An Augmented Reality Platform for the Enhancement of Surgical Decisions in Pediatric Laparoscopy

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Abstract— **The practice of Minimally Invasive Surgery is becoming more and more widespread and adopted as an alternative to the classical procedure. This technique presents many advantages for the patients, but also some limitations for 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 presence of new systems for the pre-operative planning can be of great help to the surgeon. The use of the Augmented Reality technology shows a way forward in bringing the direct advantage of the visualization of the open surgery back to minimally invasive surgery and can increase for the physician the view of the organs with information obtained from the image processing of the patient. The developed application allows the surgeon to get 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 - Augmented Reality; medical image processing; user interface; minimally invasive surgery; preoperative surgical planning

I. INTRODUCTION

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

Minimally Invasive Surgery (MIS), such as laparoscopy or endoscopy, has become very important and the research in this field is more and more widely accepted. These techniques offer the possibility to surgeons of reaching the patient's internal anatomy in a less invasive way and causing only a minimal trauma to patients.

The diseased area is reached by means of small incisions in the body, called ports. Specific instruments and a camera are inserted through these ports; during the operation a monitor shows what is going on inside the body. The surgeon does not have a direct vision of the organs and thus he is guided by camera images; this is very different from what happens in open surgery because there is no possibility to touch the organs.

The laparoscopic access is an alternative to the open entry techniques because it aims to prevent visceral and vascular injury due to division of abdominal wall layers. The reasons of a limited use of the open-access method is due to the time needed for the performance, the difficulty in maintaining the pneumoperitoneum because of the gas leakage and the lack of a particular evidence for the prevention of intra-abdominal injury using this method.

The vascular injury during the first laparoscopic access is the first cause of death in laparoscopy, second only to anesthesia and bowel injury, with a reported mortality rate of 15%.

Unlike most of vascular injuries, where the occurrence and presentation are immediate, many bowel injuries are not recognized at the time of the procedure because of the suboptimal visualization.

To overpass the several complications in the laparoscopic access, optically guided trocars are designed to decrease the risk of injury to intra-abdominal structures allowing the surgeon to visualize abdominal wall layers during the placement.

As a promising technique, the practice of MIS is becoming more and more widespread and is being adopted as an alternative to classical procedures.

Shorter hospitalizations, faster bowel function return, fewer wound-related complications and a more rapid return to normal activities have contributed to accept these surgical procedures.

The advantages of this surgical method are evident on the patients, but these techniques involve some limitations to surgeons; due to the limited field of view, the position and the orientation of the camera require frequently adjustments and significant hand-eye coordination is necessary because the instrument movements visualized on the screen not match the surgeon's hand movements.

In addition, the imagery is in 2D and the surgeon can

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estimate the distance of anatomical structures only by moving the camera. In laparoscopic surgery, the lack of depth perception and the difficulty in estimating the distance from the anatomical structures can impose limitations on delicate dissection or suturing.

Motivated by the benefits that MIS can bring to patients, many research groups are now focusing on the development of systems in order to assist the surgeons during the surgical procedures and to carry out their tasks in both faster and safer ways. Other research groups have developed solutions to support the preoperative surgical planning and the intra-operative surgical procedure.

Even though the interpretation of the computed tomography (CT) or the magnetic resonance images (MRI) remains a difficult task, the latest developments in medical imaging processing make possible the reconstruction of 3D models of the organs providing anatomical information barely detectable by CT and MRI slices or ultrasound scan and an accurate knowledge of patient's anatomy and pathologies as well.

A suitable use of these models could lead to an improvement in patient care by guiding the instruments through the body without the direct sight of the physician; in addition, these models can be the bases to build the realistic virtual environment used in Virtual Reality and Augmented Reality applications.

This paper presents an advanced platform for the visualization and the interaction with the 3D patient models of the organs built from CT images [1].

The presence of a system for the pre-operative planning can help the surgeon very much and this support is more and more important in pediatric laparoscopic surgery where you have to understand the exact conditions of the patient's organs and the precise location of the operational site.

