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A MULTIFUNCTIONAL TRAINING PLATFORM FOR ROBOTIC SURGERY

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ABSTRACT

The paper presents the technological components, hardware implementation and software solution of a minimally invasive surgery (MIS) training platform. The platform includes basic tasks for familiarizing students and surgeons with MIS. The operator training environment simulates the behavior of the operator's hands and surgical instruments, providing feedback and 3D-visualization. Research on elements of various existing platforms was conducted and described in this paper. The platform uses a virtual environment with abstract tasks. This allows for reducing training costs, providing different levels of difficulty and focusing on the skills to be acquired. Thus, through the development of this training platform, the researchers aim to improve practice-based education in minimally invasive surgery. The results from this scientific work are suitable for surgical education e.g. the acquisition of basic skills by students in the transition from MIS to work with the robotic system for surgeons. In this regard, the assessment of students' success with the platform is an important factor in the learning process that is, in general, evaluated using two approaches described in the paper. Future work will include the development of a methodology for conducting simulation activities with the system and evaluation criteria.

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1. INTRODUCTION

Effective teaching and learning include modern training tools such as laparoscopic simulators, and virtual simulators with appropriate software. New protocols (Ilchev & Otsetova-Dudin, 2022), modeling systems tools (Artamonov et al., 2023) and sensor networks, as well as systems for information collection and its subsequent processing in the fields of medicine and surgery, are being used progressively. MIS training and simulator-based curricula have proven effective in providing skills that transfer to the operating room and are an excellent cost-effective option for students and surgeons.

A key challenge for modern surgical training concerns the design and use of new training applications that must meet the needs of today's digital world. Part of the training needs in MIS stems from it being different from open surgery (Borissova & Mustakerov, 2011). The

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surgeon works through small incisions with long, thin instruments. Natural hand-eye coordination is lost due to the access point, the two-degree-of-freedom constraint, and the lack of direct line of sight. In addition, the sensitivity of the tissue interaction is impaired due to friction between the entry point and the long, thin instruments used.

Some disadvantages of MIS can be overcome by the use of a robotic system that self-positions surgical instruments with additional degrees of freedom (DoF) and that is controlled remotely using a console Prototype System for Minimally Invasive Robotic Surgery.

MIS training systems are used everywhere. Virtual Reality surgical simulators are presented in (Ivanova et al., 2021;   et al., 2019-2026). There is an international trend to include robotics and mechatronics, computers and various Internet applications in medical curricula, as well as in lifelong learning programs.

Surgical training and simulation: Robotics combined with simulation are successfully used in the field of surgical training to provide a safe and realistic environment for surgeons to practice complex procedures. Robotic simulators offer haptic feedback and realistic surgical scenarios, allowing surgeons to hone their skills and improve their skills before performing actual surgeries.

A widely used robotic MIS system (Fig. 1) is the da Vinci from Intuitive Surgical Inc., also involving the acquisition of skills to operate the console and robotic arms. However, training the surgeon in VR is not offered. The Robotic Surgery Simulator (RoSS) (Konietschke et al., 2010) or dV Trainer (Borissova & Mustakerov, 2011) can be one solution to this problem.

These systems aim to approximate the touch and feel of the daVinci system, however, the surgical console does not include the same interfaces as the daVinci system.

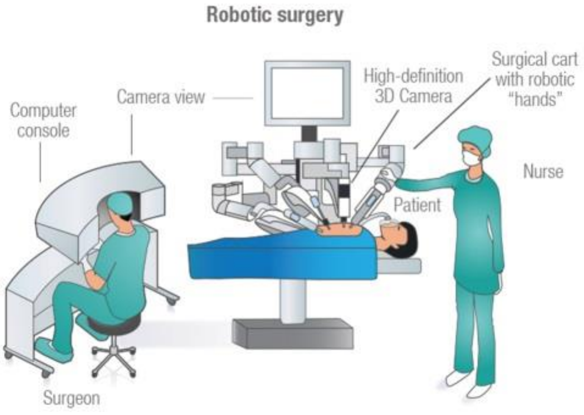


Figure 1. Robotic surgery

(Mater Private Networkp, 2024)

The use of training simulators based on the integration between haptic devices and VR is increasingly in demand in medicine. Both simulators are available for performing specific tasks such as palpation, and resection (Hamza-Lup et al., 2012; Team S.H.A.M.A.N, 2011), as well as including a set of procedures. The proposed simulator solutions allow the learner to interact with the virtual environment through a standard keyboard and haptic devices simultaneously, and the graphic interface includes a set of 3D elements - buttons, text, and inscriptions.

The development of VR, stereoscopic 3D cameras and augmented reality (AR) cameras are just some of the things that are of interest to surgery and education. The cameras used are two-dimensional with no depth perception. In contrast, the daVinci camera includes 3D visualization without the possibility of high resolution (Siddaiah-Subramanya et al., 2017). The good capabilities of this technology added to a laparoscope have significant advantages, such as capturing pathological information that may be missed by 2D techniques.

Solutions for AR visualization in laparoscopic cameras are proposed (Siddaiah-Subramanya et al., 2017) where preoperative images are registered in stationary format and overlaid on available intraoperative camera images. The last decade has witnessed several advances in the development of 3D autostereoscopic 3D displays for visualization. They can be used to observe without the need for glasses or other headgear.

This glasses-free technique provides visual experiences with quality approaching 3D depth to various imaging applications. Multi-view autostereoscopic 3D displays can offer natural 3D images using directional pixels with optical layers such as parallax barriers or lenses. However, multi-view 3D displays have limitations regarding image resolution as a result of 3D viewpoints and limited 3D viewing areas. On the other hand, the autostereoscopic 3D technique with eye tracking eliminated these limitations by focusing pixel resources, and by providing higher-resolution images (Dodgson, 2005).

Eye-tracking-based autostereoscopic 3D displays can be derived from flat-panel displays and provide motion parallax by tracking the user's eye positions through real-time pupil localization and tracking algorithms. The directional subpixel rendering method optimizes pixel resources and provides real-time rendering based on eye position (Dodgson et al., 1995).

