



Application of Computer-assisted Surgery in Urology

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The purpose of this scientific article is to show the possibility of using the HoloDoctor software and hardware complex, which includes the following modules: the anatomical atlas module, the data analysis module and the surgical intervention simulation module. HoloDoctor allows us to perform surgical operations in real time. The time of operations using the HoloDoctor is reduced by 20-30% compared to traditional methods. The developed complex provides diagnostics of treatment planning, correction of the treatment plan, minimizing the risk of medical error. The developed product can be used in educational practice by introducing it into educational programs of medical specialties.

Keywords: 3D graphics; simulation surgical system; urology; radiation diagnostics; augmented and mixed reality; HoloLens.

1. INTRODUCTION

In the modern world, it is impossible to imagine everyday life without the use of computers. Computer technologies are widely used in all spheres of human life [1-5]. In medicine, computer technologies over the past decades have firmly taken the first place in solving many diagnostic and therapeutic tasks in order to preserve human health [6-8]. Today, most specialties in medicine cannot do without high-tech diagnostic methods, which greatly contribute to the detection of many diseases at early stages in the human body [9-18].

Modern computed tomographs, due to the use of several rows of detectors, make it possible to obtain an image of the human body in a shorter time and conduct a three-dimensional reconstruction of the organ of interest, the anatomical area. To date, three-dimensional processing of images obtained on multispiral tomographs is the basis not only for analysis at the planning stage of the operational manual, but also at the stage of its actual virtual and real execution [19]. More than 70 computer programs are used to perform 3D modeling and reconstruction for medical purposes [20-24]. The largest application of 3D modeling of the pathological process from the branches of medicine belongs to orthopedics, dentistry, plastic surgery. Urology is also a promising direction for the introduction of computer-assisted surgery [25].

At the stage of preoperative planning of benefits for kidney diseases, there are many issues, the solution of which would prevent the development of most intraoperative and early postoperative complications [26-27]. To solve these issues in the treatment of kidneys, especially before performing an organ-preserving manual in order to assess the complexity of the upcoming surgical intervention, we conducted testing of the HoloDoctor software and hardware complex developed by us using HoloLens augmented reality glasses.

2. MATERIALS AND METHODS

The technological cycle of using HoloDoctor is based on the following algorithm:

1. Creation of a conveyor system for digital processing of DICOM images (in the

department of radiation diagnostics), which allows reconstructing organs with CT, MRI, then the obtained 3D models of organ systems or a separate organ after digital processing are uploaded to a PACS server or to a surgical intervention simulator for further use.

2. Upload to the graphics station from the PACS server on the ARM or from the station itself (HoloDoctor.Viewer) in the HoloDoctor.Surgery 3D simulator program, an organ or organ system (a multi-layer (segmented) model with vessels, a tumor, a kidney body, a pelvis and cups).
3. Processing of the 3D model by the operator (surgeon)
4. Saving the finished script as a 3D model or video recording to the PACS server.
5. Uploading ready-made scenarios for simulating surgical intervention in the operating room to monitors from the PACS server.

We have implemented the following functions of the surgical intervention simulator module:

- 1) Uploading 3D models of organs and organ systems (multilayer) in obj format.
- 2) Placement of key points of interest of surgical intervention; selection of surgical instruments for simulation of surgical intervention.
- 3) Incision and suturing of kidney tissue (any organs and organ systems and surrounding tissues) in real-time simulation; intraoperative navigation of surgical intervention in real time; overlay of a map of blood vessels in the kidney (renal vein, artery and their branches) (Fig. 1).
- 4) Alarms in dangerous situations during the simulation of surgical intervention.

When developing the real-time surgical intervention simulator module, the need for cross-platform product was taken into account, in particular, the need to support the display in augmented reality glasses (HoloLens glasses), the use of infrared cameras, stereo sensors (TOF cameras) and pointers with sensors.