The developed application allows the surgeon to choose the points for the insertion of the trocars on the virtual model and to overlap them, before starting the real surgical procedure, on the real patient body using the Augmented Reality technology.

II. THE AUGMENTED REALITY IN SURGERY

Appropriate visualization tools and techniques play an important role in providing detailed information about human organs, pathologies and realistic 3D models of the organs of the specific patient. The utilization of visual information together with the operation techniques help the surgeon during the surgical procedure and provide a possible solution to the problems that minimally invasive surgery can present.

In addition, the integration with the Virtual Reality technology can change surgical preparation and the surgeons can practice and perform a surgical procedure before the patient arrives in the operating room; this involves not only a reduction of complications, but also individual components of the surgery can be honed to precision.

The use of the Augmented Reality technology shows a way forward in bringing the direct advantage of the visualization of the open surgery back to minimally invasive surgery and can increase for the physician the view of the organs with information obtained from the image processing of the patient [2].

Augmented Reality can avoid some drawbacks of MIS and can lead to new medical treatments.

The Augmented Reality research aims to allow the real-time fusion between the computer-generated digital content and the real world. Thanks to Augmented Reality, it is possible to see hidden objects and therefore to enhance the users' perception and to improve the interaction with the real world. The virtual objects, displaying what the users cannot detect directly with their own senses, help them to perform real-world tasks better.

In opposition to Virtual Reality technology that gets into a synthetic environment but doesn't make possible the vision of the real world, Augmented Reality technology allows to see 3-dimensional virtual objects superimposed upon the real world.

Therefore, AR supplements reality rather than completely replace it. The user has a feeling that the virtual and real objects coexist in the same space.

Azuma [3] presents a survey of AR and describes the characteristics of AR systems, registration and sensing errors together with the efforts to overcome them. Using Azuma's definition, an AR system has to fulfil the following three characteristics:

- Real and virtual objects are united in a real environment, they appear to coexist in the same space;
- The system is interactive and it performs in real-time;
- The virtual objects are registered with the real world.

Milgram and Kishino [4] defined the Mixed Reality as an environment "in which real world and virtual world objects are presented together within a single display, that is, anywhere between the extrema of the virtuality continuum"

The Virtuality Continuum extends from the completely real through to the completely virtual environment with Augmented Reality and Augmented Virtuality ranging between.

Thus Augmented Reality is a mixture of reality and virtual reality. It includes both virtual objects and real-world elements, but the surrounding environment is real.

Fig. 1 shows the Milgram's reality-virtuality continuum.

In order to have a true AR application, the computer-generated organs must be accurately positioned on the real ones. For this reason it is necessary to carry out an accurate

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registration phase, which provides, as result, the correct overlapping of the 3D model of the virtual organs on the real patient [5], [6], [7].

In medical applications of the Augmented Reality technology, the right detection and the overlapping of the fiducial points are very important because even a very slight mistake could have very serious consequences on the patient.

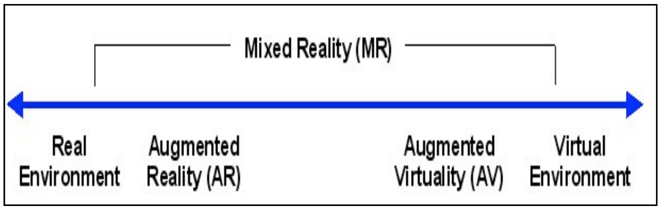

Figure 1. Milgram's reality–virtuality continuum

The integration of the registration algorithm into the surgical workflow requires a trade-off of complexity, accuracy and invasiveness. The process of registration can be obtained using the optical (infrared) tracking systems that are the best choice at the moment; these devices are already in use in the modern operating rooms.

For the registration of patient data with the AR system it is possible to have a point-based registration approach where specific fiducials can be used and fixed on the of the patient. These fiducials are touched with a tracked pointer and their positions have to match the correspondent positions of fiducials placed during the patient scanning and segmented in the 3D model. Point-based registration is known to be a reliable solution if the set of fiducials is carefully chosen. The accuracy depends on the number of fiducials, the quality of measurement and the spatial fiducial arrangement [8].