Some 3D autostereoscopic displays with eye-tracking-based, such as game consoles, smartphones, tablets, and personal computer monitors, including medical imaging diagnostic displays. In contrast, medical imaging diagnostic techniques possessing 3D depth from stereoscopic 3D displays require further research and development —There are studies that 3D medical display systems create (Kang et al., 2022). Fig. 2 shows an Autostereoscopic system for 3D medical applications with different sizes (Kang et al., 2022).

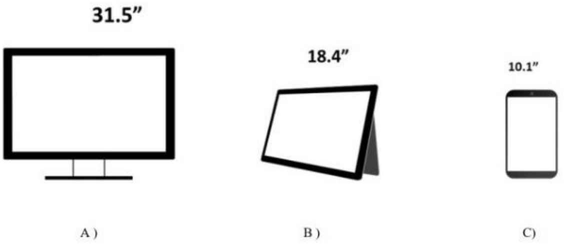


Figure 2. An Autostereoscopic system for 3D medical applications has the following sizes: A) 31,5", B) 18,4", C) 10,1" (Kang et al., 2022).

Modern displays are used in various research fields as they possess more than 6 colour views or more than 60 monochrome views and commercial large screens.

A challenge and at the same time hiding many advantages is the application of these new technologies in (MIS) (Dodgson, 2005; Travis, 1990). The observer can view objects in the whole picture by moving his head left and right as in reality, because the technique allows the eye to see different views when the head moves, providing motion parallax. These innovative information systems give the surgeon insight into a greater depth without the need to make larger incisions, so the operation is faster and safer. To get smooth the technique should have the 3D effect with more views to be transmitted.

The solutions are therefore related to a six-view autostereoscopic laparoscope arranged laterally, which requires a technique with either six lenses arranged laterally at its end or six views multiplexed in some way into a single light channel.

The Autostereoscopic Display in Laparoscopy There are several technological challenges associated with the construction of an autostereoscopic laparoscope. The image quality of a laparoscope must be similar to that of a conventional laparoscope to be acceptable as a surgical tool. In practice, it would not be difficult to make an autostereoscopic display with a sufficient resolution of 800,600 pixels is easily achievable using existing technology. The differences will be in the design of the lenses. They have small diameters and transmit less light than the larger diameter lenses used in conventional laparoscopy.

This is not an insurmountable problem and can be solved with good lens design, high-brightness input light and sensitive CCD (Charge-Coupled Device) chips. An alternative solution has been proposed with the CCD placed near the distal end of the laparoscope, eliminating the need for lenses. The fast CCD can alternatively be placed at the proximal end of the imaging scope by a large-diameter rod lens, similar to the Zeiss 2D system. If more than six views are desired such solutions are suitable, as otherwise, more views would require either smaller lenses or a larger tube (Dodgson, 2005).

Another challenge lies in the fact that the views of the six cameras may need to be aligned relative to each other for the surgeon to see a high-quality three-dimensional image. While alignment can be done optically, it can prove difficult. A simpler solution is to align the images digitally in the video multiplexer.

Virtual reality (VR) can simulate remote operations environments and allow a reduction of price because the technique is not used during training. Another advantage is that the different skills set in the program must be trained step by step, the boundaries of the real environment workspace can be ignored in the first stage of training to train only the basic skills (Cai et al., 2023).

VR simulators allow exploration of 3D models and animations. Developed mobile applications for smartphones and tablets to explore different surgical approaches. The learning system takes into account the specific human anatomy and the purpose of the operation and then positions the patient. Each virtual approach can also be divided into different phases.

VR simulators offer the training of simple movements or complex surgical procedures in a real environment close to the real thing. They reproduce the MIS by measuring movement efficiency and node reliability, uptime and even remote performance evaluation. Such simulators are expensive and lack tactile feedback and realism (Wyn et al., 2028; Giannotti et al, 2014; Munz et al., 2007).

As a result of the lack of realism, cadaver and animal models in VR simulators must be added to obtain optimal training.

Despite these, the number of VR training simulators is growing. VR simulators such as LapSimTM (Surgical Science, Gothenburg, Sweden) (LapSim, 2022) for training basic laparoscopic surgery skills and LapMentorTM (Simbionix Corporation, Cleveland, OH, USA) (Lap Mentor, 2022) comprehensive laparoscopic sigmoidoscopy training have been widely used (Wynn et al., 2018) evaluated the effectiveness of this training in terms of the process completion time, the number of right and left tool movements, and the total path length of the right and left tool movements.

A tool platform with various functions is proposed in the work. Additionally, force sensors sense at the tip of the instrument the force interactions between the instrument and the tissue and allow force feedback so that the forces between the instrument and the tissue are measured and displayed on the operator's console. Also, surgical movements and feedback forces can be scaled and adjusted to the required range to increase accuracy and sensitivity.

The report presents such a platform for skill training. A key advantage of the proposed training system is that it allows learning to be customized according to the needs of students and physicians in terms of content and method. using virtual reality simulation.

The presented work aims not only to train surgeons in basic skills in the field of mini-invasive surgery but also in specific skills in working with more complex instruments (telerobotic systems). Standard protocol is used for training basic skills in MIS and laparoscopic surgery.

The surgeon can practice skills under the constraints of the robot workspace and input devices and get used to the specifics of the environment.

The work is organized into 5 sections. The next section provides an introduction to the system hardware. Section 3 follows, where the components of the training platform and the implemented training scenarios are presented. Described in Section 4 are the ways to assess acquired skills. Last is the future work and conclusion section.

2. SYSTEM-HARDWARE

The main component in the presented work is tools designed for various medical applications in MIS (Ivanova et al., 2021; Ivanova et al., 2019-2026).

The surgeon can conveniently operate the system from an operator console. There are two modes of interaction: Haptic interfaces using haptic hand controllers and a tracking system with visual force overlay.

There are currently two stereo display technologies in use: Polarized light displays, where the user must wear glasses (Fig. 3), and autostereoscopic displays, which do not require glasses (Dodgson, 2005; Dodgson et al., 1995; Dongwoo et. al., 2022).

