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# A Smart Laparoscopic Instrument with Different Applications

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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 this context the main objective of the work design novel family laparoscopic tools with better technical characteristics, and incorporation of force and other sensors and elements in construction of tools for restore sense of touch in the process of laparoscopy. Thus it is improving some technical side of this laparoscopic instruments. In contrast to daVinchi robots by Intuitive Surgical Incorporation which instruments are designed for manipulation and imaging we offer family tools with additional functions such as diagnosis and therapeutics tasks. Therefore we decide two main problems: i) we designed and produced an original construction of an adequate experimental module for robots, where was incorporated two force sensors to provide tool-tissue information (some of which was described and discussed at previous works); and ii) we realized hardware and program resources for control and monitoring of this module which is the object of this work. The computer program includes information about various measurements of the tip tool – surface contact interactions and data obtained from the experimental module that is used to find the difference between date from previous measuring and received information in real time. Another signification advantage of the proposed program solution is the graphical visualization of the measuring and comparing 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 for robots were conducted different experiments with the designed control system.*

***Keywords**: Robot system, Therapeutics tasks, Designed control system.*

## Introduction

The main objective of this work as an answer to world facing challenges for optimal treatment of disease in laparoscopic surgery is the development of novel modular mechatronics devices with better characteristics whose target is to bring radical improvements to the quality and efficiency of our healthcare. The last decade, more than 1.5 million laparoscopic surgical procedures have been performed worldwide by daVinchi (Intuitive Surgical Incorporation, USA, http://www.intuitivesurgical.com/). Many research groups have aimed to improve the daVinchi system or to propose novel surgical robot systems.

From all mentioned above we offer smart tools with complex functions (diagnosis, therapy, manipulation and observation) and application in laparoscopic surgery. A design of an electronic interface board and program resources of the experimental module with force capabilities ware realized also. In contrast to daVinchi robots by Intuitive Surgical Incorporation and Zeus by Computer Motion (http://www.computermotion.com/) 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 [4, 8], manipulation [7], therapy and observation. By developing novel specialized instruments it has to be created more compact, simple, cheaper and easier robotic instruments than ever.

Each instrument is divided into three sections into electronic interface board, handle of the tools where is incorporated a block with embedded force sensors, a linear stepper motor and a position sensor and Different designed end effectors which are fixed to the end of the tools.

The design of an 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.

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 follows. Section 2 includes design of smart 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 included some experimental results. Finally, section 6 concludes the paper and points at the intentions to future work.

## Design and construction of smart instruments for the advanced robot system

### *An instrument for diagnosis*

The designed instrument for diagnosis poses a wide range of force capabilities measuring (0-1500 g) 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 manipulation*

On Fig. 1 is shown a smart instrument for manipulations.

### *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 therapy*

An instrument for a therapy (on Fig. 2) is a sophisticated module that incorporates engines, sensors for positioning and control of encoders and mechanical structures that perform manipulation on tissues (laparoscopic interventions). This module is designed for programmable irradiation of FEM (2.44-2.508 GHz). The radiation is local, within a radius of 1 mm from the emitter. It is possible change of the intensity and frequency of the SDR radiation as a function of the time. The broadcast signal poses four intensities. The radio signal acts on the emitters in direct contact with the emitter, the signal attenuation being realized at 100% off the sphere, with a radius of 1 mm and the centre of the tool.

## Construction design of the electronics interface board of the experimental module with force capabilities.

It was designed and produced an original construction of an adequate experimental module, where was incorporated two force sensors to provide tool-tissue information to the surgeon (which was described and discussed at previous work). On Fig. 3 is shown the experimental module with force capabilities.