To simulate the navigation of a surgical intervention in real time, we have prepared a system with additional modules (a module for HoloLens glasses and a navigation module),

which allows making an incision and stitching the tissues of a selected area on the human body or organ, choosing simulation mod for planning an operation using an alarm (warning the system about the close distance of blood vessels if the surgeon is approaching a dangerous zone), intraoperative navigation mode of surgical intervention, selection of surgical instruments - laser, scalpel, trocar, wound expander, etc. A special function of virtual angiography has also been developed, which allows you to virtually view the internal selected structures of the organ along a given trajectory. In the presented clinical case, we used this function in viewing the lumen of the ureter and the renal pelvis, exiting blood vessels before surgery (planning the course of surgical intervention).

On the surface of the human body, using markers or pointers, previously marked key points are outlined, according to which the position of virtual models of organs and real objects is combined into a single coordinate system. Virtual models can be displayed on the screen in the operating room, as well as superimposed on the image (of the human body and organs) from the cameras of HoloLens augmented reality glasses. The pointer or marker (separately) is used as a virtual camera (the pointer is a virtual camera) to observe on the screen in real time models of anatomical structures that the pointer is directed at. The surgeon places the pointer at the points of the intended use of surgical instruments (for example, trocars) and correlates the position of the pointer model with the position of the organ models, thereby the surgeon plans access to internal structures taking into account the individual anatomy of the patient.

Also, a software module (for a simulation surgical system) with the function of importing 3D models of organs or organ systems in obj format for a surgical intervention simulator has been finalized, allowing you to download a multi-layered, highly polygonal, obtained 3D model, for example, of the kidneys (with blood vessels, pelvis and cups, ureters and a tumor, or any other organ), after reconstruction with CT. The simulator module also implements the function of overlaying a map of blood vessels (a 3D model of blood vessels, for example, kidneys, is loaded automatically when importing). Thus, the following functionality is obtained: loading a 3D model, overlaying a map of blood vessels, puncture, incision, stitching, scrolling a 3D model, zooming in and out of an organ model, instrument adjustment mode, simulation and navigation mode of surgical intervention, virtual angiography, augmented reality mode.

The system of modules developed earlier is made on the basis of Unity 3D using some of the elements prepared in Houdini.

Created 3D models of kidneys, body, muscle and adipose tissue (a multi-layer model obtained with CT or PET), then a map of vessels with various neoplasms is added to visualize the work with the separation of layers and view the blood supply of the neoplasm. Such a system allows you to show basic options with bleeding (when the vessel is affected) in real-time mode (Fig. 2). When cutting the tissue, the system tracks the movement of the scalpel relative to the vessels. When approaching a given radius relative to the edge of the mesh, a warning is issued about the possibility of damage to the vessel.

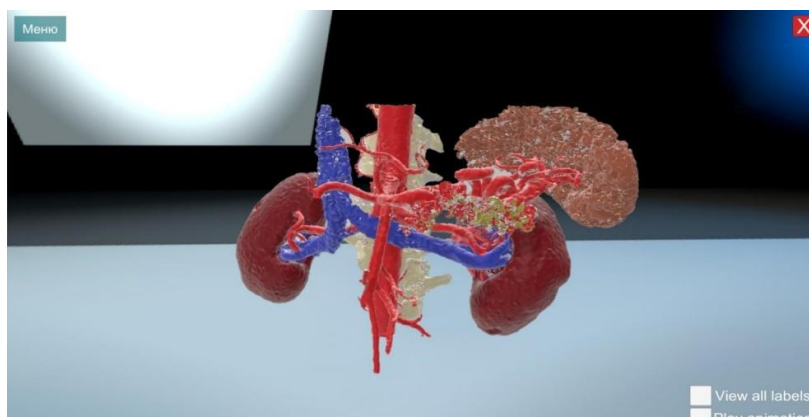


Fig. 1. Overlay of a map of blood vessels in the kidney (renal vein, artery and their branches) in the HoloDoctor program



Fig. 2. The "Alarm" mode shows options with bleeding in real-time mode

If the user ignored the warning and cut the vessel, a warning about bleeding and a timer for elimination (suturing mode) are issued. When the cut on the vessel is eliminated, the simulation continues, otherwise it ends.

This addition should contribute more to the realism of the simulation, and the caution of the user's actions, working with cutting models at different levels.