The two technologies can be combined arbitrarily (Fan et al., 2020).

Figure 3. Dedicated Display ReconJet™ Pro AR (Intel, 2016).

A Specialized Display (Recon Jet™ Pro AR) with VR elements can be incorporated into the Platform Control Unit (Intel, 2016). These smart glasses with auxiliary displays include 7% visual space and patient information is visualized.

The remaining space is used for normal monitoring. The auxiliary display data is sent over Wi-Fi from the program block, which is part of a purpose-built controller to control the platform's instruments.

The surgeon can operate without monitoring the touch screen of the spatial platform. An advantage is the autonomous power supply. its exclusion or inclusion by the surgeon as necessary

The display Recon Jet™ Pro AR, Wi-Fi is used for sending messages to it.

In the "smart control" section a sequence of movements and measurements are performed, and the results are visualized on the touchscreen and or output over the Internet to a remote client. If communication is enabled with the Recon Jet™ Pro AR Dedicated Display, Wi-Fi is used to send messages to it. In the event of deviations in the movement parameters, a "motion control" profile is automatically loaded and its execution continues.

A concept of the components included in the training platform for the exercises in MIS and telesurgical robotics is presented in Fig. 4.

A user interface maps the movement of the surgeon's hand and the tip of the instrument into the patient's body. The surgeon controls the tip of the instruments like the way hands are controlled. Movements can be scaled to any point in space. In this way, the surgeon can benefit from a full workspace of the telerobotic arm, independent of the workspace of the input device.

It is possible even if the haptic interface is broken to continue working with the tracked controls and vice versa.

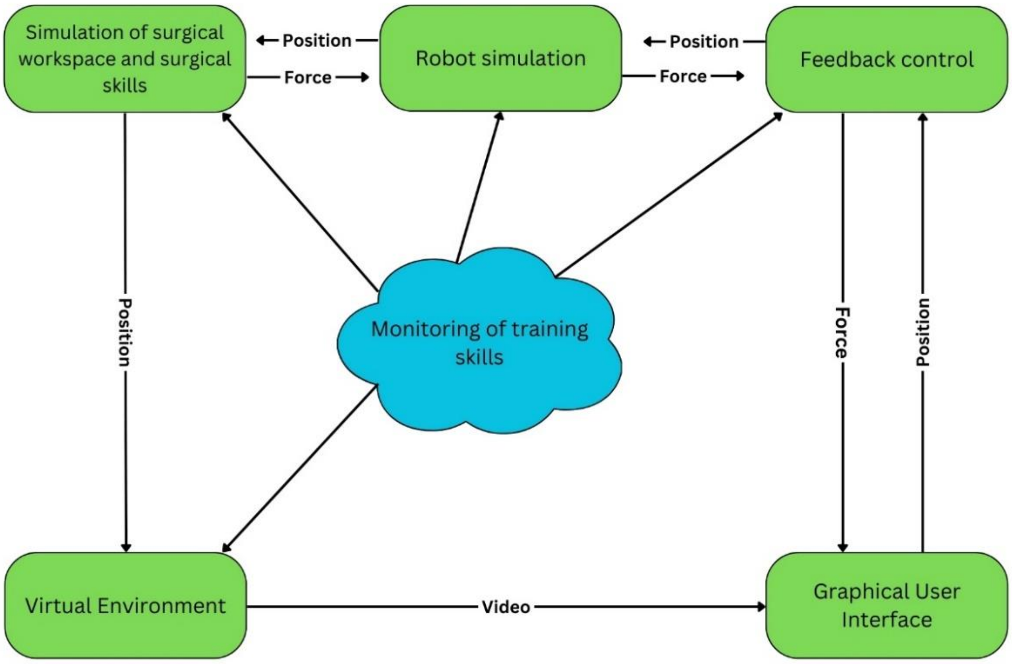


Figure 4. Conceptual model of platform for training skills in MIS and telesurgical robotics

3. DESIGN OF A MULTIFUNCTIONAL SKILLS TRAINING PLATFORM

The experimental model of the platform is focused on the specific features and training needs of a newly developed MIS robotic system.

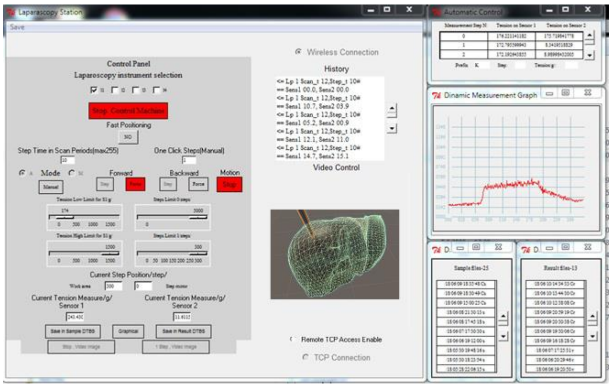
The software is developed in the Tcl scripting language using the Tk graphics library (Tcl/Tk).

The simulation is generated using the Unity Gaming Engine, which is used to develop graphical animations for conventional or VR/AR artificial representations. Unity 3D's modding capabilities include surface manipulation libraries such as the Mesh class.

Namely, the following learning skills were identified:

1) The operator connects to the remote platform with radio-controlled buttons when selecting from Mode (Control panel) as an alternative to a button on the instrument they connect.

The work with the various tools is carried out by selecting in Start control machine, which has an alternative to buttons on the tools (Fig. 5).



```
<= Lp 1 Scan_t 12,Step_t 10#
== Sens1 00.0, Sens2 00.0
<= Lp 1 Scan_t 12,Step_t 10#
== Sens1 10.7, Sens2 03.9
<= Lp 1 Scan_t 12,Step_t 10#
== Sens1 05.2, Sens2 00.9
<= Lp 1 Scan_t 12,Step_t 10#
== Sens1 12.1, Sens2 11.0
<= Lp 1 Scan_t 12,Step_t 10#
== Sens1 14.7, Sens2 15.1
```

Figure 5. The control panel of A Multifunctional Training Platform for Robotic Surgery

2) Operating console workspace limitations: The workspace of input devices is limited. When the operator's movements reach the limits in a desired direction, the tool shuts down, which is set automatically in the software. The movements must be repeated to achieve a smooth movement. Working space limitations: These limitations reduce the working space and the manipulability of instruments, a situation which the surgeon must be trained and able to handle.

