is given on *X* axis and the step of the motor is given on *Y* axis.

Under the same conditions, measurements were made with the piece of rubber generating a result file. The result is shown in Fig. 11, where the Force in grams is given on the *X* axis and the step of the motor is given on the *Y* axis.

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).

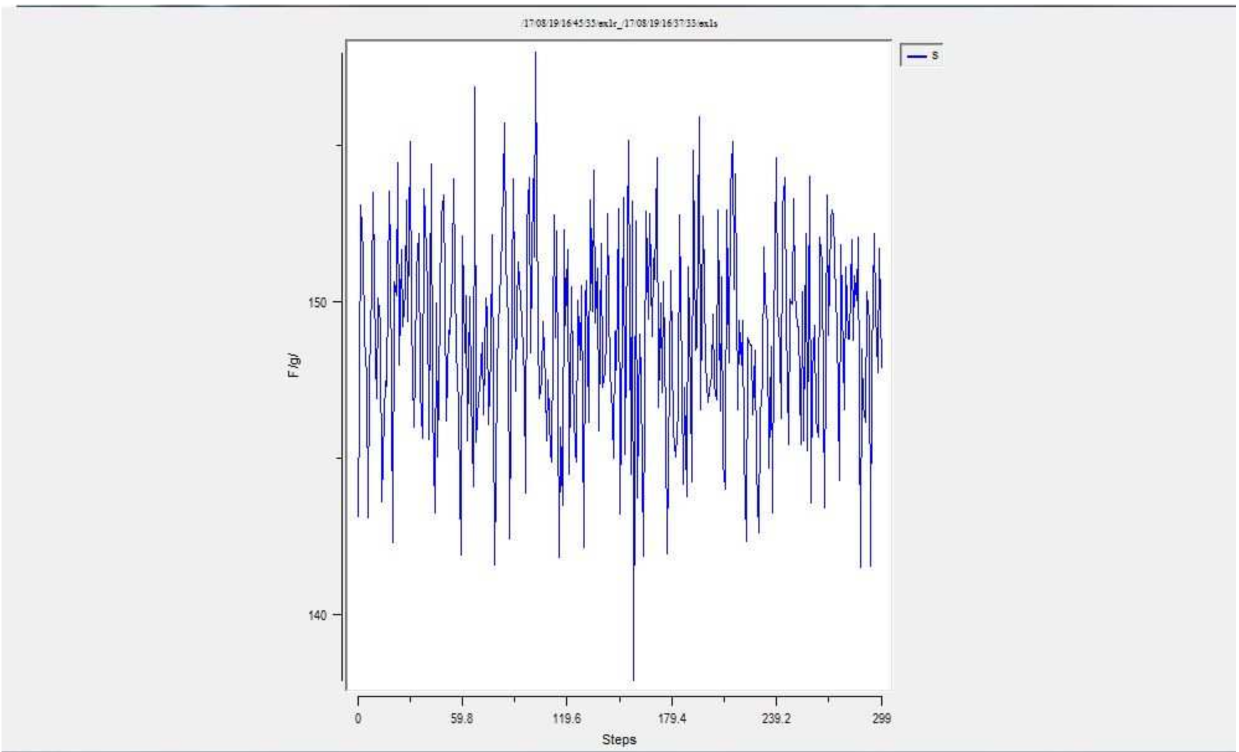


Fig. 10. Conducted Experiment with a piece of Styrofoam.

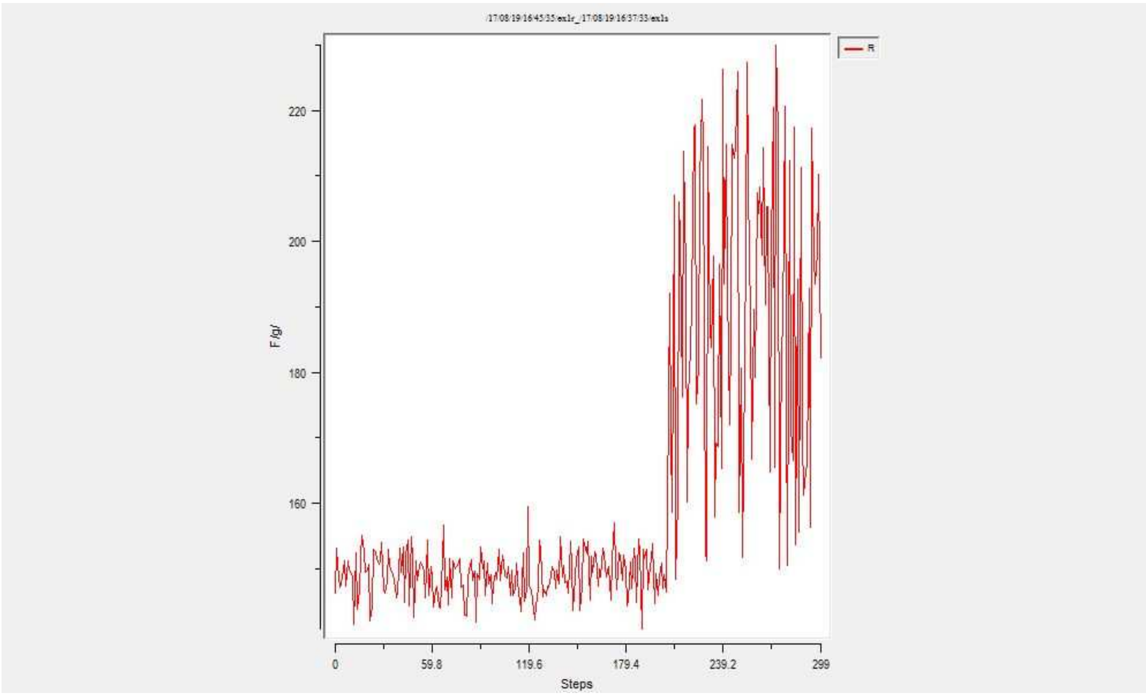


Fig. 11. Conducted Experiment with a piece of rubber.