When developing the module for simulating surgical intervention (for any components), the engine for physical recalculation of the mesh of models was used, as well as a pre-prepared dissection map (we create a dissection map on the model layer, in which a mathematical algorithm for random distribution of the surface is covered with thousands of "lines" of dissection options for this tissue. After that, any movement of the scalpel in any direction coincides with one of the variants of the dissection map, at least by 80-90% - we get incisions on any part of the organ tissue with a minimum error of a fraction of a millimeter). Thus, we have implemented the following functions:

- 1) Loading a multi-layer model (organ, vessels, superimposition of tumors on top of the organ, surrounding tissues);
- 2) The ability to make incisions in layers and push them apart;
- 3) The possibility of a simple imitation of the surgeon's error (when touching the vessel) - alarm system.

For the surgeon to work on a PC, incisions are made by simply pressing the mouse button, which is tied to the emulation of a scalpel. In

HoloLens glasses, the surgeon controls a scalpel or trocar, using gestures or a system of pointers/markers. Pointers (special sensors installed at the ends of the pointer) are necessary for accurate positioning and indication of trace points.

3. RESULTS AND DISCUSSION

3.1 Technical Implementation of the Module for Simulation of Surgical Intervention Planning for an Additional Component: Urology

Based on DICOM images and their X-ray density parameters in the resulting tomogram, segmentation (reconstruction) of tissues within the area of surgical interest is performed, then a 3D model of the human body is built in the area of the intended intervention with specific organs (kidneys with a tumor) (Fig. 3).

The study of the multilayer model allows the surgeon to more accurately localize the tumor in the kidney, assess the relative location of organs and work out a specific scenario of surgical intervention for a selected area on the body.

The next step is for the surgeon to determine the optimal access routes to the surgery area. To do this, the areas of surgical interest that will need to be accessed during the operation are highlighted on the tomogram slices, while the position of the intended puncture point on the surface of the patient's three-dimensional body is indicated on the virtual model. The surgeon searches for acceptable ways to the area of localization of the tumor, its blood supply around

the selected point. With the help of the developed function in the Holo Surgeri software module, the final security assessment of the selected access method is performed: the access path is traced through the tomogram slices, the resulting trace result is displayed in the program interface on the screen. According to these data, the surgeon can finally make sure that there are no intersections of the wound canal with vital organs – this is the final stage of preoperative planning.

3.2 Description of the Operation of the Surgical Intervention Module using HoloLens Glasses

To plan the course of the surgical operation, it is necessary to work out the operation scenario, the

patient is undergoing a standard CT or MRI procedure. Next, the radiologist builds a 3D model of the internal organs and tissues of the operating field zone from the DICOM images obtained. The developed software module for viewing DICOM images allows you to identify pathological neoplasms in order to assess the severity and dynamics of pathological processes (diseases). The next step is for the surgeon to plan an operation scenario based on the resulting 3D model.

Before starting the operation, the doctor puts on augmented reality glasses, the visualization system projects a 3D model on the skin. The surgeon begins the operation (Fig. 4).

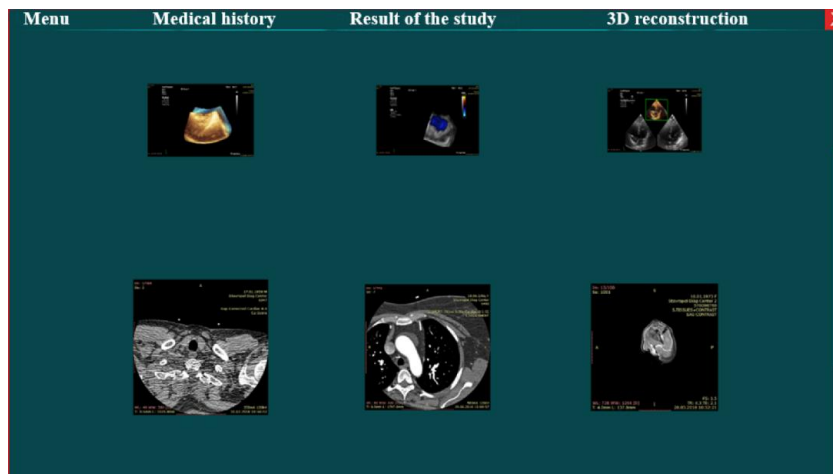


Fig. 3. Library of DICOM files of various studies in the "HoloDoctor" software package