3) Stereo visualization of the scene: It teaches the operator to get an idea of the distance and positions of instruments and tissues in the displayed scene.

4) Force feedback: The surgeon learns sensations with the system during interaction (eg, learning to substitute the sense of touch for the displayed interaction forces).

5) Scaling motions and forces: These are teleoperator-controlled motions and forces measured by the instrument and visualized on the user interface. It is possible to be scaled (within the stability limits of the control cycle). According to the task performance stage, appropriate values should be selected for their scaling. The graphical user interface for training is identical to the surgeon's workstation for controlling the smart instruments. The implementation with haptic interfaces is chosen

Fig. 4 shows the conceptual model of the minimally invasive surgery platform. The proposed system includes the following components:

A) Graphical Use Interface (GUI)

GUI integrates several special interfaces related to Monitoring training skills, which implements the scaling of forces and movements. Feedback control is related to tool simulation, which includes kinematics, hand-eye coordination, and kinematic constraints. The transformed position is referred to Simulation of surgical workspace and surgical skills. The forces and images are sent back to the surgeon's operating station. Various training tasks can be controlled by Monitoring training skills.

B) Feedback control

In this software module, control of position and force feedback in the tool-tissue interaction are carried out using controllers, force and position sensors. A system ensures almost identical behavior in the virtual training environment compared to the actual operation, thus facilitating the transfer of acquired skills to the real world. Features include targeting, virtual constraints, and motion tracking.

C) Robot Simulation

In this software module, instruments are simulated, taking into account your kinematic structure and external constraints such as trocar and MIS access point, it simulates the boundaries and dynamic behavior of the instruments with variable levels of reality. The angle constraints as well as the trocar constraint can be turned off for training purposes. The instrument's Be-direction control module is based on the mechatronic design used in it with the inclusion in the composition and bidirectional action of the force sensors, controller and position sensor.

D) Simulation of surgical workspace and surgical skills

The simulation block aims to provide visual information added on top of the work environment, enabling timely perception during the training of surgical staff.

The training simulation system provides a realistic environment for the exercise executions. The focus of this simulation is on maintaining the fidelity of interaction skills.

The platform interface provides feedback forces received from tools-object interactions. The environment simulation offers student training to cover the simulation parameters and their configuration, in addition to sending information for real-time evaluation of an exercise. A structured protocol is used. to realize all communication

The development consists of building a library of virtual simulation objects, representing 3D organ models, on which parameters characterizing the physical properties of real organs are set - minimum/maximum elasticity, minimum / maximum density, etc. (Fig. 6). The visualization of a certain simulation object is performed after reading the values for the corresponding quantities from the sensors of the laparoscopic instrument upon contact and checking for falling within the set boundaries of the objects.

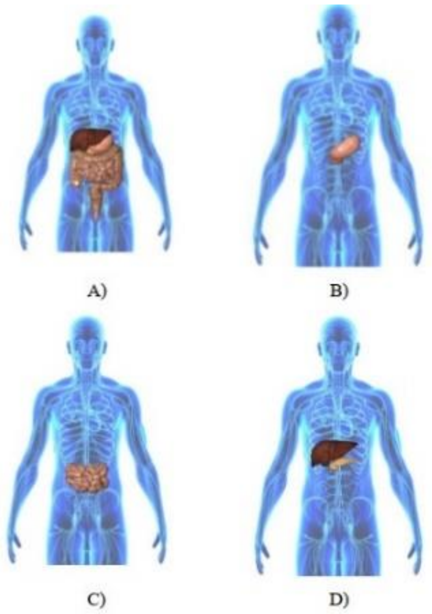


Figure 6. Libraries of 3D organ models

Where:

A) A library of digestive models that set parameters characterized by the physical properties of actual organs;

B) A library of stomach models that set parameters characterized by the physical properties of actual organs;

C) A library of entrails model that set parameters characterized by the physical properties of actual organs;
D) A library of liver and gallbladder models that set parameters characterizing the physical properties of actual organs.

Fig. 7 shows 3D instrument-organ model reactions during simulation tasks.

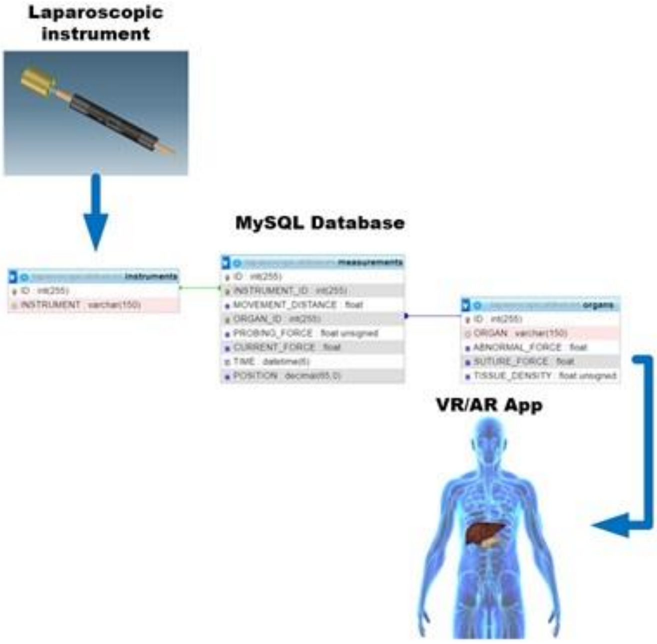


Figure 7. 3D instrument-organ model reactions during simulation tasks

E) Virtual environment

A computerized 3D model of the human digestive system is applied; VR surgical training is possible for different tasks, from simple movements to difficult procedures.

