Complex Control Systems ISSN 2603-4697 (Online)

Robotics in healthcare and some of its applications

Ani Boneva
Institute of Information and Communication Technologies, Bulgarian Academy of Sciences
Sofia, Bulgaria
ani.boneva@iict.bas.bg

Veronika Ivanova
Institute of Robotics, Bulgaria Academy of Sciences
Sofia, Bulgaria
iwanowa.w@abv.bg

***Abstract*—In recent decades, medicine has undergone a profound transformation brought about by the advent of robotic systems. Robots have gradually been integrated and are changing the way the human body is diagnosed, treated and restored. Robotic technologies are becoming an essential part of modern healthcare – from the operating room to home rehabilitation and telemedicine. The paper suggests some applications associated with robotic technology and its response to medical challenges and leads to a new generation of robots that can meet the patient's needs. In particular, the paper presents a robotic modular platform that is suitable for medical training. Directions for future work are mentioned such as a device to monitor and adjust the level of CO2 in abdominal cavity.**

***Keywords*—Robotics, Technology, Device, Medicine, Healthcare**

I. Introduction

The development of science opens up new opportunities for the application of robotics. This development is accompanied by the use of new methods and approaches in the design and implementation of robotic systems, which use modern achievements in areas such as electronics, mechanics, information systems and artificial intelligence. With its achievements, robotics finds its place in medicine. Medical robotics includes systems and devices, which use automation, sensors, AI and precision mechanics in order to assist medical staff. The idea is not to replace doctors, they simply don't have a chance at this stage, but to give them super capabilities such as more accuracy, less fatigue, faster patient recovery [1, 2, 3].

Robotics application in healthcare includes:

1. Surgical Robots and surgical robot training One of them is Da Vinci [4].

Advantages microincisions, less bleeding, fast recovery.

These robots find their application in urology, gynecology, cardiac surgery, orthopedics

Modern trends in the field of minimally invasive surgical robotics are Single port access - access through one hole. : The method is gentle, although it is not suitable for emergency cases due to the time delay

2.-Exoskeletons and robotic walkways (Lokomat). They assist patients with stroke, spinal cord injuries, neuromuscular diseases

3-Bionics and Smart prostheses-AI- controlled prosthetic limbs and sensor-enhanced prostheses.

4 Assistive robots for Daly-living support-feeding , lifting ets.

5. Social and therapeutics robots, robots nurses and companionships:

- PARO (the seal robot) for dementia [5].
- Robots for children with autism — teach empathy, social skills materials.

6. Logistics robots – for delivering medications and other support materials. They deliver medications, samples, materials. They save time and reduce errors — plus they reduce crowding around staff.

7 Cleaning robots • perform autonomous robots that use UV-C to destroy pathogens in a hospital room. With the development of COVID-19, this class of work is given a serious voice.

8 . Telepresence and telemedicine robots.

Mobile platforms with cameras and sensors that allow a doctor to remotely examine a patient. Part of the new trends — they are increasingly combined with IoT [6] and wearable devices.

Pill robots -Pill robots are motorized pill robots for human body observation. The obvious benefits of this technology are immediate diagnosis anywhere on the planet with minimum invasiveness, but the company believes that one day in the not-too-distant future, an army of rice-grain-sized surgeons may operate on you while you go about your normal daily routine. The obvious advantages of this technology are immediate diagnosis anywhere with minimal invasiveness, but a trend in the near future is that an army of surgeons the size of a grain of rice can operate while you go about your normal daily life [7].

9. Diagnostic and imaging robots. Precision biopsy Robots, MRI/CT navigation, robotic ultrasound. They perform precisely activities that are achieved difficultly by a human hand.

Robotics applications in healthcare is shown in Figure 1.