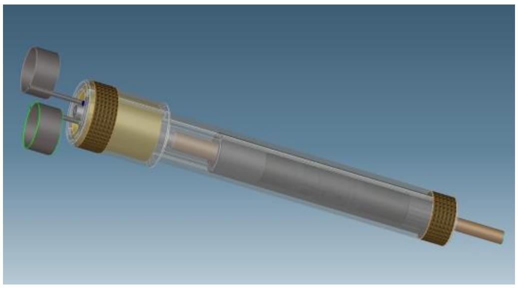

Fig. 1 An instrument for manipulation

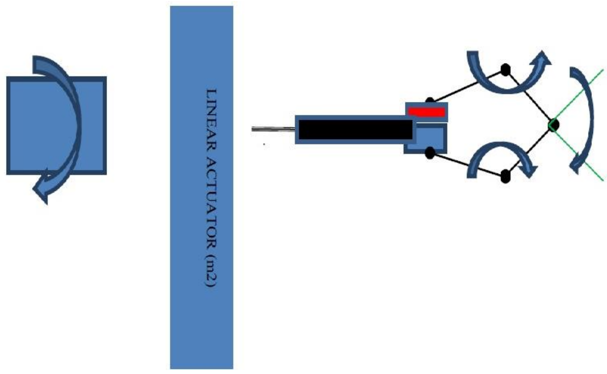


Fig. 2 An instrument for therapy with application in laparoscopy

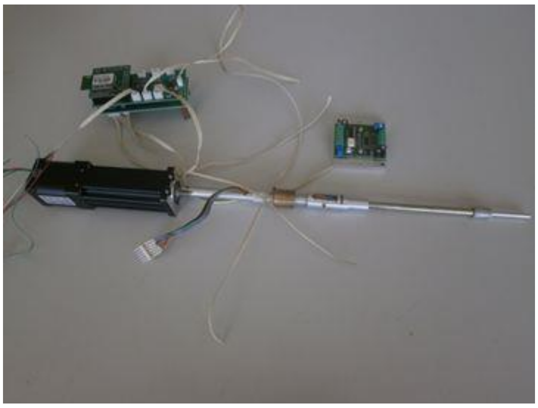

Fig. 3 An experimental module with force capabilities

### *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 (www.primopal.com), a position sensor and 2 force sensors by Honeywell – USA (http://www.honeywell.com/).

It was 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 highquality 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.

The advanced robot system with laparoscopic intelligent instruments requires an appropriate force sensor which measurements the interaction between instrument tip and organs / tumors / tissues / stones and returns information to the operator' fingers. For purposes of the force experimental module we use two Force sensors FSS1500NSB by Honeywell – USA which are very appropriate for medical application. FSS sensor allows to very precise measurement of gripping force in the requisite operating range from 0 to 1500 g and due to their linear – in its convenient conversion constant voltage. Another important function of this sensor is to fix the moment of contact of the jaw to organs / tissues / blood vessels respectively, the time was extended. The range of the force sensor is 0 to 1500 g with sensitivity of 0.12 mV/g.

### *Electronics interfaces board for smart instruments*

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 we designed the hardware for control of the experimental force module we decide 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) microcontroller JN5148-01-M00 (https://www.nxp.com/products/wireless-connectivity/zigbee/zigbee-pro-and-ieee802.15.4-module:JN5168-001-M00?lang_cd=en); 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 on Fig. 4.

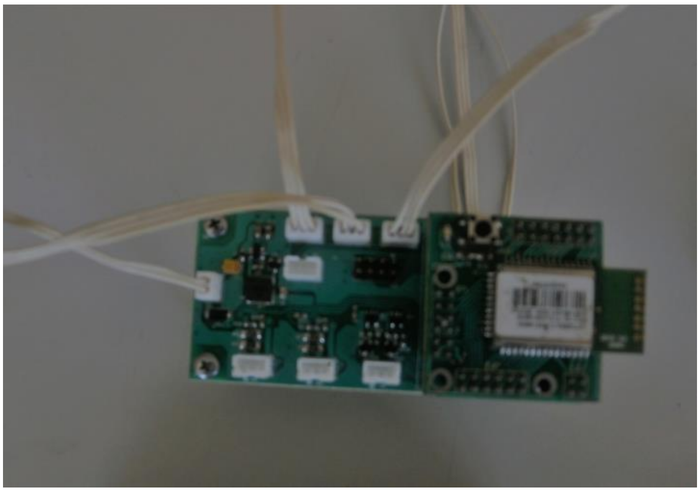

Fig. 4 Control module

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 incorporated modules simultaneously. 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.