The virtual environment of the platform allows ´surgical interactions with 3D organ models and animations. Through developed mobile applications, it is possible to explore different surgical approaches. The virtual training includes 3D organ models and animations.

A training system aimed at understanding human positioning according to the patient's anatomy and purpose. The training in 3D mode is divided into phases.

The virtual environment replicates a complex MIS by measuring various procedure parameters, including movement efficiency and node reliability, operation time, and even remote performance evaluation.

F) Monitoring of training skills

The module for monitoring the training skills is interconnected with all other modules - it communicates with all of them to process the information from the performed exercises. This is the interface with which training skills are monitored, controlled, evaluated and moderated in the results of the current training tasks and difficulty level.

Additional modules for monitoring blood pressure, heart rate and others can be added to the platform (Georgieva-Tsaneva et al., 2024)

The task of the surgeon. Instrument and surgeon movements. Forces.

There are two fundamentally different ways of performing surgical tasks:

- Instruments are moved manually by the surgical team;
- The instruments are driven by a specialized, multi-armed robot/s, and the control is remote (the operating surgeon observes the movements of the executive organs of the spine and indirectly with a keyboard or joystick makes the necessary correction).

The surgeon can focus on different training skills and can cover the difficulty level of the training task

The surgeon's task is homeostasis (stopping bleeding), grasping, cutting hollow abdominal organs (stomach, small and large intestines, bile, and others), and moving tissues in one direction or another.

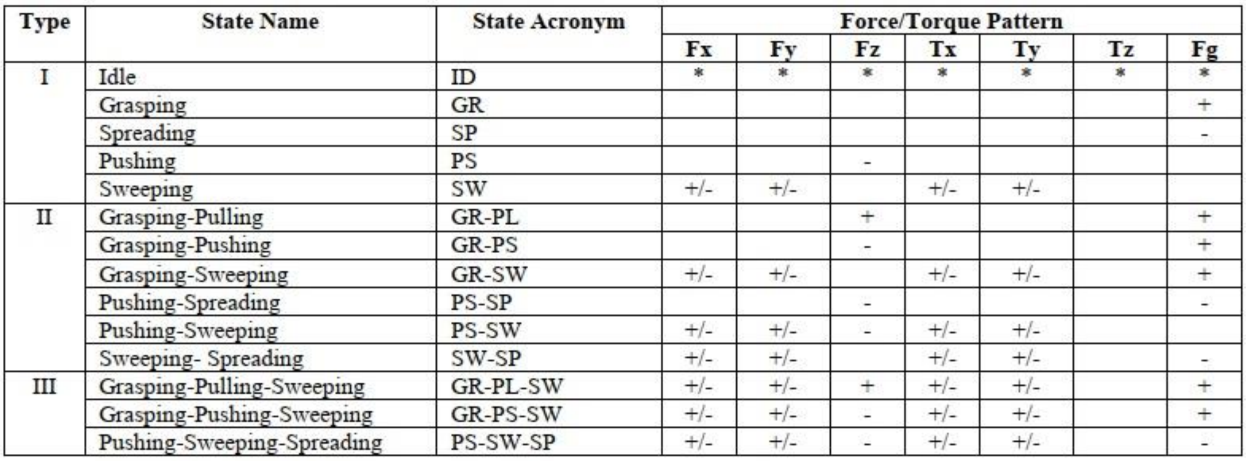
Movements when repairing the gallbladder from the liver bed are cutting-grabbing and/or twisting, stretching-simultaneous. Up and down, left and right movements are limited between 10 and 50 degrees. The back-and-forth movement cannot be more than 100 mm (Atanasova-Georgieva, 2020). Movements of the surgeon:

- Free movement until it contacts the tissues.
- Instrument orientation to the proper grip of the tissues and or for the instrument blades to the tissue.
- Pushing and/or touching tissues.
- When cutting, the plane of the blade is held against the tissues, with approximately constant contact and force.
- Fast rotation and back translation to release or repair.

Some authors have investigated the interaction between the tip of the tool and the tissue in the three directions (Table 1). Each surgical step can be decomposed into a finite number of steps determined by the way the surgeon interacts with the tissues (Rosen et al, 2001).

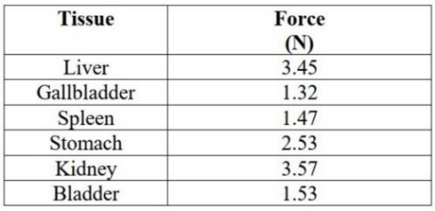
Some authors have performed in vivo tests with different types of needles and tissues where force and resolution are from 2.5 N to 0,01 N, respectively. Table 2 includes Abdominal Probing Force Measurements (Atanasova-Georgieva, 2020).

Table 1 Tool tip-tissue interactions in the three directions (Rosen et al., 2001).



Type	State Name	State Acronym	Force/Torque Pattern						
			Fx	Fy	Fz	Tx	Ty	Tz	Fg
I	Idle	ID	*	*	*	*	*	*	*
	Grasping	GR							+
	Spreading	SP							-
	Pushing	PS			-				
	Sweeping	SW	+/-	+/-		+/-	+/-		
II	Grasping-Pulling	GR-PL			+				+
	Grasping-Pushing	GR-PS			-				+
	Grasping-Sweeping	GR-SW	+/-	+/-		+/-	+/-		+
	Pushing-Spreading	PS-SP			-				-
	Pushing-Sweeping	PS-SW	+/-	+/-	-	+/-	+/-		
	Sweeping- Spreading	SW-SP	+/-	+/-		+/-	+/-		-
III	Grasping-Pulling-Sweeping	GR-PL-SW	+/-	+/-	+	+/-	+/-		+
	Grasping-Pushing-Sweeping	GR-PS-SW	+/-	+/-	-	+/-	+/-		+
	Pushing-Sweeping-Spreading	PS-SW-SP	+/-	+/-	-	+/-	+/-		-

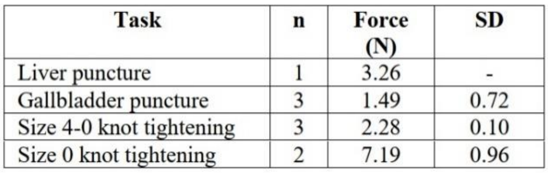
Table 2. Abdominal Probing Force Measurements



Tissue	Force (N)
Liver	3.45
Gallbladder	1.32
Spleen	1.47
Stomach	2.53
Kidney	3.57
Bladder	1.53

In Table 3 information about Suture Task Force Measurements is included (Atanasova-Georgieva, 2020).

