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Family Intelligent Devices to Robots as a response to MIS Robotic Challenges

Veronika Ivanova (1), Ani Boneva (2) and Plamen Vasilev (3)

(1) Institute of Robotics, Bulgarian Academy of Sciences, Sofia Bulgaria (e-mail: iwanowa.w@abv.bg)

(2) Institute of Information and Communication Technologies,
Bulgarian Academy of Sciences, Sofia Bulgaria (e-mail: ani.boneva@iict.bas.bg)

(3) University of Chemical Technologies and Metallurgy,
Sofia Bulgaria (e-mail: plamen.vasilev@uctm.edu)

***Abstract*—Minimally-Invasive Surgery (MIS) is modern technology for diagnostics and repaired of many surgical problems, ensuring excellent results and care for patients. In order to increase the applicability of MIS in surgical practice, the use of robots is beginning to improve operational efficiency. The scope of this work is to present the design of novel family devices to MIS Robots with better technical characteristics than ever including compact, convenient, simplified, better possibilities and suitable price thereby and the small hospitals to can apply similar technical solutions and patient benefit from it. The paper may to give some good ideas about how robotic technology can response to MIS challenges and this will lead to a new generation surgical robots able to meet the patient's needs and surgeon facilitates.**

***Keywords*—device, robotics, surgical robots, robot-assisted surgery, instruments, MIS procedures.**

I. Introduction

In the last years Minimally-Invasive Surgery (MIS) has revolutions results in medicine that ensure excellent care for patients. But some of surgical tasks such as suturing remain still difficult to perform compared to open surgery.In order to increase the applicability of MIS , in surgical practice, the use of robots is beginning to improve operational efficiency [1][2]. MIS robotics requires small size, limited displacements, high accuracy, reduced and précising force, that enable less traumatic access in the patient's body [3]. The question for scientists remains whether or not to develop specific robots for each organ or pathology develop highly flexible robots capable of operating on different tissues.

Many robot prototypes have been successfully developed such as Zeus [4],[5] and daVinci [6], MiroSurge [7], Avatera [8], Revo-I [9], Versius [10] and Senhance [11]. These systems include master-slave as the surgeon controls the remote slave manipulators by controlling the main manipulators. Because movements of the surgeon's hand are reproduced by slave manipulators, these surgical robots can intuitively allow operation. Commercial robots in operating rooms are large, complex, and expensive, which significantly increases operating costs and limits their MIS applications. For example daVinchi robot requires a large operating space, time-consuming setup procedure and high costs, the daVinci surgical robotic system may not be the best for MIS and hospitals despite of this it has been well-received by the clinical practice.

One of the trends in the field of surgical robots is their miniaturization- Developments related to these robots include the one port access in MIS [12], the robot that mounted on the patient's body [13], a robot that can accounting the manipulations [14]. Other problems that try to be decided are relates to compact, portable and economic benefits [15]. Of interest is the work [16] related to a modular manual surgical robot with small interchangeable 4-DOF tools that require less setup time. Hand-eye coordination is an unsolved problem with this type of system.

One of last MIS robot design is a robot that can provide 4-DOF and poses the high efficiency and dexterity [17]. This master-slave includes table-based structural design and thus try to solve the large volume and heavy weight problems of existing master-slave MIS robots and the poor intuitive manipulability problems of existing handheld robots.

Multi-armed robots built with System Redundancy and minimum 7 Degrees of freedom and together with collaborative control are used to improve MIS and avoid collisions [18]. The surgeon manages and controls procedures using a console that has built-in vision and haptic feedback functions.

This work described our efforts for improving some technical side and design of instruments and devices for MIS as response to robotic challenges. For that reason family intelligent devices to robots are designed - for diagnosis, therapy [19], manipulations and observation of the organs.

The paper is organized as follow: After a short introduction, Family Intelligent Devices to Robots are introduced discussing their architectures and main

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characteristics in Section 2. Section 3 describes Wirelesses modules. In section 4 some experimental results are included. Finally, section 5 is dedicated to conclude and points at the intentions to future work.