## 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 measurement's software programs was developed using TCL/TK language (www.tcl.tk). In previous work we used TCL/TK language for different applications [9, 10]. 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 such results of the program results.

## *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 (TCL/TK) language. 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.

## *Basic functions of the software package and the 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 top 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 [1, 2].

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 и DTBS Results**

DTBS Samples и 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 on Fig. 5).

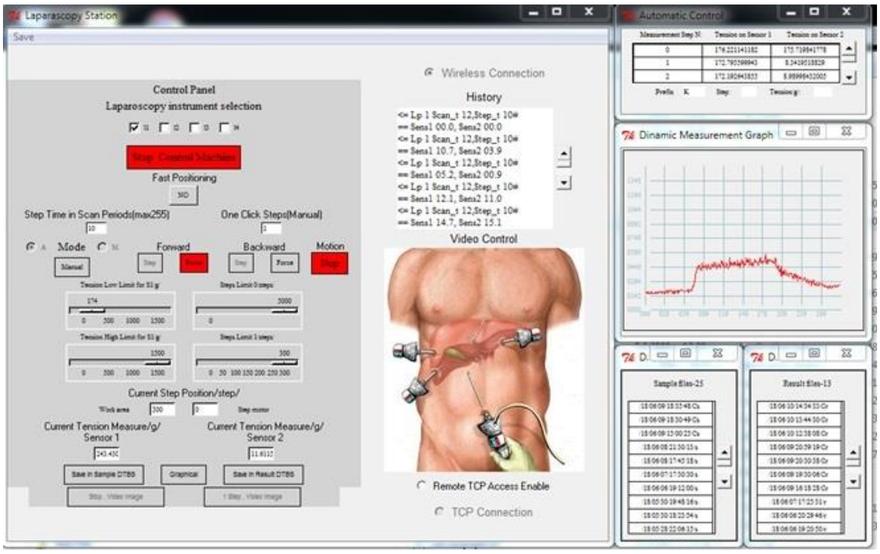


Fig. 5 Control panel

**Mode**

It is a control program button with two alternative states – Auto and Manual, which are basic function with two possibilities. 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.

Analyse of the results consists of Automatic Control, Dynamic Measurement Graph и 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 results by Measurement Graphic, too (see on Fig. 6).

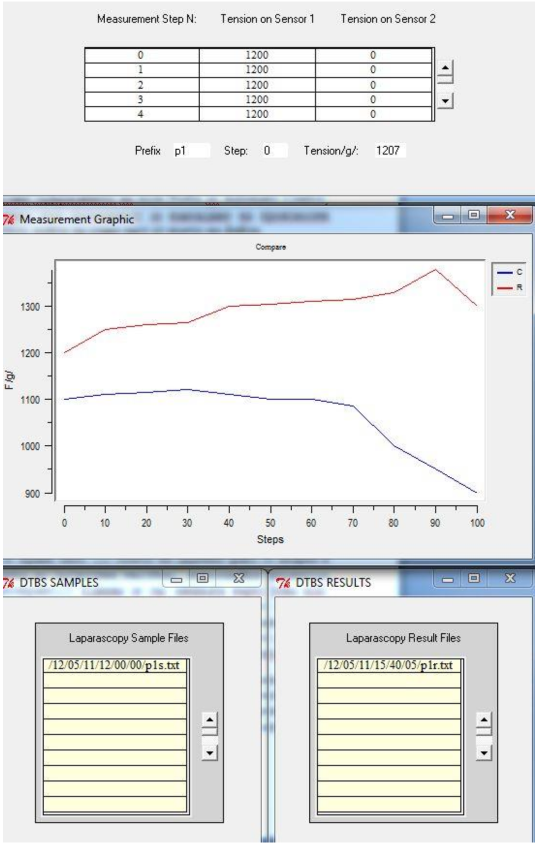


Fig. 6 Measurement graphics from the program

## Experimental studies of the structure of biological tissues through mechanical effects with a smart laparoscopic instrument