The simple augmentation of the real scene is not realistic enough because, although the organ positions are computed correctly, the relative position in depth of real and virtual images may not be perceived.

Indeed, in AR applications, although virtual objects have been correctly positioned in the scene, they are visually overlapped with all real objects, creating a situation that is not sufficiently realistic.

In particular, this effect is not acceptable for surgical AR applications and it is necessary, in addition to a proper positioning of the organs in the virtual scene, in order to ensure a correct visualization.

Some solutions have been proposed, but the issue of correct depth visualization remains partially unsolved.

Augmented Reality provides an intuitive human-computer interface. In surgery this technology makes it possible to overlay virtual medical images on the patient, allowing surgeons to have a sort of "X-ray vision" of the body and providing a view of the patient's anatomy.

Augmented Reality technology offers the same visual advantages as open surgery in minimally invasive surgery and increases the physician's visual knowledge with information gathered from patients' medical images.

The patient becomes transparent and this virtual transparency makes it possible to find tumours or vessels not using the touch, but simply visualizing them thanks to augmented reality.

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

For instance, a physician might also be able to see the exact location of a lesion on a patient's liver or the right place where to drill a hole on the skull in brain surgery or where to perform a needle biopsy of a tiny tumour.

In general, AR technology may be used in minimally invasive surgery for:

- Training purposes;
- Preoperative planning;
- Advanced visualization during the real procedure.

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 are developing many image-guided surgery systems.

Devernay et al. [9] propose the use of an endoscopic AR system for robotically assisted minimally invasive cardiac surgery. One of the problems closely linked to endoscopic surgery is that, because of the narrow field of view, sometimes it is quite difficult to locate the objects seen through the endoscope. The information coming from the 3D anatomical model of the patient's organs (built from MRI or CT-scan) and the position of the endoscope are not sufficient because some organs are displaced by the inflated gas. They propose a methodology to achieve coronary localization by Augmented Reality on a robotized stereoscopic endoscope adding "cartographic" information on the endoscopic view and by indicating the position of the coronaries with respect to the field of view.

Bichlmeier et al. [10], [11] focus on the problem of misleading perception of depth and spatial layout in medical AR and present a new method for medical in-situ visualization that allows for improved perception of 3D medical imaging data and navigated surgical instruments relative to the patient's anatomy. They describe a technique to modify the transparency of video images recorded by the colour cameras of a video see-through HMD. The presented method allows for an intuitive view on the deep-seated anatomy of the patient providing visual cues to perceive correctly absolute and relative distances of objects within an AR scene. The results can be applied for designing medical AR training and educational applications. Fig. 8 shows an application of the developed method. The medical AR scene

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is presented to the observer using an “AR window” [20].

Samset et al. [12] present tools based on novel concepts in visualization, robotics and haptics providing tailored solutions for a range of clinical applications. Examples from radio-frequency ablation of liver-tumours, laparoscopic liver surgery and minimally invasive cardiac surgery will be presented.

Navab et al. [13], [14] introduce the concept of a laparoscopic virtual mirror: a virtual reflection plane within the live laparoscopic video that is able to visualize a reflected side view of the organ and its interior. The Laparoscopic Virtual Mirror is able to reflect virtually the 3D volume as well as the laparoscope or any other modelled and tracked instruments. Combining this visualization paradigm with a registration-free augmentation system for laparoscopic surgery, it is possible to get a powerful medical augmented reality system that could make minimally invasive surgeries easier and safer to perform.

Kalkofen et al. [15] overlay carefully 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. They solve the problem of augmentations occluding useful real imagery with edges extracted from the real video stream.

De Paolis et al. [16] 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. Since the simple augmentation of the real scene cannot provide information on the depth, a sliding window is provided in order to allow the occlusion of part of the organs and to obtain a more realistic impression that the virtual organs are inside the patient’s body. In addition, distance information is provided to the surgeon and an informative box is shown in the screen in order to visualize the distance between the surgical instrument and the organ concerned. When the distance between the surgical instrument and some specified organs is under a safety threshold, a video feedback as well as an audio feedback in the form of an impulse are provided. The frequency of this impulse increases when the distance between the surgical instrument and the organ concerned decreases.