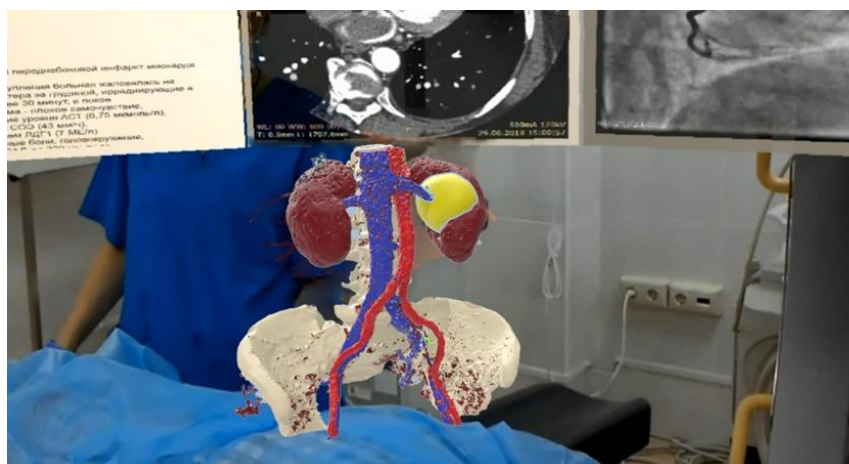


Fig. 4. 3D reconstruction of the left kidney with a neoplasm obtained with CT using Doctorcd-Slicer, HoloDoctor modules HoloViewer and HoloSurgery

3.3 The Module Testing

The next stage of the work is the direct preoperative adaptation of the virtual model with the patient's body, in this regard, the reference points on the 3D model are compared with the corresponding points on the body of the real patient (Figs. 5,6). This operation is performed using stereo sensors and a 3D marker or pointer by sequentially entering the coordinates of the reference points. As a result, the matrix of transformation of coordinate systems is calculated and, in the future, the movements in

space of the pointer tip and its axes of symmetry can be displayed on a virtual 3D model.

The study of the multilayer model allows the surgeon to more accurately localize the tumor in the kidney, assess the relative location of organs and work out a specific scenario of surgical intervention for a selected area on the body.

The access points indicated by the computer program are evaluated by a surgeon, in our case, a urologist performing minimally invasive operations on the organs of the retroperitoneal space.

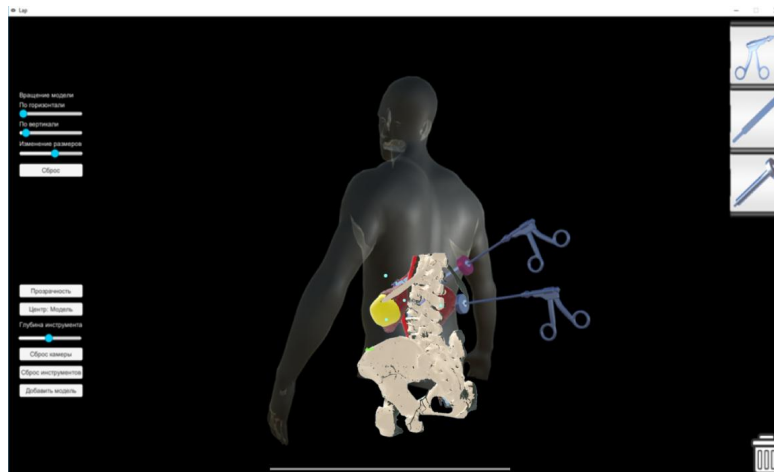


Fig. 5. Tracing the access path through the tomogram slices, the resulting trace result is displayed in the program interface on the screen. The area of surgical interest (4 points highlighted from the back on the 3D model), where a 3D model of the human body is being built in the area