Micro and macro stimulating methods for analyses of biological tissues with a smart laparoscopic Instrument. The macro and micro stimulation method [6] includes a robot tool with incorporated force sensors. The force is measured by the sensors in the direction opposite to the instrument displacement. The instrument displacement is implemented through a sequence of single linear steps with identical length and direction, called macro stimuli. The tool-tissue interactions are implemented through an end-effector at the tip of the tool. Every macro stimulus leads to micro displacements (micro stimuli) at the contact tissue point in a direction perpendicular to the contact tangential plane. The micro-stimuli interact with the tissue and lead to its reaction, which modulates the stress and forms a micro force in a direction opposite to the micro displacement. The total sum of micro forces (its component in the direction of the tool displacement) is counted by a tactile sensor. It is used in the assessment of the tissue structure. In the following text, the operation of a robotic tool with a conical shape of the end-effector will be investigated. The end effector is shaped conically with an angle of the tip $2\alpha$. The translation of the end-effector is a result of a single macro stimulus with equal steps $L_0$ and a direction defined by the straight line $O$-$O1$. After each step, the contact point of the tissue and the tool performs a micro displacement in a direction perpendicular to $O$-$O1$ with a length $D_1$, which leads to a micro stimulus with a length $L_1$ (a micro displacement perpendicular to the tangent plane to the conical contact point). The tissue reaction is the generation of the micro force $F_m$. Its component in the direction of the displacement of the tool $F_{mt}$ and the similar components of the micro forces generated at the other contact points are summed up and measured by the incorporated tactile sensor. A series of measurements is performed according to a pre-set time interval [12].

Fig. 7 shows the movement of the end-effector, which is done via a sequence of macro stimuli, each having a length $L_0$ in a predefined direction. Every macro stimulus generates micro stimuli and micro displacements with a length of $L_1$ at the contact points of the tissue. The following equation holds:

$$L_1 = L_0 \sin \alpha \ . \tag{1}$$

The exceptions are the new contact points that occur when the tip of the tool interacts with the tissue. They are located on the surface on the cone, which is bound by its tip and its cross-section with a plane perpendicular to the axis *O*-*O*1 and located at a distance $L_0$ from its tip.

At these points, the micro displacements are determined by:

$$L_1 = r \ , \tag{2}$$

where $r$ ranges from 0 to $L_0$.

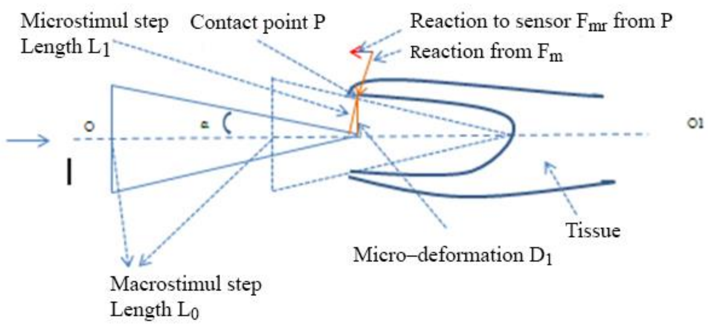


Fig. 7 Movement of the end-effector

From Eq. (2), it follows that:

$$\sigma(t) = \xi \times E \times e^{-\frac{t}{\tau}} \ . \tag{3}$$

$\xi$ is a monotonous function $P(L_1)$, whose value is constant during the test measurements of $\sigma$:

$$\xi = P(L_1) \ . \tag{4}$$

Eq. (4) can be rewritten as:

