An Augmented Reality Application for the Enhancement of Surgical Decisions

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***Abstract*— The practice of Minimally Invasive Surgery is becoming more and more widespread and is being adopted as an alternative to the classical procedure. This technique has some limitations and comes at a cost to the surgeons. In particular, the lack of depth in perception and the difficulty in estimating the distance of the specific structures in laparoscopic surgery can impose limits on delicate dissection or suturing. The availability of new systems for the pre-operative planning can be of great help to the surgeon. The developed application allows the surgeon to gather information about the patient and her/his pathology, visualizing and interacting with the 3D models of the organs built from the patient's medical images, measuring the dimensions of the organs and deciding the best insertion points of the trocars in the patient's body. This choice can be visualized on the real patient using the Augmented Reality technology.**

Keywords - user interface; Augmented Reality; medical image processing

I. INTRODUCTION

One trend in surgery is the transition from open procedures to minimally invasive laparoscopic operations where visual feedback to the surgeon is only available through the laparoscope camera and direct palpation of organs is not possible.

Minimally Invasive Surgery (MIS) has become very important and the research in this field is ever more widely accepted because these techniques provide surgeons with less invasive means of reaching the patient's internal anatomy and allow entire procedures to be performed with only minimal trauma to the patient.

The diseased area is reached by means of small incisions inside the body; specific instruments and a camera are inserted in the body and what is happening inside the body is shown in a monitor. The surgeon does not have a direct vision of the organs and he is thus guided by the camera images. This surgical approach is very different from the one of open surgery, where the organ can be fully visualized and handled.

As a promising technique, the practice of MIS is becoming more and more widespread and is being adopted as an alternative to the classical procedure. The advantages of using this surgical method are evident for the patients because the possible trauma is reduced, the postoperative recovery is nearly always faster and scarring is reduced.

Despite the improvement in outcomes, these techniques have their limitations and come at a cost to the surgeons. In particular, the lack of depth in perception and the difficulty in estimating the distance of the specific structures in laparoscopic surgery can impose limits on delicate dissection or suturing.

Due to the great deal of difficulties involved in MIS related to perceptual disadvantages, many research groups, motivated by the benefits MIS can bring to patients, are now focusing on the development of surgical assistance systems.

On the other hand, advances in technology are making possible to develop systems that can help surgeons to perform their tasks in ways that are both faster and safer.

Latest developments in medical imaging acquisition and computer systems make possible the reconstruction of 3D models of the organs providing anatomical information barely detectable by CT and MRI slices or ultrasound scan as well as the safe guidance of instruments through the body without the direct sight of the physician.

The emerging Augmented Reality (AR) technology has the potential to bring the advantage of direct visualization in open surgery back to minimally invasive surgery and can increase the physician's view of his/her surroundings with information gathered from patient medical images.

In contrast with Virtual Reality technology where the user is completely immersed in a synthetic environment and cannot see the real world around him, AR technology, which consists of the addition of extra information to the real scene, allows the user to see virtual objects in addition to the real world. The user is under the impression that the virtual and real objects coexist in the same space.

In medicine, Augmented Reality technology makes it possible to overlay virtual medical images onto the patient, allowing surgeons to have a sort of "X-ray" vision of the body and providing them with a view of the patient's anatomy. The patient becomes transparent and this virtual transparency will therefore make it possible to find tumors or vessels not by locating them by touch, but simply by visualizing them through Augmented Reality.

The virtual information could be directly displayed on the patient's body or visualized on an AR surgical interface, showing where the operation should be performed.

This paper presents an advanced platform for the visualization and the interaction with the 3D patient models of the organs built from CT images.

The availability of a system for the pre-operative planning can be of great help to the surgeon and this support is even more important in pediatric laparoscopic surgery where a good understanding is needed of the exact conditions of the patient's organs and the precise location of the operational site.

In addition, the developed application allows the surgeon to choose the points for the insertion of the trocars on the virtual model and to overlap them on the real patient body using the Augmented Reality technology.