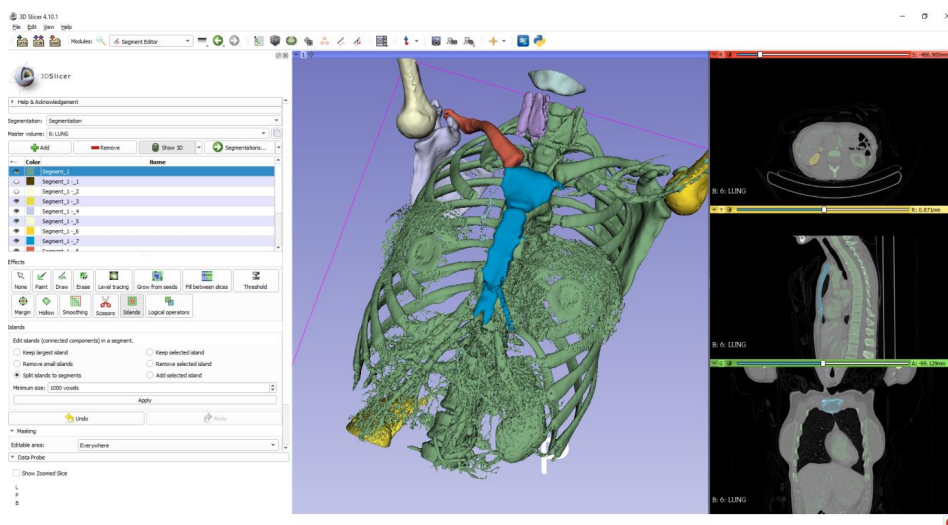


Fig. 6. Comparison of reference points on the 3D model with the corresponding points on the body of a real patient

Table 1. Comparison of HoloDoctor, DoctorCT-Slicer and Vitrea software

HoloDoctor	DoctorCT-Slicer	Vitrea
1. Automated assessment of the shape and volume of detected tumors.	1. Image processing is carried out only in manual mode	1. Improved 2D, 3D and 4D visualization and analysis of medical images.
2. Loading the obtained 3D models of an organ or organ systems into the simulation module.	2. Loading the obtained 3D models of an organ or organ systems into the simulation module.	2. Image processing is carried out in manual mode
3. Visualization and segmentation of Dicom images in semi-automatic mode	3. Reconstruction of the organ using a small amount of contrast agent.	3. Conducting quantitative and functional analysis of images and 3D models.
4. Conducting quantitative, morphological and functional analysis of images and 3D models.	4. Export images to a graphic file or a new series of DICOM images	4. Export images to a graphic file or a new series of DICOM images
5. View and describe Dicom in HoloLens mixed reality glasses.	5. Calibration of image sizes; display of image projections on images of other series.	5. Reconstruction of the organ using a small amount of contrast agent.
6. Open source code of the software package.	6. The ability to send a 3D model for 3D printing.	6. Carrying out a multiplanar reconstruction.
7. Reconstruction of the organ without the use of a contrast agent.	7. Construction of three-dimensional models based on several series of images of the same fabrics taken in different modes.	
8. The function of semi-automatic removal of artifacts during Dicom reconstruction.		
9. The ability to highlight the anatomical structures of organs by tinting objects.		
10. The ability to send a 3D model for 3D printing.		
11. Preservation of a multi-layered painted model of the organ.		

As a result, the developed system helps to choose the optimal volume of resection, increase the accuracy of surgical intervention, shorten the operation time, reduce the amount of blood loss and tissue damage to the patient, reduce the likely risks and complications.

To compare the results of studies (CT and MRI reconstructions), two programs were used: DoctorCT-Slicer and Vitrea. The results obtained are illustrated in Table 1.

4. CONCLUSION

The modules of the prototype of the HoloDoctor software package have been developed. It is established that the software package and its modules (a simulator of surgical intervention, viewing DICOM images) have proven their efficiency and effectiveness on the example of clinical cases with kidney diseases. Thus, 60 patients with kidney neoplasms, metastases, and stones were successfully operated on from 2018 to 2020 at the Stavropol Diagnostic Center. The developed software package allowed surgeons to reduce the time of operations by 1-2 hours, depending on the complexity of the operation, and also allowed them to expand the field of view of surgical intervention, using simulation, to simulate the most successful course of the operation in the program.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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