$$\sigma(t) = P(L_1) \times E \times e^{-\frac{t}{\tau}} \ . \tag{5}$$

The stress $\sigma(t)$ at the point $q$ in a constant tissue area can be defined by the reaction of its deformation $L_1$ and it is a function of the time. If $\Delta S(q)$ is the area of a micro-surface within the end-effector surface, in which there is a contact point $q$ with stress $\sigma$, then a micro-force is formed on this micro-surface, whose projection $F_{mt}(p)$ on the axis *O*-*O*1 can be defined as:

$$F_{mt}(p) = \sin \alpha \times \Delta S(q) \ . \tag{6}$$

Summing up $F_{mt}(p)$ at all contact points $q$, we receive the force which is measured by the tactile sensor at a given moment:

$$F = \sum_{q \in \{contact\ poins\}} (F_{mt}(q)) \equiv F_{mt}(p)\,. \tag{7}$$

To refine the estimate of the magnitude of the force $F$, which is measured by the tactile sensor, let us examine in detail the force interaction between the tool and the tissue. The conical manipulator can be regarded as being composed of two segments:

1. $K0$, which includes the points of the conical surface that are at a distance or less than or equal to $L_0$ (the length of the macro-stimulation steps) from the plane, which is orthogonal to the axis $O$-$O1$ and passes through its tip. $K0$ creates new contact points with the tissue.
2. $K1$ includes the points of the cone surface which are located at a distance larger than $L_0$ (the length of macro-stimulus steps) from the plane which is orthogonal to the axis $O$-$O1$ and passes through its tip. $K1$ always interacts with contact points which have already been created and for which Eq. (7) is in force.

In Fig. 8, the segmentation of the conical end-effector is shown.

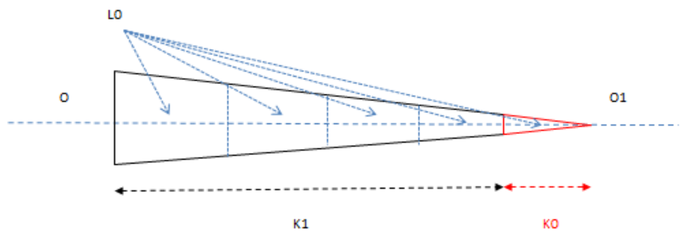


Fig. 8 Segmentation of the conical end-effector.

The tool performs a sequence of movements. Each one is the result of a macro-stimulus and generates translation movement with a step $L_0$. As a result, the segments $K0$ and $K1$ perform a displacement of the contact points at a distance $L_1$ perpendicular to the surface of the cone and determined by Eq. (8) or Eq. (7), respectively. The tissue reacts at each contact point and a micro force $F$ is formed along the axis $O$-$O1$ and the total force $F$ is obtained by Eq. (8):

$$F = F0 + F1, \tag{8}$$

where $F0$ is the sum of the force reactions formed at the contact points of the tissue with $K0$ and $F1$ is the sum of the force reactions formed at the contact points of the tissue with $K1$.

When performing a sequence of macro stimulations, the force measured by the sensors tends to increase. This is due to the increase in the number of contact points in a series of consecutive macro stimulations:

1. For the first macro stimulus this includes only the new contact points that are formed by $K0$;
2. For the second macro stimulus, this includes the new contact points that are formed by $K0$ and the existing contact points that are formed by $K1_1$;
3. For the $n$ + 1 stimulus, this includes the new contact points that are formed by $K0$ and the existing contact points that are formed by $K1_n$.