This work is part of the ARPED Project (Augmented Reality Application in Pediatric Minimally Invasive Surgery) funded by the Fondazione Cassa di Risparmio di Puglia. The aim of the ARPED project is the design and development of an Augmented Reality system that can support the surgeon through the visualization of anatomical structures of interest during a laparoscopic surgical procedure.

II. PREVIOUS WORKS

In general, AR technology in minimally invasive surgery may be used for training purposes, pre-operative planning and advanced visualization during the real procedure. Several research groups are exploring the use of AR in surgery and many image-guided surgery systems have been developed.

Devernay et al. propose the use of an endoscopic AR system for robotically assisted minimally invasive cardiac surgery [1].

Samset et al. present tools based on novel concepts in visualization, robotics and haptics providing tailored solutions for a range of clinical applications [2].

Bichlmeier et al. focus on handling the problem of misleading perception of depth and spatial layout in medical AR and present a new method for medical in-situ visualization [3].

Navab et al. introduce the concept of a laparoscopic virtual mirror: a virtual reflection plane within the live laparoscopic video, which is able to visualize a reflected side view of the organ and its interior [4], [5].

Kalkofen et al. carefully overlay synthetic data on top of the real world imagery by taking into account the information that is about to be occluded by augmentations as well as the visual complexity of the computer-generated augmentations added to the view [6].

De Paolis et al. present an Augmented Reality system that can guide the surgeon in the operating phase in order to prevent erroneous disruption of some organs during surgical procedures [7].

Soler et al. present the results of their research into the application of AR technology in laparoscopic. They have developed two kinds of AR software tools (Interactive Augmented Reality and Fully Automatic Augmented Reality) taking into account a predictive deformation of organs and tissues during the breathing cycle of the patient [8].

The collaboration between the MIT Artificial Intelligence Lab and the Surgical Planning Laboratory of Brigham led to the development of solutions that support the preoperative surgical planning and the intraoperative surgical guidance [9].

Papademetris et al. describe the integration of image analysis methods with a commercial image-guided navigation system for neurosurgery (the BrainLAB VectorVision Cranial System [10].

III. THE 3D MODELS OF PATIENT'S ORGANS

In MIS, the use of images registered to the patient is a prerequisite for both the planning and guidance of such operations. From the medical image of a patient (MRI or CT), an efficient 3D reconstruction of his anatomy can be provided in order to improve the standard slice view by the visualization of the 3D models of the organs; colors associated to the different organs replace the grey levels in the medical images.

In our case study the 3D models of the patient's organs have been reconstructed using segmentation and classification algorithms provided by ITK-SNAP [11].

ITK-SNAP provides semi-automatic segmentation using active contour methods, as well as manual delineation and image navigation; it also fills a specific set of biomedical research needs.

In our case study, the slice thickness equal to 3 mm has caused some aliasing effects on the reconstructed 3D models that could lead to inaccuracies.

Therefore we have paid special attention during the smoothing of the reconstructed models in order to maintain a good correspondence with the real organs.

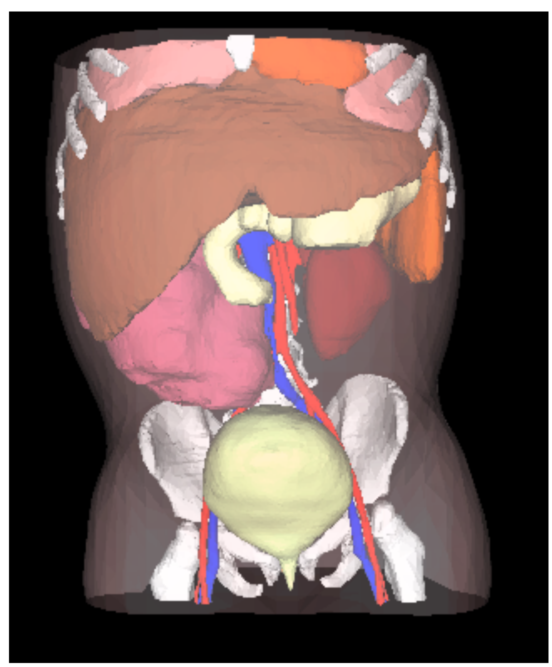

Figure 1. 3D model of the patient's organs.