II. FAMILY INTELLIGENT DEVICES TO ROBOTS

A) A Robotic Diagnostic device, taking into account tissue formations reactions in mechanical force micro-impacts

Laparoscopic device 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.

In the firmware of the microcontroller, a specialized algorithm for the recognition of the tumor formation within the studied area is realized. Deviations from reference values are indicators of the presence of tumor formations. The task of the diagnostic procedure is their detection and fixation during the movement of the end effectors in the direction determined by the trocar. In the present work, an indirect approach to the study of tissue structure was chosen, which is based on the use of mechanical macro stimuli for measurement and subsequent comparative analysis of the measured data with a class of reference models taken under the same initial conditions and recorded in a special database. This method has some advantages over the known direct ways for biological microstructure characterization. Among the more important of them are: i) the analysis is made on the basis of a micro-parameter τ (which determines the type of viscoelastic environment). This parameter is measured by means of macro-screening – Force and Time individually for each macro stimulus.

There is no need to measure deformation and strain, which are often difficult to determine; ii) τ is the result from 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 the average relaxation time; iii) this method is useful for real-time diagnostics and force-feedback interacting 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 Block diagram of the operation with diagnostics device during force measuring of tissues can be seen on Figure.1.

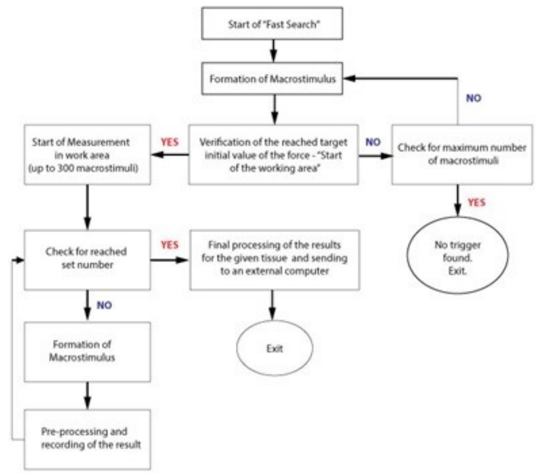

Figure 1 Block diagram of the operation of the diagnostics device

Measurements of the forces generated by tissue response to a given micro stimulus depend significantly on the profile of the end effector used. The four end-effector profiles were made, the most suitable one being selected for working with the diagnostic device due to its axial symmetry and obtaining good end-effectors. One of the experiments illustrating the operation of the device is presented in the last section.

B)A Robotic Therapeutic device

A Therapeutic robotic device for irradiation of the tissue formations with micro wave radiation; In contrast to other similar work of local tumor therapy, the paper discusses a device for surgical robots that simultaneously examines biomechanical tissue characteristics and then applies local tumor therapy.The device is designed to perform microwave irradiation of tissue formations using a special active manipulator module [20]

In the firmware of the microcontroller a specialized algorithm for control of the intensity and the time recipe of the radiation is realized. The radiation is located in a spherical area with a radius of 1 mm around the radiator and influences the rapid healing of open wounds, ulcerative disease, etc.

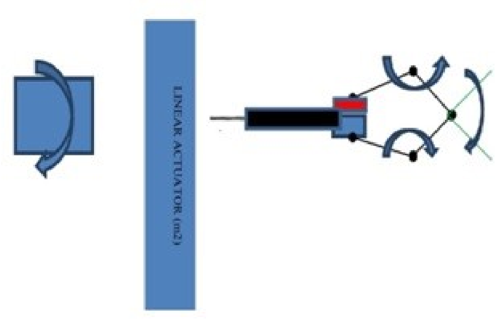

Figure 2. A Robotic Therapeutic device

The therapeutics device architecture has: High-precision channels for sensors, an analogue-digital converter of measured forces, a local indication for direct control of the applied force on the sensor, transferring channels for measured data to the device control system and transmitting wave channel to radio signals. The therapeutics device works in two modes: at the beginning the biomechanical properties of tissues are studied, after that information is transmitted and calculated.