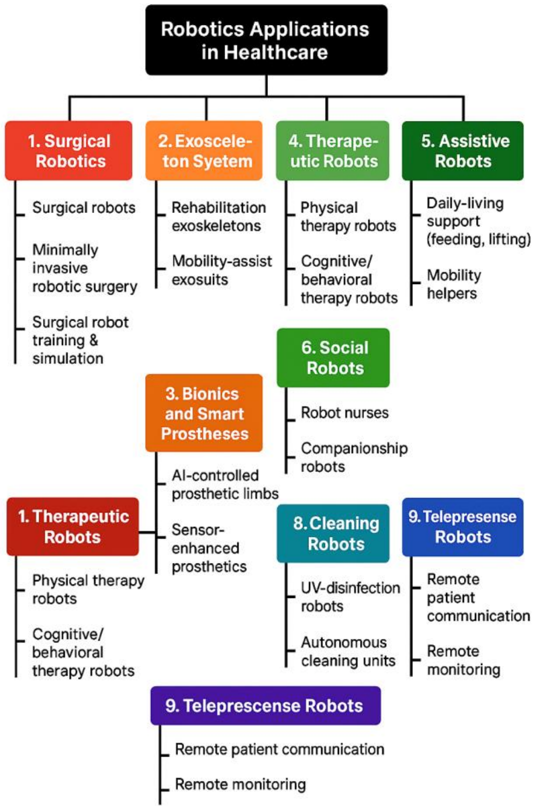

Fig.1. Robotics applications in healthcare

Technological enabling healthcare robots:

- Remote, mimics or gesture control;
- Voice control ;
- Machine visions ;
- Tactile sensors .

Main Benefits of robots in healthcare –save costs, reduce waste and improve patient care. Robots are revolutionizing medicine, although they don't come with much fanfare, they are changing everyday life and treatment outcomes. Fewer errors, faster surgeries, more accurate diagnoses, a safer environment. Combined with artificial intelligence, the entire sector is literally being "renovated." [2, 3].

II. ROBOTIC MODULAR PLATFORM AND ITS ELEMENTS

This chapter discusses a robotic modular platform and its elements. The first of them is the System for Analysis and Control of Mechanical Properties of Biological Tissues. Its application is for diagnostics of anomalous formations of a studied object. [8]

System for analysis and control of the mechanical properties of biological tissues or diagnostics device

The system uses controlled micromovements of the mounted manipulator to detect areas with structural or mechanical deviations and to determine their precise position in real time.

It is designed as an intelligent mechatronic device, the advantage of which is the ability to determine the parameter "relaxation time" τ, characterizing the internal structure of the tissue (elasticity and viscosity). This parameter is used as the main characteristic of the studied object and its change outside the specified limits signals the presence of anomalous areas in the object. The diagnostic approach applies both macro- and micro-stimulation, in which an instrument equipped with force sensors estimates the mechanical structure and response of the biological tissue.

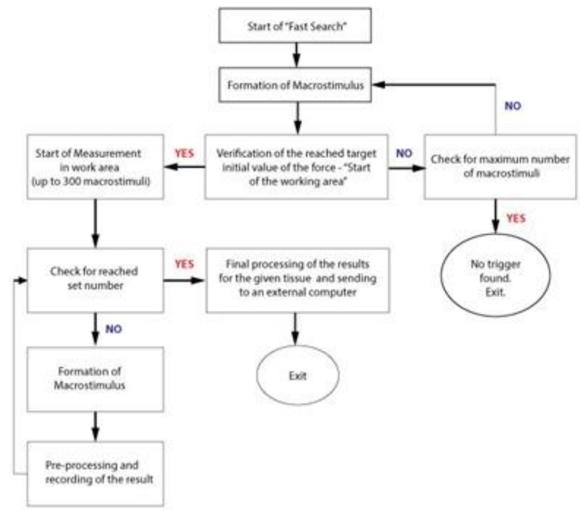

Fig 2. Block diagram of the operation of the diagnostics device

The 21st century has witnessed new and profound knowledge about cancer and significant progress in its treatment. However, problems related to the increasing incidence and successful outcome of its treatment remain. Radiation therapy (RT) is used for all types of cancer and is part of the procedure for its treatment. One of the disadvantages is excessive scattering and irradiation of healthy tissues. Advances in robotics and mechatronics can be used to optimize tumor treatment by personalizing the therapeutic dose based on clinical parameters and anatomical information.