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By means of the user interface it is possible to display all the organs of the abdominal region or just some of these using the show/hide functionality; it is also possible to change the transparency of each organ.

The clinical case is a two-year-old child with a benign tumor of the right kidney.

Figure 1 shows the result of the image processing using ITK-SNAP; the skin and the muscles of the abdominal region are displayed in transparency and the tumor is shown in magenta.

I. THE DEVELOPED APPLICATION

The developed application is supplied with a specific user interface that allows the user to take advantage of the feature offered by the software.

Starting from the models of the patient's organs, the surgeon can notice data about the patient, collect information about the pathology and the diagnosis, choose the most appropriate positions for the insertion of the trocars and overlap these points on the patient's body using the Augmented Reality technology.

In this way it is possible to use this platform for the pre-operative surgical planning and during the real surgical procedure too.

In addition, it could be used in order to describe the pathology, the surgical procedure and the associated risks to the child's parents, with the aim of obtaining informed consent for the surgical procedure [12].

In the developed application, as shown in Figure 2, all the patient's information (personal details, diseases, specific pathologies, diagnosis, medical images, 3D models of the organs, notes of the surgeon, etc.) are structured in a XML file associated to each patient.

A specific section for the pre-operative planning includes the visualization of the virtual organs and the physician can get some measurements on the organ or pathology and measure the distances.

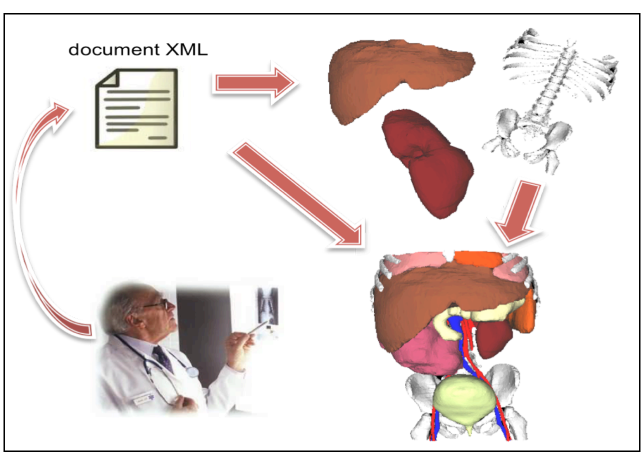

Figure 2. Patient's data collected in a XML file.

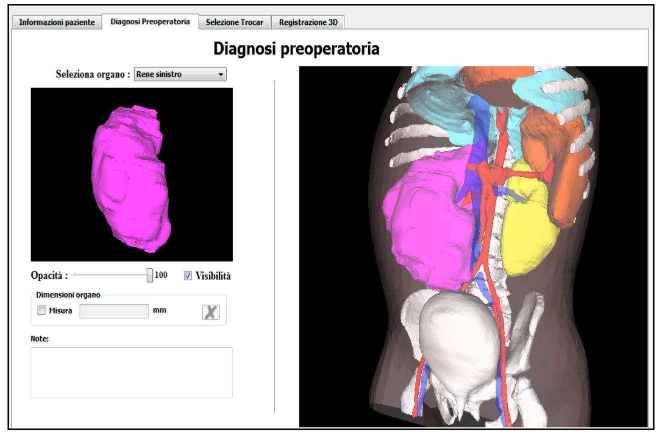

Figure 3. Section for the interaction with the organs.

Figure 3 shows the specific section of the user interface for the interaction with the 3D models of the patient's organs.

By means of a detailed view of the 3D model, the surgeon can choose the trocar entry points and check if, with this choice, the organs involved in the surgical procedure can be reached and if this is the correct choice in order to carry out the procedure in the best way.

Complications associated with initial abdominal entry are a prime concern for laparoscopic surgeons. In order to minimize first access-related complications in laparoscopy, several techniques and technologies have been introduced in the past years. The problem of blind access is that it may imply vascular injuries caused by the blind entry of instruments in the abdominal cavity.

A possibility to solve this problem may be the direct visualization of under-layer viscera and vessels.