1) Transparent SubMode (smart transmitter) – directly transfers measured data to the next control system. In this case the calculation of the P control is done in the control system of the device;

2) Calculating SubMode – the P control is built in the program inside the control module. In this case the control module generates a direct task for implementation.

In Figure 3 is shown a block diagram of the developed communication concept for a device digital controller component in the first mode.

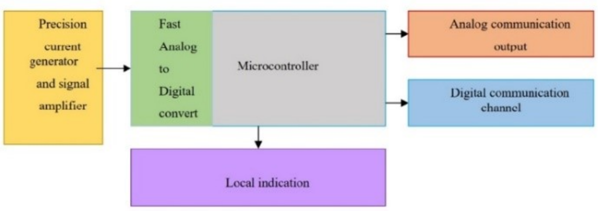

Figure 3. Scheme of the communication of the therapeutic device

C) *An observation robotic device for to monitor the tissues formations wirelessly*.

This is a wireless device for ECG (DECG that allows ECG analysis and monitoring of the patient to be carried out complexly in combination with other diagnostic and therapeutic mode of operation activities. The proposed device provides detection and rapid warning of abnormal heart rate during surgery. Innovative uMAC wireless network stack is designed for module-control block communication. Control computer program processes and monitors (remotely or directly) received information from wireless device that is connected to patient.

Figure 4. Device gen4-IoD-28T [21]

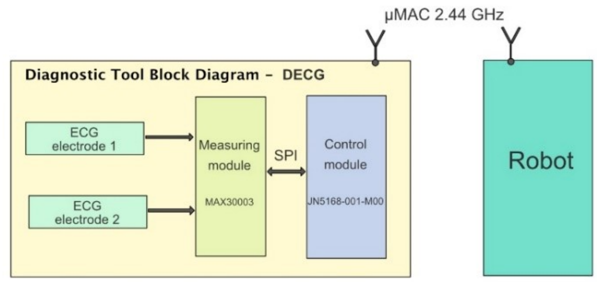

Figure 5 An Observation Device Block Diagram (DECG)

D) *A manipulating robotic device for graspring, holding, and moving of irregular shape objects*

A manipulator device for a robot is designed designed to grasping, holding, and moving of irregular shape objects in minimally invasive surgery - organs, tissues, blood vessels [22] (Figure 6). Due to the specificity of the human body and the restrictions imposed by the environment (movements are carried out in narrow space), the engines are located the base of the instrument, outside the trocar and the human body. The manipulating device to the robot has a total of four degrees of freedom (3 translations and 1 rotation) and allows obtaining an optimal space and control of the force feedback control using the direct kinematics problem of the proposed scheme and simulation program, The possible movements in the working area are two. The angle of rotation, around the axis of the device is 360 degrees. This movement is realized by one of the motors. The two execution links are fully open at the rotation angle of 120 degrees depending on the position. It allows moving only one of the links. The movement of the links is implemented by the motors and the wiring mechanisms. The length of the end - effectors is 6–8 mm by the limitations and specifics of the working area.

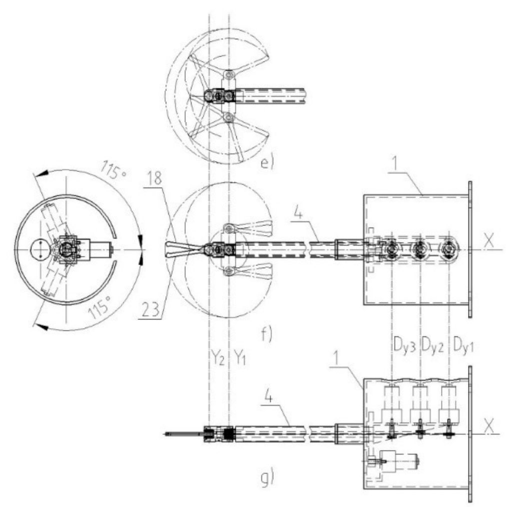

Figure 6. Working area of the manipulating robotic device at the initial, open and closed position.