Table. 3. Suture Task Force Measurements



Task	n	Force (N)	SD
Liver puncture	1	3.26	-
Gallbladder puncture	3	1.49	0.72
Size 4-0 knot tightening	3	2.28	0.10
Size 0 knot tightening	2	7.19	0.96

The research shows the following results: soft tissue a force of 0.2 N is required, on average soft tissue is applied 0.5 N gripping force and hard tissue 0.9 N. The forces can be in different ranges because human tissues are different - it depends on the age, the health of the patient, whether he is male or female and other factors. In general, the maximum force varies between 1.5 and 3 N. The force is from 6 to 12.5 N. Rarely, does the instrument lift the tissue, so the applied force is combined with the forces due to the properties of the tissues and those of gravity. Cutting and spreading forces are from 3 to 6 N (Gupta et al., 1996; Picod et al., 2005).

4. ASSESSMENT OF ACQUIRED SKILLS

Assessment of student work is an important factor in the learning process (Ivanova M. et al., 2023). Of the studies conducted to assess the skills of medical students and nursing staff in the field of minimally invasive surgery, two assessment approaches have been reported: 1) the checklists for objective structured assessment of technical skills (OSATS) and 2) GOALS (Global Operative Assessment of Laparoscopic Skills) (Watanabe et al, 2017; Asif et al, 2021).

As a means of automating the process of surgical skill assessment, numerous efforts have been made to develop automatic surgical skill assessments (ASSA), most of these methods require specific types of kinetic data, such as instrument movement, tracking of hand movement, eye movement tracking detailed in (Snaineh & Seales, 2015). Various approaches such as neural networks (Kitaguchi et al., 2021) and elements of artificial intelligence (Pedrett et al., 2023) have also been used.

Methods using AR have been developed to overcome some disadvantages of working with laparoscopic instruments and basic evaluation methods have been identified. More information on the subject is given in (Zorzal et al., 2020). These approaches help to objectively assess surgical competencies before performing minimally invasive surgery (MIS) (Sheng et al., 2020). Surgeons are expected to easily and quickly master more complex techniques such as laparoscopy. Simulation is emerging as an additional training tool in laparoscopic surgery by training in a safe, controlled and standardised environment, without risk to the patient, and the acquired skills are transferred to the operating room (Percul et al., 2024).

The application of simulation is increasingly increasing worldwide and is becoming an important tool in various surgical training programs. In some countries, the approval of these training courses is a prerequisite for obtaining a surgeon's certificate (Ferrufino et al., 2015). The article reviews important aspects of the application of simulation in laparoscopic surgery, including the most used software simulators and training programs, training methodologies, and the various key ways to evaluate simulation training. Simulation allows for unlimited practice and repetition without endangering the patient. Both self-study and mentoring by a qualified surgeon in group training are practised. Task performance is assessed before and after training. Speed and the GOALS scale were used to assess each student's performance and to compare the groups (Percul et al., 2024).

The main goal of any simulation program is to transfer the acquired skills to a real scenario. Kirkpatrick (Kirkpatrick, 1996) defined 4 levels necessary to evaluate the effectiveness of the training program (reaction, learning, transfer and organizational value), establishing that at level 3 the important thing is to determine whether the acquired skills and knowledge lead to a better performance in real scenarios or not. In the case of surgical training, effectiveness can be defined as the degree to which simulation can prepare surgeons to perform surgery procedures on patients (Kirkpatrick, 1996). Recent studies have shown that knowledge gained from training simulation tools is transferable to the operating room (Kirkpatrick, 1996), most of it in basic laparoscopic procedures and some approaching advanced laparoscopy. However, evidence supporting the effectiveness of simulation-based surgical training compared to the traditional model is inconsistent. One of the main reasons for the high variability of the results is the lack of rigorous methodologies aimed at obtaining the reliability and validity of the assessment tools (Adrales et al., 2003). More information on the evaluation of virtual reality training in laparoscopy and minimally invasive surgery to improve the surgical skills of trainees can be found (Elessawy et al., 2021; Ackermann et al., 2024).

The examination on the subject is intended to be a test with questions related to laparoscopic instruments and a practical part that reports the results of experiments performed by each student with simulated. A methodology for conducting simulation activities with the system and evaluation criteria is under development.

5. CONCLUSION

Using digital platforms for surgical training enhances traditional training by supporting existing teaching methods while being accessible anytime, anywhere.
The developed Multifunctional Training Platform for Robotic Surgery and the applied virtual reality software are suitable not only for training surgeons but also for medical students. The platform includes training tasks for acquiring basic skills in MIS and transitioning from MIS to working with a robotic system.

As future work, we expect this system to move to the next stage and be tested by surgeons and students. The obtained results will be able to be used to improve the training platform. Organ models from various systems in the human body such as the heart excretory system and respiratory, can be developed and added to the learning platform.

Means are provided to protect the information and the conduct of the exam, taking into account the results of experiments performed by each student with the simulator.

The results show that this platform is a good solution for surgical training. Educational tasks can also be developed to acquire useful skills in the field of minimally invasive surgery.