Soler et al. [17] present the results of their research into the application of AR technology in laparoscopic and NOTES (Natural Orifice Transluminal Endoscopic Surgery) procedures. 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. A preclinical validation has been performed on pigs and results are very encouraging and represent the first phase for surgical gesture automation that will make it possible to reduce surgical mistakes.

The collaboration between the MIT Artificial Intelligence Lab and the Surgical Planning Laboratory of Brigham [18] has led to the development of solutions that support the preoperative surgical planning and the intraoperative surgical guidance.

Papademetris et al. [19] describe the integration of image analysis methods with a commercial image-guided navigation system for neurosurgery (the BrainLAB VectorVision Cranial System).

III. The Informed Consent

In the current climate of increasing awareness, patients are demanding more knowledge of the operative process. The term "informed consent" explains the process by which, before treatment, comprehensive and impartial information regarding a planned operative procedure is provided to a patient so that he can understand the implications of the procedure before consenting.

Informed consent is a process of communication between patient and physician that results in the patient's authorization or agreement to undergo a specific medical intervention.

In the communications process the physician discusses with the patient about the patient's diagnosis (if known), the nature and purpose of a proposed treatment or procedure, the risks and benefits of a proposed treatment or procedure, the risks and benefits of an alternative treatment or procedure and the risks and benefits of not receiving or undergoing a treatment or procedure.

Bollschweiler et al. [20] present the results of the study of a new method of consenting improved using a multimedia-based information program (MM-IP). 80 patients undergoing laparoscopic cholecystectomy went through the standard informed consent process and a group of patients were also given access to a MM-IP. Questionnaires were used to evaluate the effectiveness of the MM-IP for improving the consent process and were completed before surgery in order to evaluate how patients perceived their own understanding of important aspects of their illness. Patients positively evaluated the use of the MM-IP.

Eggers et al. [21] present a multimedia program aimed at obtaining informed consent from obese patients before gastric banding. The result emphasizes that the multimedia program clearly benefits both surgeons and patients, but the personal contact with the surgeon remains essential because the information presented in multimedia format do not alleviate patient anxiety.

Wilhelm et al. [22] evaluate the impact of an extended education on patients undergoing cholecystectomy. For extended patient information, a professionally built DVD was used and the quality of education was evaluated using a purpose-built questionnaire. They prove the positive impact of an information DVD on patients knowledge;

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nevertheless, they assert that the multimedia tools cannot replace personal interaction and should only be used to support daily work.

IV. 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 the guidance of this kind of operations. From the medical image of the patient (MRI or CT) it is possible to obtain an efficient 3D reconstruction of his anatomy and improve the standard slice view by means of the visualization of the 3D models of the organs.

The 3D models of the patient's anatomy are built from the medical images (MRI or CT) of a patient by means of the application of segmentation and classification algorithms. The grey levels in the medical images are replaced by colours and associated to the different organs.

Several research teams deal with the task of segmentation and developed techniques that allow extracting the patient's organs from CT-scan or MRI automatically or interactively.

Nowadays there are different software used in medicine for the visualization and the analysis of scientific images and the 3D modelling of human organs; Mimics [23], 3D Slicer [24], ParaView [25] OsiriX [26] and ITK-SNAP [27] play an important role among these tools.

In our case studies, the 3D models of the patient's organs have been reconstructed using segmentation and classification algorithms provided by ITK-SNAP and by 3D Slicer.

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.