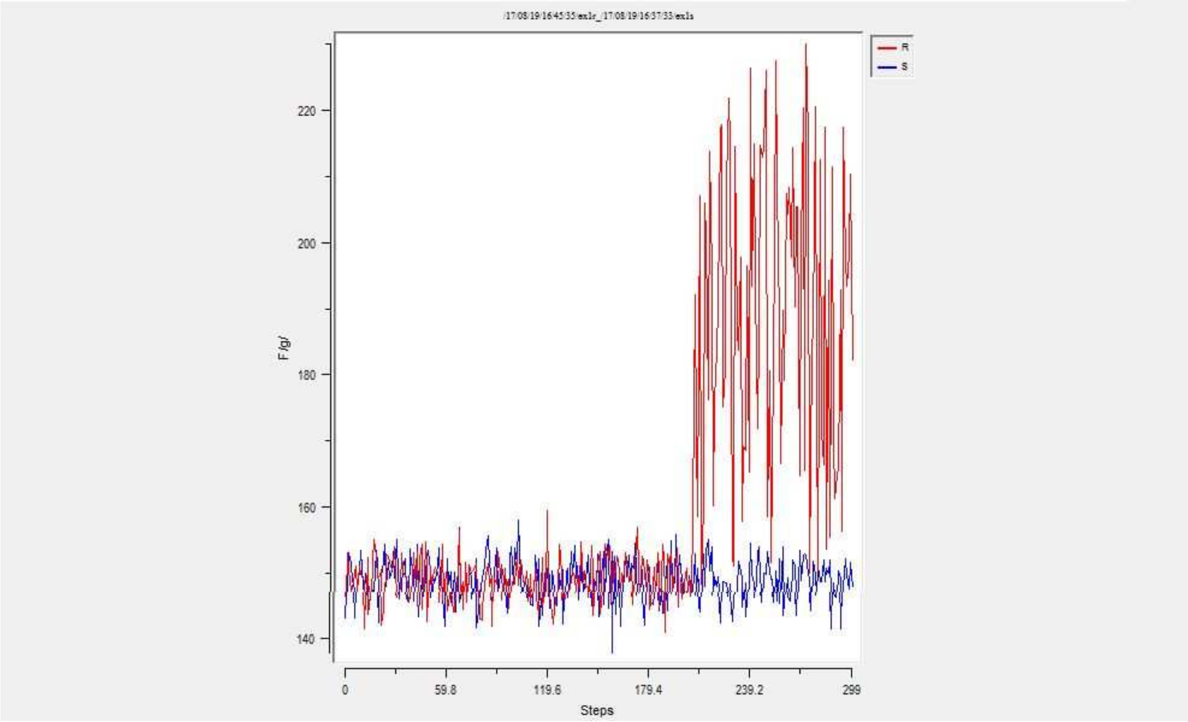


Fig. 12. Comparison of Conducted Experiment with pieces of Styrofoam and rubber.

Figure 12 presents selected results from first and second conducted experiments using pieces of Styrofoam and rubber respectively, where the Force in grams is given on the *X* axis and the step of the motor is given on the *Y* axis The same experiment was conducted with a piece of memory material. The results are similar.

The aim of the conducted experiment was 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 g) for both insertion and retraction of the instrument. Different types of end-effectors for experiments were implemented. It was recognized the presence or lack of the tools-surface force interactions.

Therefore there are 2 errors – error of measuring of the force and error of the positions of the tool which depends on the motor:

- Measurement errors: accuracy of measurement is 1 gram − 1/15% but performing averaging of 10 results, the measurement error of 0.5% was accepted;
- Positioning errors of the linear actuator: assuming that a step is no missed, the error is 1 micro step (about 6 μm) and the length of the measured area is 300 microns, it is about 0.3%. But in the initial search, there may be 1 micro step error that leads to a higher value of the error of about 0.6%.

  The pictures are displayed in automatic scaling mode. The program looks for max *Y* and min *Y*, than each value of *Y* is displayed between *Y*max and *Y*min.

Figure 13 shows the experimental module for robots with application in laparoscopic surgery.

Fig. 13. Experimental module for robots.

5. CONCLUSIONS AND INTENTIONS TO FUTURE WORKS

Hardware (electronics control board) and user-friendly software for control and monitoring of an experimental module with force capabilities are discussed in this paper. The computer program includes information about various measurements of contact surfaces and data obtained from the experimental module used to find the difference between saved data from previous measuring and received information in real time. Another significant advantage of the proposed program solution is the graphical visualization of the measuring and comparing of the results. Therefore, the surgeon can submit the adequate command to force interaction between the instrument and tissue.

Further intentions of this work are:

- to design and produce family of tools with various applications in the area of laparoscopic surgery which can execute different tasks (for example an instrument for manipulation, visualization and, or therapy of cancer);

- to design and produce hardware and user-friendly software for the group of the tools which has to work together,
- the investigation can be made with different materials of similar properties of human tissues in order to compare the results.

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