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References:

Ackermann, J., Pape, J., Vogler, F., Pahls, J., Baumann, J., Holthaus, B., ... & Alkatout, I. (2024). The Feasibility of Practical Training in Minimally Invasive Surgery at Medical School—A Prospective Study on the Pelvitrainer. *Medicina, 60*(1), 159. doi: https://doi.org/10.3390/medicina60010159

Adrales, G., Chu, U., Witzke, D. & et al. (2003). Evaluating minimally invasive surgery training using low-cost mechanical simulations. *Surgical Endoscopy, 17,* 580–585. doi: https://doi.org/10.1007/s00464-002-8841-7

Artamonov, Y., Golovach, I., Rosinska, H., Stanko, S., & Krant, D. (2023). Modeling the Operation of Multi-Scenario Systemsp, *Proceedings on Engineering Sciences*, *5*(2), 219-226, doi: 10.24874/PES05.02.004

Asif, H., McInnis, C., Dang, F., Ajzenberg, H., Wang, P. L., Mosa, A., ... & Winthrop, A. (2022). Objective structured assessment of technical skill (OSATS) in the surgical skills and technology elective program (SSTEP): comparison of peer and expert raters. *The American Journal of Surgery*, *223*(2), 276-279. doi: https://doi.org/10.1016/j.amjsurg.2021.03.064

Atanasova-Georgieva V. (2020). Laparoscopic Executive Tools for Robots (*PhD Thesis*, Institute of Robotics, Bulgarian Academy of Sciences). Retrieved from http://ir.bas.bg/competitions/atanasova/avto_ata.pdf (in Bulgarian).

Borissova, D., & Mustakerov, I. (2011). Methodology for Design of Web-based Laparoscopy e-Training System. European *Journal of Open, Distance and E-Learning – EURODL,*

https://old.eurodl.org/?p=archives&year=2011&halfyear=2&article=448

Cai, X., Wang, Z., Li, S., Pan, J., Li, C. , & Tai, Y. (2023). Implementation of a Virtual Reality Based Digital-Twin Robotic Minimally Invasive Surgery Simulator. *Bioengineering*, *10*(11), 1302, 1-17, doi: https://doi.org/10.3390/bioengineering10111302

Dodgson, N. (2005). Autostereoscopic 3D displays. *Computer*, *38*(8), 31–36, doi: 10.1109/MC.2005.252

Dodgson N., A., Wiseman, N. E., & Lang, S. R., & Dunn, D. C. (1995). Autostereoscopic 3D Display in Laparoscopic Surgery, Computer Assisted Radiology. *Computer Assisted Radiology, 95*. Springer, Berlin, 1139–1144.

Dongwoo, K., Jin-Ho Choi, & Hwang, H. (2022). Autostereoscopic 3D Display System for 3D Medical Images. *Applied Sciences*, *12*(9), 4288, 1-17, doi: https://doi.org/10.3390/app12094288

Elessawy, M., Mabrouk, M., Heilmann, T., & et al. (2021). Evaluation of Laparoscopy Virtual Reality Training on the Improvement of Trainees' Surgical Skills, *Medicina, 57*(2), 130, 1-13. doi: https://doi.org/10.3390/medicina57020130

Fan, Z., Ma, L., Liao, Z., Zhang, X. & Liao, H. (2020). 33 - Three-Dimensional Image-Guided Techniques for Minimally Invasive Surgery, *Handbook of Robotic and Image-Guided Surgery*, 575-584, doi: https://doi.org/10.1016/B978-0-12-814245-5.00033-5

Ferrufino, F. L., Cohen, J. V., Schaffner, E. B., Eulufi, F. C., Müller, F. P., Castillo, J. M., ... & Wilson, C. B. (2015). Simulation in laparoscopic surgery. *Cirugía Española (English Edition), 93*(1), 4-11. doi: https://doi.org/10.1016/j.ciresp.2014.02.011

Georgieva-Tsaneva, G., Gospodinova, E., & Cheshmedzhiev, K. (2024). Examination of Cardiac Activity with ECG Monitoring Using Heart Rate Variability Methods, *Diagnostics*, *14*(9), 926, 1-20, doi: https://doi.org/10.3390/diagnostics14090926

Giannotti, D., Patrizi, G., Casella, G., Di Rocco, G., Marchetti, M., Frezzotti, F., ... & Redler, A. (2014). Can virtual reality simulators be a certification tool for bariatric surgeons?. *Surgical endoscopy*, *28*, 242-248. doi: 10.1007/s00464-013-3179-x

Gupta V., Reddy N. P., Batur, P (1996). Force in computer science surgical tools: Comparasion between laparoscopic and surgical forceps. *Proceedings of 18th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Amsterdam, The Netherlands, IEEE Xplore, 223–224. doi: 10.1109/IEMBS.1996.656926

Hamza-Lup, F. G., Seitan, A., Popovici, Dorin M., & Bogdan. Crenguta M. (2012). Medical Simulation and Training: "Haptic" Liver. *Proceedings of the 7th International Conference on Virtual Learning*, Brasov, Romania, 27-33, doi: https://doi.org/10.48550/arXiv.1812.03325

Ilchev, S., & Otsetova-Dudin, E. (2022). Device model and communication protocol with low overhead for sensors and actuators in smart buildings. *In International Conference on Computer Systems and Technologies (CompSysTech '22)*, June 17, 18, University of Ruse, Ruse, Bulgaria, ACM, New York, USA, 33-38. doi:10.1145/3546118.3546141

Intel (2016). Recon Jet™ Pro AR", *User Manual*, Retrieved from https://www.intel.com/content/dam/support/us/en/documents/emerging-technologies/wearable-devices/Recon_Jet_Pro_User_Manual_120116.pdf (last visited 7.05.2024)

Ivanova, M., Petkova, P., & Petrova, T. (2023). Educators' Support Through Predictive Analytics in an Assessment Process. Methodologies and Intelligent Systems for Technology Enhanced Learning, Workshops - 13th International Conference. MIS4TEL 2023. *Lecture Notes in Networks and Systems*, *769*, Springer, Cham. doi: https://doi.org/10.1007/978-3-031-42134-1_15

Ivanova, V., Bachvarov, D., Boneva, A., Andreev, R. & Dobrinkova, N. (2019-2026). System for analysis and control of mechanical properties of biological tissues, *Utility Model.*, Registration №: 4347/BG/U/2019/4347-[5]/28.11.2023, Bulletin on Patent Office in the Republic of Bulgaria, 12.1, 6622-6631, https://bulletin.bpo.bg/2019/binder-2019-12-16.pdf (in Bulgarian)

Ivanova, V., Boneva, A., Vasilev, P., Ivanov, S., & Lekova, S. (2021). Augmented Reality based Training of Surgical Staff to Operate a Laparoscopic Instrument. *Proceedings of the 7th IEEE International Conference "Big Data, Knowledge and Control Systems Engineering" (BdKCSE'2021)*, IEEE Xplore, 1-7, doi: 10.1109/BdKCSE53180.2021.9627307

Rosen, J., Solazzo, M., Hannaford, B., & Sinanan, M. (2001). Objective laparoscopic skills assessments of surgical residents using Hidden Markov Models based on haptic information and tool/tissue interactions. *Studies in health technology and informatics, 81*, 417-423. doi: 10.3233/978-1-60750-925-7-417.