The reaction of the tissue to every segment $K0$, $K1_1$, ..., $K1_n$ is as follows generates a corresponding force that is measured by the sensor. In the general case, for predefined $L_0$ and $\alpha$, the tissue reaction measured by the tactile sensor for the $n^{th}$ macro stimulus can be written as:

$$Fn = F0 + F1_n. \tag{9}$$

It can be shown that there is a common multiplier $e^{-\frac{t}{\tau}}$ in both addends on the right side of Eq. (9) because of which:

$$Fn = e^{-\frac{t}{\tau}} \times M(L_0, E, \alpha, n), \tag{10}$$

where $Fn$ is the force measured for the $n^{th}$ macro stimulus. The function $M(L_0, E, \alpha, n)$ depends on the parameters of the tool, the elastic modulus of the tissue $E$, and the sequential index $n$ of the macro stimulus. A characteristic of this function is that it does not change its value during the time necessary to perform the macro stimulus. Due to this reason, the force $Fn$ can be measured at the beginning of the second phase of the macro stimulus (for $t = 0$). Subsequently, the value of $\tau$ can be determined through a series of measurements

## *A device for micro and macro stimulation*

Every macro stimulus includes two operational phases [3, 11, 12]:

1. Generation of stimulation. The tool performs a translation step that moves the end-effector. During the execution of this phase, a sufficient force is applied to the tool to ensure the movement and the deformation of the tissue under test.
2. Holding phase. It starts after the successful completion of the first phase. During this phase, a retention force is applied to the manipulator, which is less than the displacement force but sufficiently large to ensure that the tissue deformation that occurred during the first phase is retained. A series of successive measurements of the force generated by the tissue reaction are done over time by means of a tactile sensor built into the slider of the manipulator.

The linear actuator executes a translation movement of the manipulator by performing a step of pre-defined length $L_0$. To ensure that the movement is executed, an incremental encoder is coupled to the bipolar stepper motor. Each step is initiated by the microcontroller, which sends a narrow pulse to the motor driver and processes the encoder data to monitor the completion of the step. Then, it starts the second macro stimulation phase. During the second phase, the microcontroller performs successive measurements of the built-in tactile sensor readings.

During this period, the bipolar stepper motor is in retention mode, which is ensured by maintaining a constant current through its windings without initiating a new step (the driver always works in active state). The holding phase ensures the correct measurement of the tactile sensor response force and the processing of this data by the micro controller.

On Fig. 9 the time diagram for micro stimuls is shown.

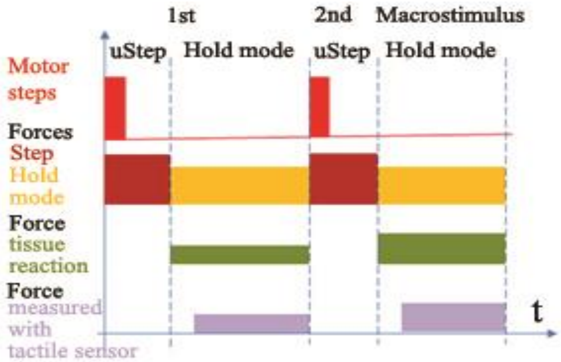


Fig. 9 Time diagram of a macro stimulus

The macro stimulus generator must have specific electromechanical properties. It must be capable of generating steps of a very small length $L_0$. This is necessary in order to emulate the requirements of the Time and Relaxation test as well as possible. The test assumes an instantaneous generation of the deformations in the examined tissue:

1. A minimal impact on the tissue by the manipulator.
2. It must block the movement of the manipulator during the second phase. This is related to the construction of the device and the manipulator body, which houses the tactile sensor that measures the force of the tissue reaction.
3. In the course of successive macro stimuli, the step that corresponds to the last macro stimulus must begin from the position at which the previous macro stimulus has been completed.

The device shown in Fig. 10 fulfills all these requirements and provides the generation of steps in the range of 8 to 48 micrometers.