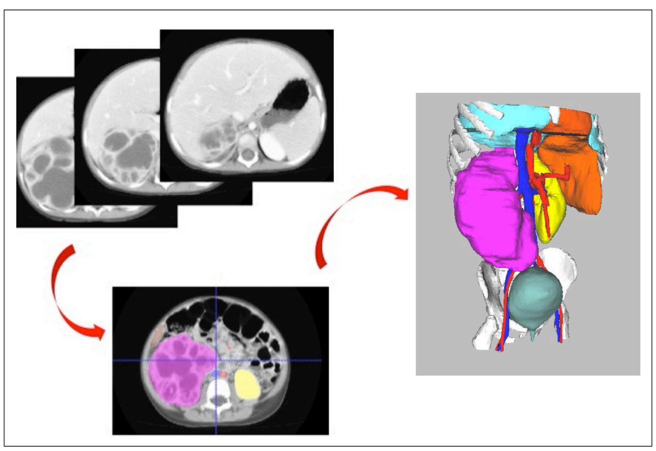

Figure 2. An example of the image processing using ITK-SNAP.

3D Slicer is a multi-platform, free and open-source software package for visualization and medical image computing. The platform provides functionality for segmentation, registration and three-dimensional visualization of multi-modal image data.

Fig. 2 shows the result of the image processing using ITK-SNAP; the skin and the muscles of the abdominal region are displayed in total transparency and the tumour is shown in magenta.

V. THE CASE STUDIES

We processed two different case studies: the first case study, shown in Fig. 3, concerns a two-year-old child with a benign tumour of the right kidney; the second case study, shown in Fig. 4, concerns a twelve-year-old child with a tumour of the peripheral nervous system (ganglioneuroma).

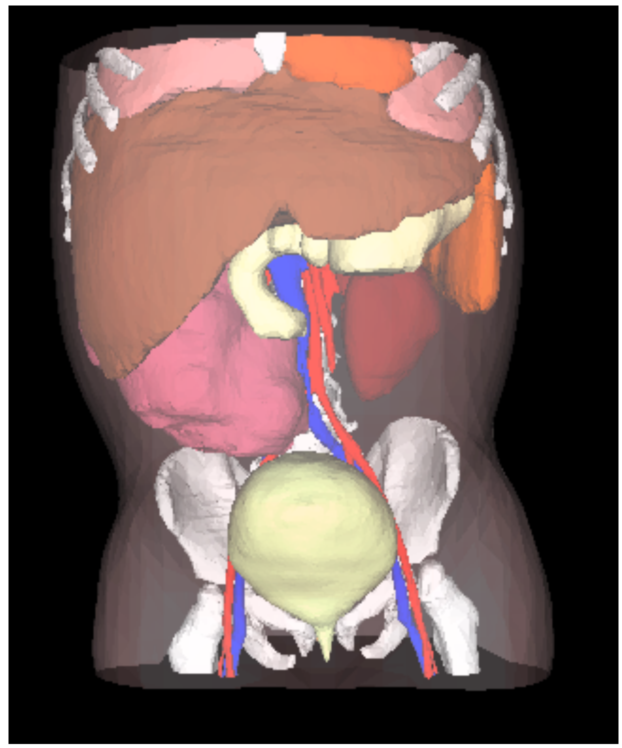

Figure 3. 3D model of a child with a tumour at the kidney.

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 to the smoothing of the reconstructed models in order to maintain a good correspondence with the real organs.

In our application, the mesh editing has been carried out using the open-source MeshLab software application [28].

A radiologist has validated the obtained 3D models.

VI. THE USED TECHNOLOGIES

In the application, it is necessary to use an optical tracker in order to detect without delay the right position and orientation of the surgical tool used by the surgeon. The tracking system is also used in order to permit the overlapping of the virtual organs on the real ones in the

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augmented visualization of the scene during the real surgical procedure.

Among the different tracking systems based on mechanical, optical or visual technologies, we chose an optical tracker (the Polaris Vicra of the NDI Inc.) in order to avoid the problems typical of the mechanical systems associated to the use of metal devices.