A solution for a surgical robot device in local tumor therapy is proposed, consisting of a diagnostic device, upgraded with a generator that generates a programmed frequency, forms the necessary radio signal and feeds it to an emitter for performing radiotherapy. An electromagnetic field with a pre-programmed frequency and intensity is formed in the patient's body. The advantage is a gentle local therapy, in which the tumor is under control, while protecting the organs that are close to the diseased tissues. Another significant advantage of the solution is that the device simultaneously studies the characteristics of biomechanical tissues and applies local tumor therapy, unlike other solutions. Robotic Device for local tumor therapy is shown in Figure 3.

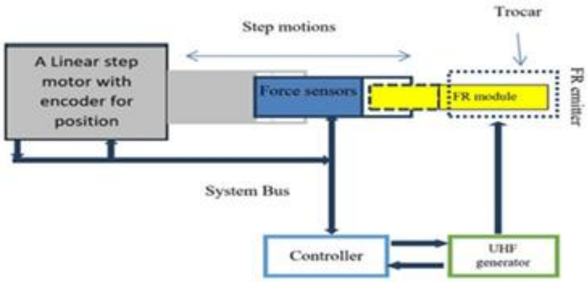

Fig 3 Robotic Device for local tumor therapy

The experiment involves searching for a deviation in the specified area with a specified power - the red graph. The blue graph shows the frequency of the generated RF signal used for irradiation. When the deviation is detected, the formation of microsteps is terminated and the generator starts operating in accordance with the specified program. Upon reaching the specified frequency, in the case of 434 MHz, the irradiation is maintained at the specified frequency and intensity for the time specified by the therapeutic program - in this case 10 seconds. Then the generator is turned off and the frequency drops to a minimum. For the red graph, the number of microsteps is located on the X axis. The search for the specified power value is shown on the Y axis. For the blue graph, the microsteps of the device are shown on the X axis, and the frequency of the irradiating signal in MHz is shown on the Y axis. Results obtained in simulation are shown in Figure 4.

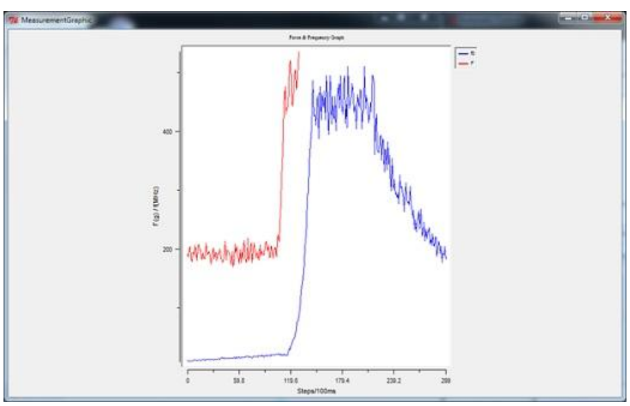

Fig. 4. Local therapy results obtained in simulation

System for collecting, processing and visualizing data with application in medicine – MOS. In order for a control device to function adequately, it is necessary to have appropriate software, an appropriate system for A Multifunctional Operator Station has been developed - the architecture of which can be seen in the figure. In addition to the other elements, the interest here is the training and simulation block and the Expert System block.

A part of software programmed using artificial intelligence techniques.

Such systems use data with expert knowledge to offer advice or make basic decisions in the field of medical diagnosis.

The components required for this block are:

- Knowledge database with facts, rules and constraints;
- Interpreter-Component for signal processing - using logical functions.

The Operating Station serves as a fundamental interface for the supervision and control of technological processes. To meet the requirements of real-time control systems, Operating Station (OS) software must possess capabilities for real-time processing, multitasking execution, and graphical visualization. Several software platforms are available for constructing Operating Stations, each offering specific advantages in terms of system architecture, functionality, and efficiency. Among the most commonly used platforms are UNIX, Linux, and Windows, which function as operating systems equipped with built-in features essential for a wide range of applications.

