Advanced Interface for the Pre-operative Planning and the Simulation of the Abdominal Access in Pediatric Laparoscopy

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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 presents some limitations for 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 to delicate dissection or suturing. The presence of new systems for the pre-operative planning can be very useful to the surgeon. In this paper we present an advanced interface for the pre-operative planning of the surgical procedure and the choice of the abdominal access points in pediatric laparoscopy; using the Augmented Reality technology, these points are overlapped on the real patient's body. Two case studies have been considered for the building of 3D models of the patient's organs from the CT images. The developed application allows the surgeon to gather information about the patient and 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 points to insert the trocars in the patient's body.

Keywords: Augmented Reality, user interface, image processing, surgical pre-operative planning.

1 Introduction

One trend in surgery is the transition from open procedures to minimally invasive laparoscopic operations where the visual feedback to the surgeon is only available through the laparoscope camera and the 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 patients.

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

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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 in the patient because the trauma is reduced, the postoperative recovery is almost always faster and the scarring is reduced.

Despite the improvement in outcomes, these techniques show their limitations for the surgeons. In particular, the lack of the perception of the depth and the difficulty in estimating the distances of the specific organs in laparoscopic surgery can impose some limits on delicate dissection or suturing.

Anyway, the overall risk of complications is of 8.0% in laparoscopy versus 15.2% in laparotomy. Among these, more than 50% of laparoscopic complications occur during the initial entry into the abdomen.

In order to minimize entry-related complications, several techniques and technologies have been introduced in the last years; these include many types of abdominal entries. The choice of a technique more than another depends on the operator experience, the school and the speciality of the surgeon, the laparoscopic upgrading and the work environment. Many surgical techniques are not used yet because some surgeons don't want to change the old method for the one [1].

The laparoscopic access is an alternative to the open entry techniques aiming 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 performance, the difficulty in maintaining the pneumoperitoneum because of to the gas leakage, and the lack of major evidence for the prevention of intra-abdominal injury by 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 major 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 major and minor complications in the laparoscopic access, optically guided trocars are designed to decrease the risk of injury to intra-abdominal structures by allowing the surgeon to visualize abdominal wall layers during the placement [2].

Many research groups, motivated by the benefits that MIS can bring to patients, are now focusing on the development of surgical assistance systems. The progress in technology makes possible the development of systems that can simulate the surgical procedure in a realistic virtual environment [3].

The last 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 can provide the advantage of a direct visualization in open surgery also in minimally invasive surgery and can increase the physician's view of his/her surroundings with information gathered from patient medical images.

In medicine, Augmented Reality technology makes possible to overlay virtual medical images on 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 internal organs. The patient becomes transparent and therefore this virtual transparency makes possible to find tumors or vessels not locating them by touch, but simply visualizing. The virtual information could be directly displayed on the patient’s body or visualized on an AR surgical interface.

In general, AR technology in minimally invasive surgery may be used for training purposes, pre-operative planning and advanced visualization during the real procedure.

Samset et al. [4] present tools based on novel concepts in visualization, robotics and haptics providing tailored solutions for a range of clinical applications. Examples of radio-frequency ablation of liver tumors, laparoscopic liver surgery and minimally invasive cardiac surgery will be presented.

Bichlmeier et al. [5] 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 improved perception of 3D medical imaging data and navigated surgical instruments relative to the patient’s anatomy. They describe a method for integrating surgical tools into the medical AR scene in order to improve navigation.

Navab et al. [6] introduce an interaction and 3D visualization paradigm that presents a new solution for using 3D virtual data in many AR medical applications. They introduce the concept of a laparoscopic virtual mirror: a virtual reflection plane within the live laparoscopic video, that allows visualizing a reflected side view of the organ and its interior. A clinical evaluation investigating the perceptive advantage of a virtual mirror integrated into a laparoscopic AR scenario has been carried out.

De Paolis et al. [7] 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 the realistic impression that the virtual organs are inside the patient’s body. The 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.

In this paper we present 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 of the exact conditions and a precise location of the patient’s organs is very important. The pathology can totally change the positions of the organs in the small body of the patient and the standard entry points used in laparoscopic could not be the more appropriate.