These four intelligent devices 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 Operation station 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.

III. WIRELESSES MODULES

The mode of operation of the devices implies the possibility of forming precise movements while taking into account the impact resistance forces generated by the studied contact medium. These forces, transformed into voltage by pressure sensors embedded in the instrument, characterize the biological material and allow the possibility of matter of different consistency to be evaluated by comparison with reference measurements. In order to determine with sufficient accuracy, the deviation of the measured parameters from the reference ones characteristic of healthy tissue, it is necessary for the apparatus to have the ability to adjust and adapt its characteristics. Objective results of the study can be achieved by controlling the movements in the laparoscopic instrument using a specialized microcontroller. It must be able to communicate with other microcontrollers embedded in other tools involved in the operational process. The management of all instruments involved in the laparoscopic operation, together with the information obtained from their work, must be marked in a computing device that performs supervisory control and maintains specialized databases - Local operator station. From the above, it follows that the natural solution to the problems of communication connectivity between the various tools and the local operating station is the construction of a network structure in which the controlling microcontrollers participate as network nodes. The use of a cable connection in such a network is impractical for technical and technological reasons, which is why a solution based on a wireless radio link was chosen.

There are different hardware solutions for wireless local area networks (WLANs), as well as the protocols and stacks they support. The NXP microcontrollers used in this project are characterized by the ability to simultaneously implement wireless communication and control technological processes, which dramatically reduces development costs and production costs. In addition, the use of network solutions supported by them (ZigBee, JenNet, IEEE 802.15.4, etc.) creates serious difficulties in their application in this field.

These are caused by the need for the various laparoscopic instruments to be able to communicate with each other or with the VOC at all times. Standard network protocols require strict adherence to a set of access and time constraints. To solve these and other similar problems, a wireless LAN based on IEEE 802.15.4, but having a uMAC network stack and a non-standard topology, is used in this work. Figure 6 shows the topology of a uMAC network designed to control the four devices under consideration.

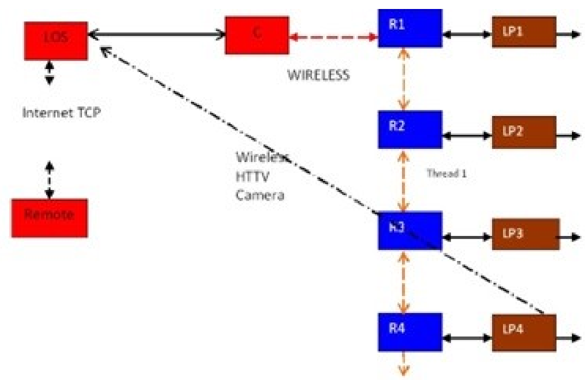

Figure 7. uMac MIS WLAN

Autonomous wireless modules.

The autonomous wirelesses 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 Operating Station to make adequate control decisions.

IV. EXPERIMENTS AND RESULTS

They are conducted experiments to demonstrate a work principle of the devices.

On the Figure 8 is shown conducted experiment with the diagnostic device where Human tissue graphic is compared to Sample graphics model.

The step of the motor is shown on the axes X. Measuring force is shown on the axes Y. Force minimum is 0.045 N., Force maximum is 0.245 N, an amplitude is 2,36.

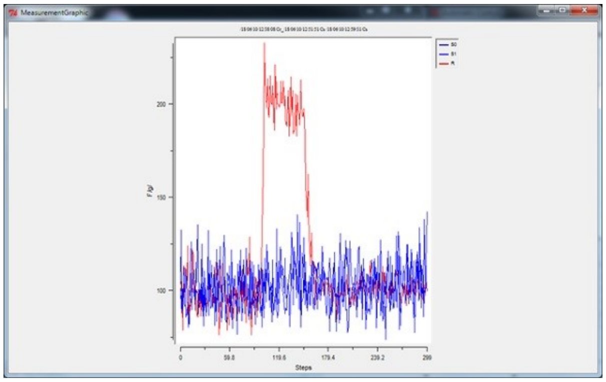

Figure 8. Comparative graphic from experiments with human tissue- samples

To receive and visualize data, a special application for augmented reality was developed, scripts for connecting to an external database (SQL, Mk4Tcl [23, 24]) were added to the program, from which to integrate data from the external sensors of a smart device.