An alternative approach involves the use of open-source software implemented through scripting languages such as Tcl/Tk , Perl, and Python. These languages enable the seamless integration of executable code with resource requests directed to the operating system, embedded within procedural constructs. The adoption of scripting languages provides developers with direct access to system resources, significantly reducing development time while enhancing flexibility and scalability.

This chapter focuses on the design and implementation of an Operating Station for a Robotic System for Diagnostic and Therapeutic Tasks in Laparoscopic Surgery, leveraging the Tcl/Tk [9] scripting language under the Windows operating system. The development of such a system presents numerous challenges, as modern Operating Stations (OS) are inherently complex, integrating multiple interdependent subsystems that must communicate efficiently with each other as well as with external data sources. To simplify development and enhance system reliability, this work proposes an implementation based on widely adopted and well-documented technologies. In particular, Tcl/Tk is utilized due to its rich set of built-in libraries, multi-threading support, and cross-platform capabilities, making it highly suitable for real-time control applications. Furthermore, game engines written in C-based languages—both compiled and highly computationally efficient—are integrated to provide virtual reality (VR) functionalities for enhanced visualization and simulation in surgical applications.

The expert system block interacts with a graphical user interface that visualizes in a meaningful way all possible solutions, with the possibility of selection (pop-up windows, radio buttons, etc.). Multifuntional Operationg station is shown in Figure 5 [10].

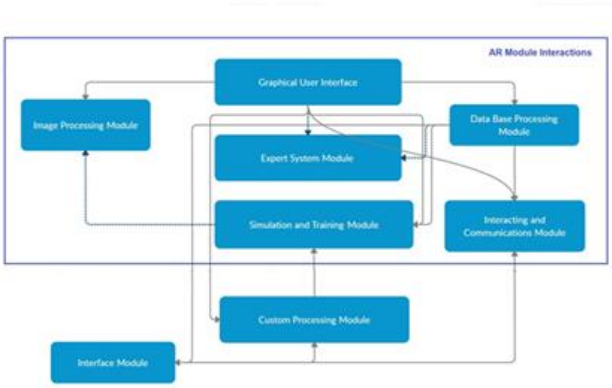

Fig 5. Multifuntional Operationg station

A mobile application for virtual and augmented reality has also been developed, as an upgrade to an operator station. An additional database has been developed for storing data from a lap instrument connected to the MOS, storing characteristics of various instruments and tissues.

When receiving contact data with a surface and depending on the data on its characteristics, the mobile application starts a training video and provides data on the measured values of the studied object (organ).

The application is suitable for training medical students and novice doctors.

Unity [11] is a software platphorme, that provides implementation of AR-VR

Two modes of operation are possible here.

AR mode provides the core functionality of MOSAR [10] , with live video enhanced with instrument and control displays, and AI-based video analysis. VR Surgical Training Simulator Mode allows surgeons to acquire, develop, and maintain skills in a variety of realistic environments with controls for safe operations. After surgery or virtual training, surgeons can review their performance. Architecture of Mobile AR-VR application for MOS is shown in Figure 6.

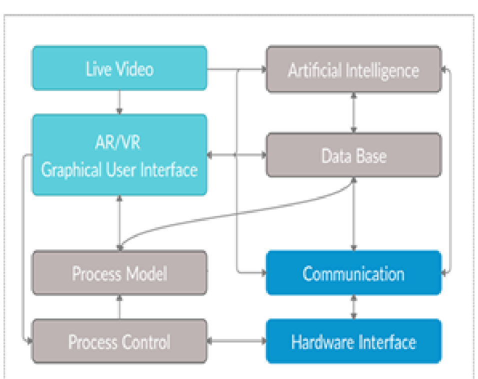

Fig 6. Architecture of Mobile AR-VR application for MOS

The ES block is replaced by an artificial intelligence block, and the graphical user interface is based on Virtual and Augmented Reality.

Robotics combined with simulation has been successfully used in the field of surgical training, providing a realistic environment for surgeons to practice complex procedures, allowing them to refine their acquired skills before performing real operations. A conceptual model of a training platform is proposed, where the monitoring of training tasks includes a virtual environment, simulation of the surgical workspace and surgical skills, robot simulation, force and position feedback, and a graphical user interface. A Model of Robot Platphorme for surgical training is shown in Figure 7.