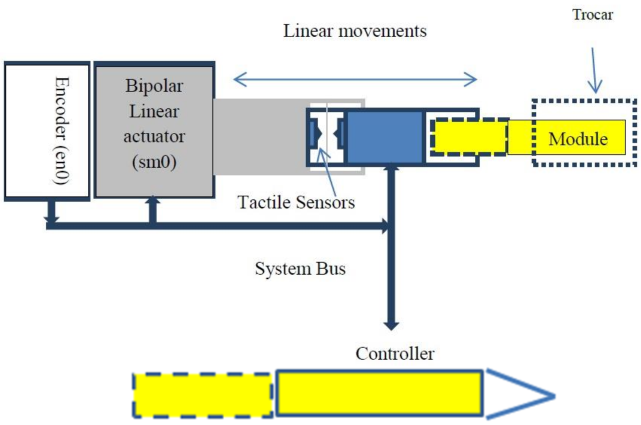


Fig. 10 A linear actuator based on a bipolar stepper motor
with a conical manipulator and a built-in tactile sensor

### *Analysis of the output signal from the research instrument*

The purpose of the research instrument is to form a series of macro stimuli to create deformations in the contact points with the tissues and to analyze the incoming information about the force of the reaction from the built-in tenzo-sensor. On the basis of this analysis, the relaxation time $\tau$ is determined, which characterizes the mechanical properties and the structure of the tissue [5].

The analysis is done separately for each of the generated macro stimuli. It involves the formation of a manipulator translation movement with a step $L_0$ (the first phase of the macro stimulation). Immediately after the motion, the initial reaction force $F_b$ is read out by means of the tactile sensor. At this point, a timer is activated, which measures the time intervals at which the reaction force is measured during the second phase of the macro stimulation. During these measurements, the condition for the newly measured force $F_c$ to have a magnitude less than or equal to $F_b/e$ is monitored, where "$e$" is the Euler number. When this condition is met, it is assumed that the readings of the timer are equal to the relaxation time $\tau$. The second phase of the macro stimulus ends and it is possible to start the next macro stimulus. Typically, macro stimulations are generated at fixed time intervals, e.g. 100 ms. This value is also used as a time-out when determining $\tau$. The actions described above are illustrated in Fig. 11.

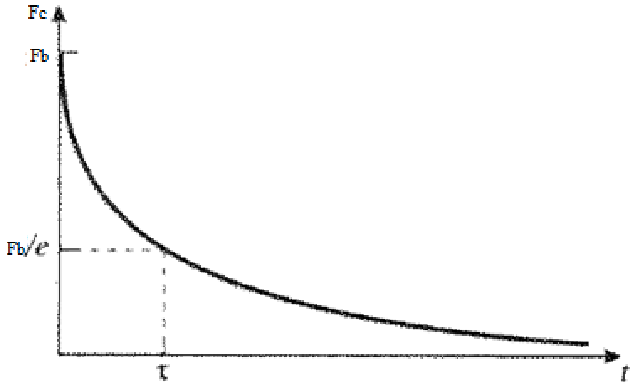


Fig. 11 Determination of the relaxation time $\tau$

By performing a sequence of macro stimulations and determining $\tau$ for each of them, we can scan the structure of the biological tissue. The inability to measure $\tau$ within the limiting period or a sharp change in the value of this parameter are indications of abnormal areas in the tissue that may be the result of the presence of tumour nodes in its composition.

## Conclusion

Hardware (construction) and user-friendly software for control and monitoring of smart instruments for diagnosis and therapy are discussed in this paper. In conformance with the requirements software programs was developed using TCL/TK language. A method for analysis of the structure of biological tissues was presented. This method poses a number of advantages:

1. The analysis is made on the basis of one micro-parameter τ that determines the type of viscoelastic environment. This parameter is measured by means of macro values – force and time – separately for each macro stimulus. There is no need to measure the deformation and strain, which are often inaccessible to the researcher.
2. $\tau$ is the result of direct force measurements, which integrate the micro responses at every contact point for the given macro stimulus. In this context, the parameter filters the noise and reports an average relaxation time.
3. This method is useful for real-time diagnostics and force feedback interaction in surgical robotics. It is possible to scan accurately the change of τ and locate precisely the areas where the parameter makes sharp changes in its value.

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