Creating an application using augmented reality consists in adding the behavior of the virtual environment (added objects) when the smart device sensors (MEMS) interact with the real world. In the created application, when the displayed image appears, a 3D liver model is associated with it and triggered on the display along with a dataset from the MySQL database [25]. Format conversion of a model of liver is used to visualize augmented images and video streams, based on information from the device On Figure 9 is shown a liver model for experiments with the device

When the image is displayed, a 3D liver model is associated with it and triggered on the display among a dataset from the MySQL database.

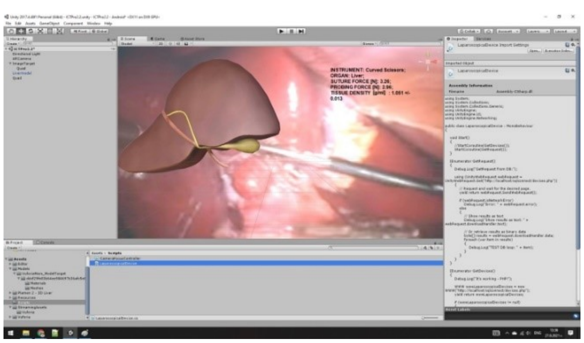

Figure 9. Experiments with a liver model

On the Figure 10 is shown an experiment with the therapeutics device. The experiment includes a search in the work area for a deviation with a set force value. It is shown in the red graphic. The blue graph shows the frequency of the generated RF signal used to irradiate the subject.

When the deviation is detected, the formation of the micro steps is terminated and the generator starts operating in accordance with the set program. Upon reaching the set frequency, in the case of 434 MHz, radiation is maintained at the set frequency and intensity for the time defined by the therapy program - in this case 10 seconds. After that, the generator turns off and the frequency drops to the minimum. The number of the micro steps is located along the X axis, along with the time in units of 100 ms.

100 ms is the time to take 1 micro step. Along the Y axis is located the power in grams, along with the frequency of the irradiation signal in megahertz.

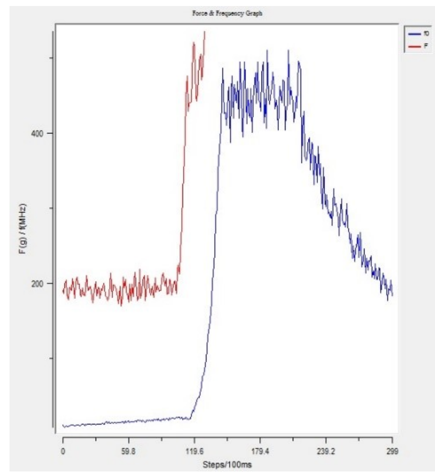

Figure 10. Graphics from conducted experiments with the therapeutics device.

V. Conclusions and intentions for future work

The scope of this work is to present the design of novel family devices to MIS Robots with better technical characteristics including compact, convenient, simplified, better possibilities and suitable price thereby and the small hospitals to can apply similar technical solutions and patient benefit from it.

The devices are intentioned for diagnosis, therapeutics, manipulations and observation procedures and introduced discussing their architectures and main characteristics. Wirelesses modules are described which serve devices. Some experimental results are shown. The paper may give some good ideas about how robotic technology can response to MIS challenges and this will lead to a new generation surgical robots able to meet the patient's needs and surgeon facilitates.

Several directions can be pursued as future work. One of them is to develop a device to monitor and adjust the level of CO_2 in abdominal cavity of a patient during surgical procedures. A computer program with information about various models of tissue should be developing too. The information obtained from devices will be used to find the appropriate tissue model and submitting the necessary command to interaction between devices and tissues.

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