Our application, by means of an Augmented Reality module, supports the placement of the trocars on the real patient during the surgery procedure and simulates the insertion of the trocars in the patient body in order to verify the correctness of the chosen insertion sites.

The Augmented Reality surgery guidance aims to combine a real view of the patient on the operating table with virtual renderings of structures that are not visible to the surgeon. In this application we use the AR technology in order to visualize on the patient's body the precise location of selected points on the virtual model of the patient.

For the augmented visualization, in order to have a correct and accurate overlapping of the virtual organs on the real ones, a registration phase is carried out; this phase is based on fiducial points and an optical tracker is used. The tracker system consists of 2 IR cameras and uses a position sensor to detect infrared-emitting or retro-reflective markers affixed to a tool or object; based on the information received from the markers, the sensor is able to determine position and orientation of tools within a specific measurement volume.

Usually an optical tracker is already in the modern operating rooms and provides an important help to enhance the performance during the real surgical procedures.

Figure 4 shows the section for the accurate choice of the trocar insertion points.

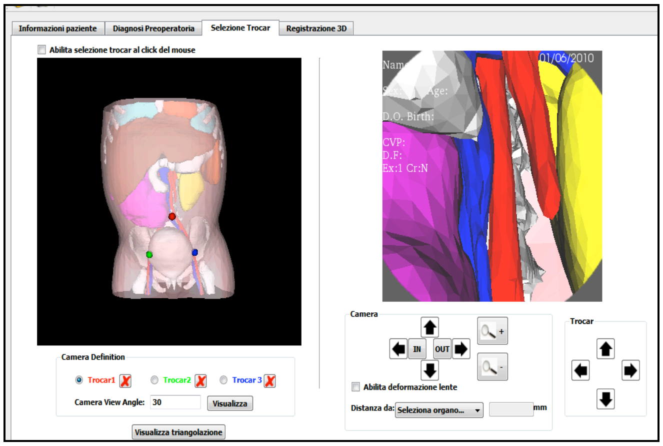

Figure 4. Section for the choice of the trocar insertion.

Using the augmented visualization, the chosen entry points for the trocars can be visualized on the patient's body through the Augmented Reality technique in order to support the physician in the real trocar insertion phase.

Figure 5 shows the augmented visualization with the trocar entry points overlapped on the patient's body.

Figure 5. The augmented visualization.

II. USABILITY TESTS

In order to evaluate the validity and the usability of the developed application and to receive possible suggestions from the users, some tests have been carried out. The test phase has been realized in order to allow the users to check all the functionalities of the application.

After a short period of training (5 minutes), the users have been tried to carry out different procedures and, subsequently, they have reported the impressions on a specific questionnaire. 15 subjects have been tested the application for an average time of 7 minutes and 43 seconds.

The obtained results can be considered satisfactory and some annotations to improve the user interface and the usability of the application have been considered.

III. CONCLUTIONS AND FUTURE WORK

The developed application offers a tool to visualize the 3D reconstructions of the patient's organs, obtained by the segmentation of a CT scan, and to simulate the placement of the trocars in order to verify the correctness of the insertion sites.

Furthermore the system retains patient and pathology information that the surgeon can insert and includes an Augmented Reality module that supports the placement of the trocars on the real patient during the surgery procedure.

An accurate integration of the virtual organs in the real scene is obtained by means of an appropriate registration phase based on fiducial points fixed onto the patient. In addition, a complete user interface allows a simple and efficient utilization of the developed application.

The platform can support the physician in the diagnosis step and in the preoperative planning when a laparoscopic approach will be followed. In addition, this support could lead to a better communication between physicians and patient's parents in order to obtain their informed consent.

The building of a complete Augmented Reality system that could help the surgeon during the other phases of the surgical procedure has been planned as future work; the acquisition in real time of a patient's video and the dynamically overlapping of the virtual organs to the real patient's body will be developed taking into account the surgeon point of view and the location of medical instrument.

An accurate AR visualization modality will be developed in order to provide a realistic depth sensation of the virtual organs in the real body.

Accuracy and usability tests will be also carried out.

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