Kang, D., Choi, J.-H., & Hwang, H. (2022). Autostereoscopic 3D Display System for 3D Medical Images, *Applied Sciences*, *12*(9), 4288, 1-17. doi: https://doi.org/10.3390/ app12094288

Kirkpatrick, D. (1996). Great Ideas Revisited: Revisiting Kirkpatrick's Four-Level Model. *Training & Development, 50* (1), 54-57.

Kitaguchi, D., Takeshita, N., Matsuzaki, H., Igaki, T., Hasegawa, H., & Ito, M. (2021). Development and validation of a 3-dimensional convolutional neural network for automatic surgical skill assessment based on spatiotemporal video analysis. *JAMA Network Open*., *4*(8):e2120786, 1-10. doi:10.1001/jamanetworkopen.2021.20786

Konietschke, R., Tobergte, A., Preusche, C., Tripicchio, P., Ruffaldi, E., Webel, S., & Bockholt, U. (2010). A Multimodal Training Platform for Minimally Invasive Robotic Surgery, *IEEE Xplore*, 1-6, doi: 10.1109/ROMAN.2010.5598608

Lap Mentor (2022). A Comprehensive Simulator for Learners of All Levels. Surgical Science. Retrieved from https://simbionix.com/simulators/lap-mentor/

LapSim (2022) Training simulators for laparoscopy— LapSim®. Surgical Science. Retrieved from https://surgicalscience.com/simulators/lapsim/

Mater Private Networkp, Robotic Surgery, (2024) Retrieved from https://www.materprivate.ie/our-services/robotic-surgery

Munz, Y., Almoudaris, A. M., Moorthy, K., Dosis, A., Liddle, A. D., & Darzi, A. W. (2007). Curriculum-based solo virtual reality training for laparoscopic intracorporeal knot tying: objective assessment of the transfer of skill from virtual reality to reality. *The American journal of surgery, 193*(6), 774-783. doi: 10.1016/j.amjsurg.2007.01.022

Pedrett, R., Mascagni, P., Beldi, G., Padoy, N., & Lavanchy, J. L. (2023). Technical skill assessment in minimally invasive surgery using artificial intelligence: a systematic review. *Surgical endoscopy, 37*(10), 7412-7424. doi: https://doi.org/10.1007/s00464-023-10335-z

Percul C., Prodan, S., Vagni R., Busaniche, J., Lobos, P., Moldes, J., & Elmp,G. (2024). The role of mentorship in minimally invasive surgery simulation training. *Journal of Pediatric Surgery Open*, *5*, 100069, 1-5. doi: https://doi.org/10.1016/j.yjpso.2023.100069

Picod G., Jambon A. C., Vinatier D., Dubois, P. (2005). What can the operator actually feel when performing a laparoscopy? *Surg. Endosc*. *19*, 95–100. doi: https://doi.org/10.1007/s00464-003-9330-3

Sheng, B., Masood, S. & Younhyun Jung (2020). Chapter Twenty - Virtual and augmented reality in medicine, Biomedical Information Technology, ISBN 978-0-12-816034-3, Elsevier, 673-686, doi: https://doi.org/10.1016/B978-0-12-816034-3.00020-1

Siddaiah-Subramanya M., Kor Woi Tiang & Masimba Nyandowe, (2017). A New Era of Minimally Invasive Surgery: Progress and Development of Major Technical Innovations in General Surgery Over the Last Decade. *The Surgery Journal*, *3*(4), e163-e166. doi: 10.1055/s-0037-1608651

Snaineh, S., & Seales B. (2015). Minimally Invasive Surgery Skills Assessment Using Multiple Synchronized Sensors, IEEE International Symposium on Signal Processing and Information Technology (ISSPIT), Abu Dhabi, United Arab Emirates, *IEEE Xplore*, 314-319, doi: 10.1109/ISSPIT.2015.7394351

Team S.H.A.M.A.N (2011). Simulation in Healthcare for Advanced Medical Applications, Team Activity Report, Retrieved from https://radar.inria.fr/rapportsactivite/RA2011/s.h.a.m.a.n/s.h.a.m.a.n.pdf

Travis, A. R. L. (1990). Autostereoscopic 3-D display. *Applied Optics*, *29*(29), 4341-4342. doi: https://doi.org/10.1364/AO.29.004341

Watanabe, Y., Madani, A., Ito, Y. M., Bilgic, E., McKendy, K. M., Feldman, L. S., ... & Vassiliou, M. C. (2017). Psychometric properties of the Global Operative Assessment of Laparoscopic Skills (GOALS) using item response theory. *The American Journal of Surgery*, *213*(2), 273-276. doi: http://dx.doi.org/10.1016/j.amjsurg.2016.09.050

Wynn, G., Lykoudis, P., & Berlingieri P. (2018). Development and implementation of a virtual reality laparoscopic colorectal training curriculum. *The American Journal of Surgery*, *216*(3), 610-617, doi: https://doi.org/10.1016/j.amjsurg.2017.11.034

Zorzal, E. R., Gomes, J. M. C., Sousa, M., Belchior, P., da Silva, P. G., Figueiredo, N., ... & Jorge, J. (2020). Laparoscopy with augmented reality adaptations. *Journal of biomedical informatics, 107*, 103463. doi: https://doi.org/10.1016/j.jbi.2020.103463

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