The developed application allows the surgeon to choose the points for the insertion of the trocars on the virtual model and to overlap these on the real patient’s body using the Augmented Reality technology.

2 The 3D Models of Patient's Organs

In MIS the use of the registered images of the patient is a prerequisite both for the pre-operative planning and the guidance during the operation. 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; colors associated to the different organs replace the grey levels in the medical images.

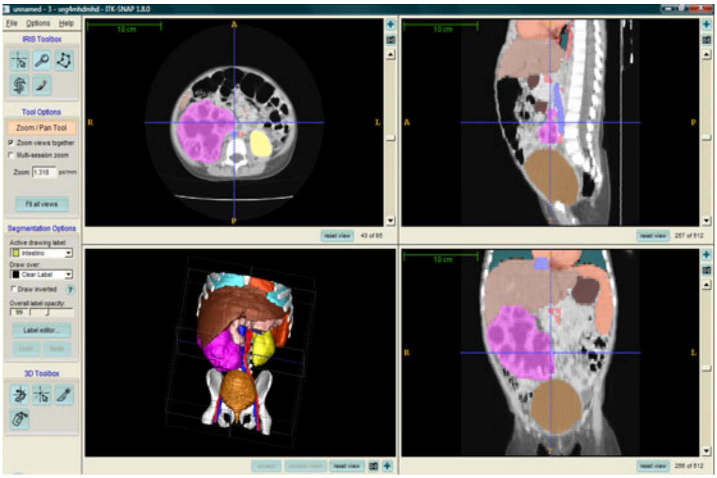

Fig. 1. The result of the image processing using ITK-SNAP

The 3D models of the patient's organs have been reconstructed using segmentation and classification algorithms provided by ITK-SNAP that provides a 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 [8].

In our case studies, 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.

Figure 1 shows the result of the image processing using ITK-SNAP.

By means of the developed 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.

We have done the image processing of two different case studies. The first one is a two-year-old child with a benign tumor of the right kidney; the second clinical case is a twelve-year-old child with a tumor of the peripheral nervous system (ganglioneuroma). These two case studies are shown in figure 2 where the skin and the muscles of the abdominal region are displayed in transparency and some organs are hidden in order to better visualize the tumors (in magenta and in orange).

3 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. 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.

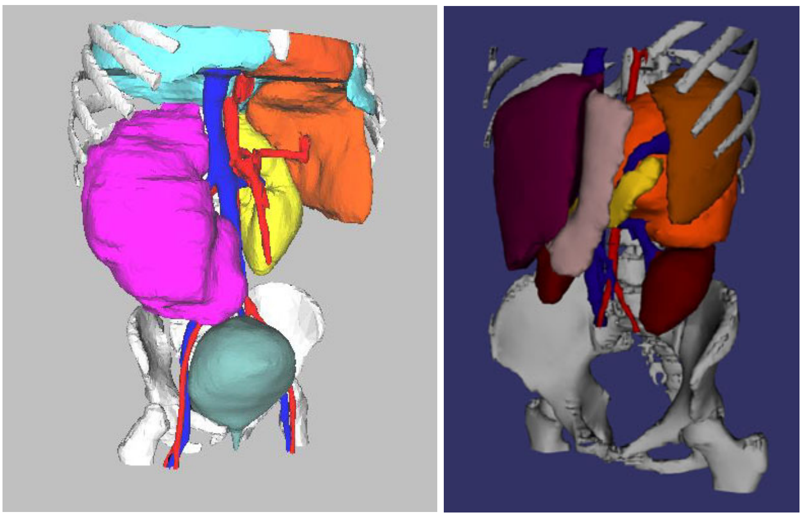

Fig. 2. The 3D models of two case studies

Starting from the models of the patient's organs, the surgeon can notice 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.

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 [9].

In the developed application, as shown in figure 3, 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 of organ or pathology sizes and some distances.

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.

Sometimes, using the standard insertion points for the surgical tools, also a simple surgical procedure can be very difficult due to the specific anatomy of the different patients. The surgeon can have some difficulties to reach the specific organ or the interaction of the surgical tools can be very hard. In this case the surgeon 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.