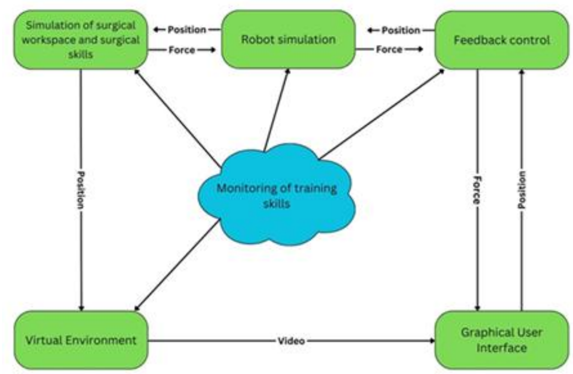

Fig 7. Conceptual model of platform for training skills in MIS and telesurgical robotics

Wireless mobile ECG device - The developed wireless mobile ECG (DECG) measures the electrical potential between two points of the human body, forms an ECG-gram and sends it on request via the wireless network to a specialized controller. The device consists of two modules - Measuring, developed based on MAX30003 [13]; Control, developed based on JN5168-001-M00 [14]. The control module controls the operation of the measuring device and provides communication of the device via a wireless interface - uMac or wired - USB. uMAC is based on the IEEE 802.15.4 stack. The measuring module generates the patient's ECG via two serviced electrodes and sends the information via an internal SPI interface to the control module. The MAX30003 (Analog Devices) specialized integrated circuit is a single-lead ECG front-end chip that has a built-in heart rate detection (R-R detection) function. Suitable for portable applications, it detects the ECG signals of the heart. The MAX30003, which performs all the analog signal processing from the electrodes and supports an interface via SPI [12, 13].

The MAX30003 has been carefully selected to take care of almost all analog operations, including acquisition, filtering, amplification, and digital conversion of the microvoltages produced by the heart. ECG device and uMAC conection with robots are shown in Figure 8. The Diagnostic Tool (DECG) feeds the measured information via the µMAC protocol to Block A of the Dedicated Controller, which via RS 232 C protocol feeds the gen4-

IoD-28T information (Block of the RMLI Dedicated Controller). Detailed information on the operation of the gen4-IoD-28T (Figure 9) is given in the description of [15, 16]. The measured information is accumulated in a local database on a SD card and is submitted to the RMLI Operator's Station upon request

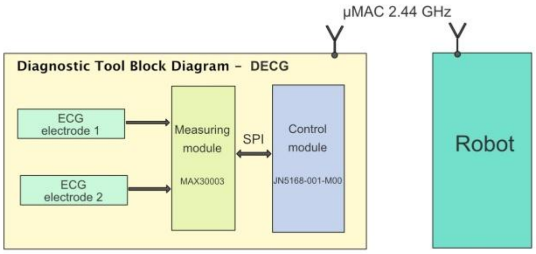

Fig. 8. ECG device and uMAC conection with robots

Fig. 9. Device gen4-IoD-28T [16].

More detailed information about the device can be found at Ivanova et. al. [15].

III. CONCLUSIONS AND INTENTIONS FOR FUTURE WORK.

The paper outlines key applications of robotic technologies in addressing the challenges of minimally invasive surgery (MIS), highlighting their role in shaping a new generation of surgical systems capable of better meeting patient-specific needs. Building on these advancements, several directions for future research are identified. One important avenue involves the development of a dedicated device for monitoring and regulating carbon dioxide levels within the abdominal cavity. Another promising direction is the creation of simulation software based on augmented and virtual reality (AR/VR) to support advanced training of emergency medical personnel in the operation of ECG devices. Additional work includes the design of pulse-monitoring systems and realistic models of laparoscopic instruments and human organs to improve surgical training and procedural planning. Further research should also explore the integration of STEMM (Science, Technology, Engineering, Mathematics, and Medicine) principles in the context of MIS, as well as the broader potential of the Internet of Medical Things (IoMT) for interconnected, data-driven surgical environments.