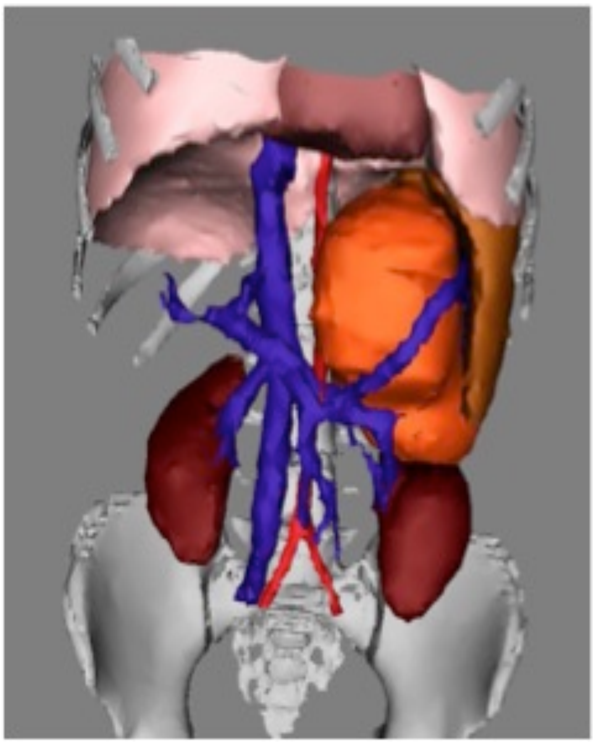

Figure 4. Virtual model of a child with a ganglioneuroma.

The Polaris Vicra optical system [29] tracks both active and passive markers and provides precise, real-time spatial measurements of the location and orientation of an object or tool within a defined coordinate system.

The system uses a position sensor to detect infrared-emitting or retro-reflective markers affixed to a tool or object; using the information received from the markers, the sensor is able to know position and orientation of the tools within a specific measurement volume. The system consists of 2 IR cameras and some tools with reflective beads placed on known geometry frames. The system can calculate the real position of the tool in the space with an accuracy of 0.2 mm and 0.1 of a degree.

The tracking technology is usually used in the modern operating rooms and provides an important help to enhance the performance during the real surgical procedures.

VII. THE USER INTERFACE

The developed application is supplied with a specific user interface that allows the user to take advantage of the feature offered by the software. The application is provided of 4 sections with the aim to provide support to the surgeons in the different steps of the surgical procedure such as the study of the case, the diagnosis, the pre-operative planning, the choice of the trocar entry points and the simulation of the surgical instruments interaction.

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

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.

It is possible to use this platform in order to describe the pathology, the surgical procedure and the consequent risks to the child's parents, with the aim of obtaining informed consent for the surgical procedure.

VIII. THE DEVELOPED APPLICATION

In the developed application, as shown in Fig. 5, 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.

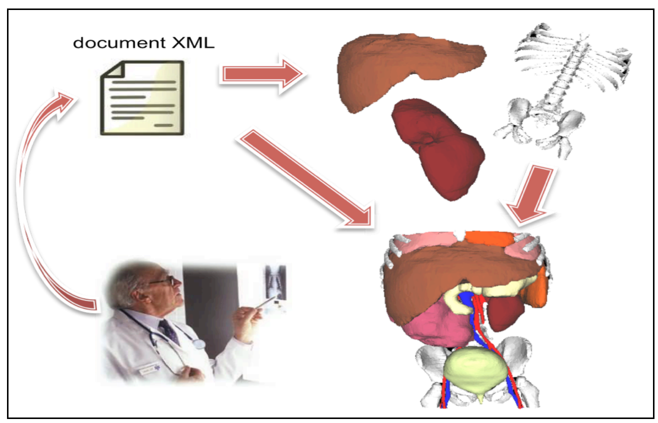

Figure 5. Patient's data collected in an XML file.

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

For the computation of the distance between a pair of points we have used the PQP library (Proximity Query Package) [30]. This section is shown in Fig. 6.

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 the procedure can be carried out in the best way.

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Fig. 7 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 the choice allows carrying out the procedure in the best way [31].

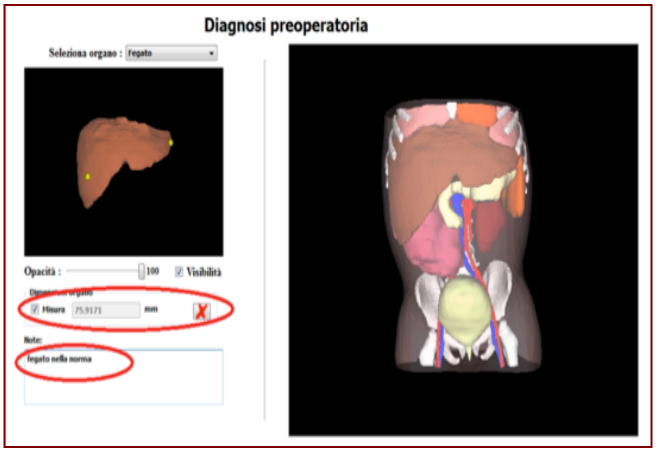

Figure 6. Example of a measurement of organs.

Complications associated with starting first abdominal entry are the first concern for laparoscopic surgeons. In order to minimize first access-related complications in laparoscopy, several techniques and technologies have been introduced in the last years.

The problem of blind access is that it may imply vascular injuries caused by the blind entry of instruments in the abdominal cavity. This problem can be solved with the direct visualization of under-layer viscera and vessels.

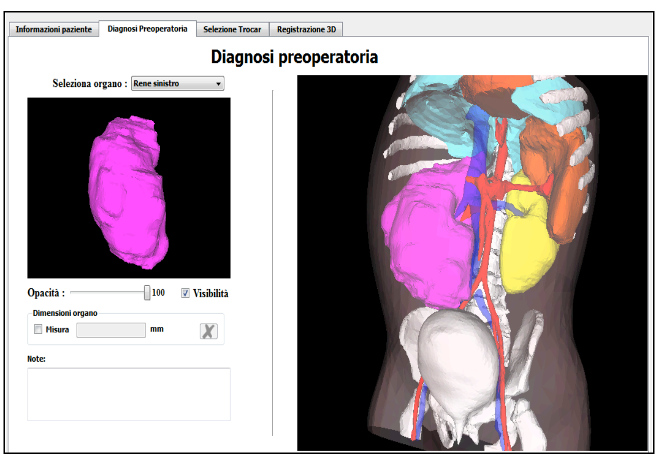

Figure 7. Section for the interaction with the organs.

Sometimes, using the standard insertion points for the surgical tools, also a simple surgical procedure can be very difficult because of the specific anatomy of the different patients. The surgeon can find it difficult to reach the specific organ or to interact with the surgical tools. In this case he has to choose another insertion point in order to be able to carry out the surgical procedure in the most suitable way.

Our aim is to avoid the occurrence of this situation during the real surgical procedure using the visual information provided by means of the 3D models of the patient's anatomy.

In the developed application, in order to verify if the chosen insertion points allow reaching properly the specific organ interested to the surgical operation and permitting to carry out the procedure in a correct way, it is also possible to simulate the interaction of the surgical instruments.

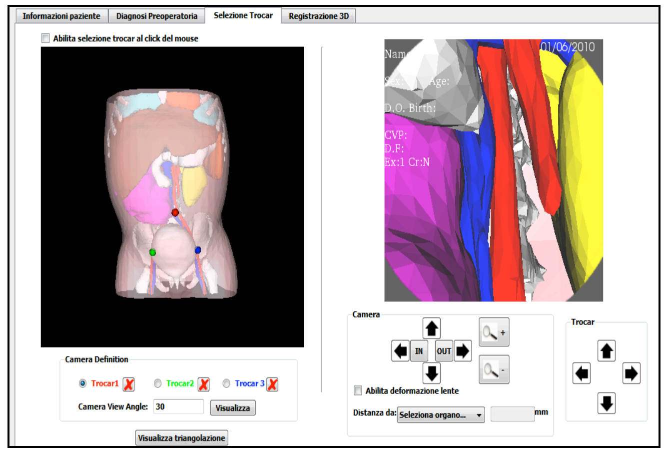

Figure 8. Section for the choice of the trocar insertion.

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 on the use of an optical tracker.

Fig. 8 shows the section for the accurate choice of the trocar insertion points.

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.

Fig. 9 shows the specific section for the simulation of the

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surgical tools interaction with the possibility to move the trocar entry points using the arrows.