REFERENCES

[1] Ivanova, V., Boneva, A., Metodiev., V., Integrating STEMM Principles in Laparoscopic Surgery Training, In 34th International Scientific and Technical Conference Automation of Discrete Production Engineering, 29.06– 2.07 2025, Bulgaria, 2025, pp. 123-137, DOI: https://doi.org/10.53656/adpe-2025.11

[2] Arun Agrawal, Rishi Soni, Deepak Gupta, Gaurav Dubey, The role of robotics in medical science: Advancements, applications, and future directions, Journal of Autonomous Intelligence, 7(3), 2024, pp. 1-8, DOI: 10.32629/jai.v7i3.1008

[3] Standard Robots, Robotics in healthcare, October 2025, https://standardbots.com/blog/10-ways-robotics-are-being-used-in-healthcare-today

[4] Intuitive, https://www.intuitive.com/en-us/products-and-services/da-vinci

[5] Sense Medical Limited, 2025, https://www.paroseal.co.uk/training

[6] Ivanova, V., Boneva, A., The Internet of Medical Things Application - Challenges and Future Directions, j. „Complex Control Systems“ - Proceedings of the International Scientific Conference “Robotics & Mechatronics 2024”, 7, Art. No. 5, 2024, pp. 1-6, http://ir.bas.bg/ccs/2024/07/5.pdf

[7] National Institute of Biomedical Imaging and Bioengineering, Robotic pill can orally deliver large doses of biologic drugs, March 2, 2022, https://www.nibib.nih.gov/news-events/newsroom/robotic-pill-can-orally-deliver-large-doses-biologic-drugs

[8] Ivanova, V., Bachvarov, D., Boneva, A., Andreev, R., Dobrinkova, N., System for analysis and control of mechanical properties of biological tissues, Utility Model., Registration №: 4347/BG/U/2019/4347-[10]/04.06.2025 г, Utility model number: 3323/31.10.2019, Bulletin on Patent Office in the Republic of Bulgaria, 12.1, 2019-2029), pp. 6622-6631, https://bulletin.bpo.bg/2019/binder-2019-12-16.pdf (in Bulgarian)

[9] Tcl Developer Xchange, https://www.tcl-lang.org/

[10] Ivanova V., Vasilev, P., Stoianov, I., Andreev, R., Bonev, A., Design of Multifunctional Operating Station based on Augmented Reality (MOSAR). Journal Cybernetics and Information Technologies, 21 (1), 2021, pp. 119-136, DOI: 10.2478/cait-2021-0009

[11] Unity Technologies, Scripting API, https://docs.unity3d.com/ScriptReference/Physics.html

[12] Maxim Integrated, MAX30003: Ultra-Low Power, Single-Channel Integrated Biopotential (ECG, R-to-R Detection) AFE, Data Sheet, 2021, https://datasheets.maximintegrated.com/en/ds/MAX30003.pdf

[13] ADI Engineer Zone, Are there instructions to connect the ECG leads for the MAX30003 or MAX30001?, 2024, https://ez.analog.com/temperature_sensors/w/documents/21199/are-there-instructions-to-connect-the-ecg-leads-for-the-max30003-or-max30001

[14] NXP Laboratories UK, Data Sheet: JN5168-001-Myy, JenNet-IP, ZigBee PRO and IEEE802.15.4 Module, Data Sheet, 2013, https://www.nxp.com/docs/en/data-sheet/JN5168-001-MXX.pdf

[15] Ivanova, V., Boneva, A., Ivanov, S., Vasilev, P., A Wireless Device to Modular Robotized Instrument for Health Information, Computer Science & Engineering: An International Journal (CSEIJ), 13(2), 2023, pp. 21- 33, DOI:10.5121/cseij.2023.13203

[16] 4DSystems, Gen4-Internet of Displays Series, Data Sheet, 2021, pp. 1-23, https://eu.mouser.com/datasheet/2/451/gen4_iod_datasheet_r_1_5-1627290.pdf