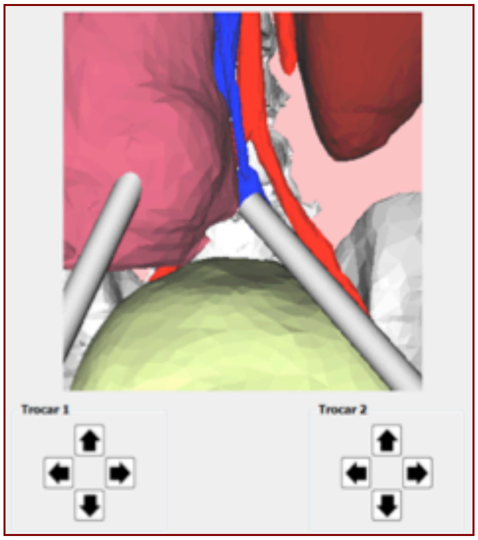

Figure 9. Simulation of the surgical tools interaction.

Fig. 10 shows the augmented visualization of the chosen trocar entry points overlapped on the patient's body (a dummy). The yellow points are the fiducials used for the registration phase and the red ones are the trocar insertion points.

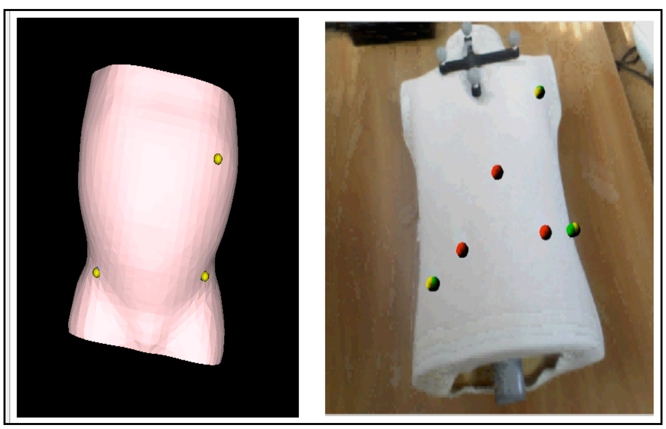

Figure 10. The augmented visualization.

IX. 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 tried to carry out different procedures and, subsequently, they have reported the impressions on a specific questionnaire. 15 subjects have been testing 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. In particular, the users have suggested:

- To improve the session for the choice of trocar entry points by means of a more accurate explication about the use of the arrows in the interface;
- To provide a more simple way to store the measurements of the organs.

Fig. 11 shows a graph with the test answers about the usability of the different sessions of the application.

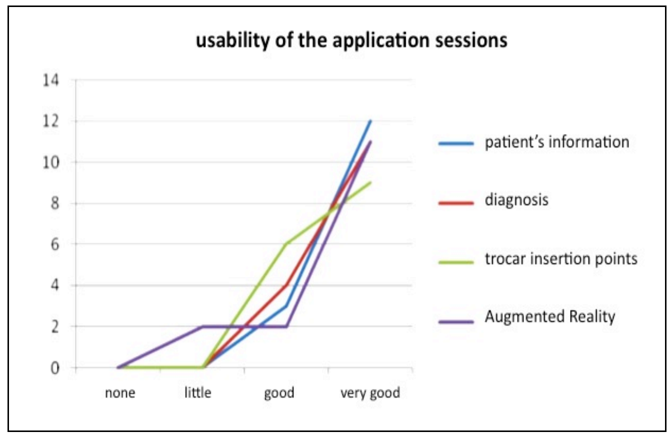

Figure 11. Test answers about the usability of the application sessions.

X. CONCLUTIONS AND FUTURE WORK

The developed platform offers a tool to visualize the 3D reconstructions of the patient's organs, obtained by the segmentation of a CT scan.

The system allows interacting with the models in order to choose the more appropriate insertion pints of the trocars and to simulate the placement of these in order to verify the validation of this choice. The Augmented Reality module supports the placement of the trocars on the real patient's body 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.

Furthermore the platform permits to store the patient and the pathology information that the surgeon can note during the use.

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

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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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