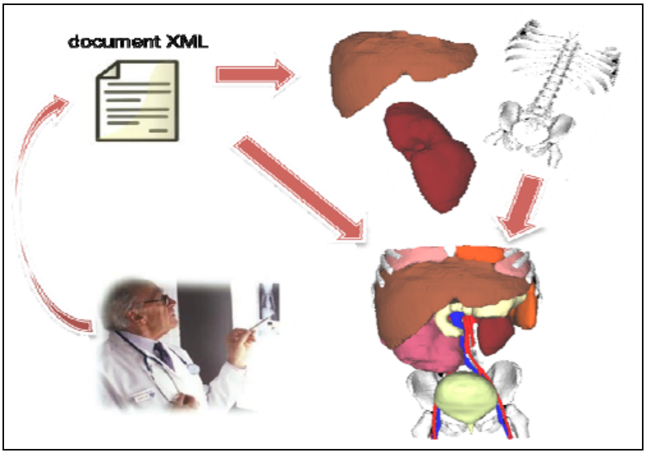

Fig. 3. Patient's data are collected in a XML file

In the developed application, in order to verify if the chosen insertion points allow properly reaching the specific organ interested by 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 4 shows the specific section of the user interface for the simulation of the surgical tool interaction with the possibility to move the trocar entry points using the arrows.

In the application we also use the AR technology in order to visualize on the patient's body the precise location of the 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.

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

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. In our application, we have used the Polaris Vicra optical tracker of NDI; the system consists of 2 IR cameras and uses a position sensor to detect retro-reflective markers affixed to the surgical tools or located on the patient's body; based on the information received from these markers, the sensor is able to determine position and orientation of tools within a specific measurement volume.

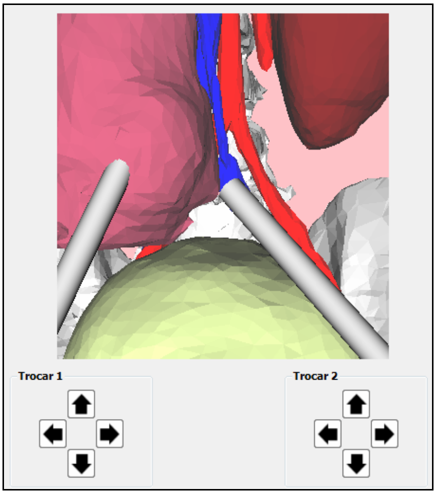

Fig. 4. Simulation of the surgical tools interaction

Taking into account the visual information provided in the AR section of the developed application, it is possible to start the real surgical procedure with an augmented visualization of the chosen trocar entry points on the patient's body.

Figure 5 shows the specific section of the user interface for the choice of the trocar insertion points.

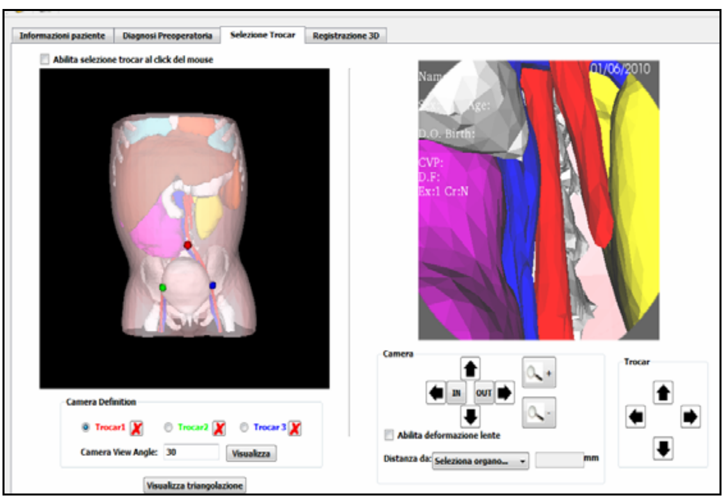

Fig. 5. Choice of the trocar insertion points

4 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 permitted the users to check all the functionalities of the application.

After a short period (5 minutes) for the training of the application, the users have been tried to carry out the 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. 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.

Figure 6 shows a graph with the test answers about the usability of the different sessions of the application.

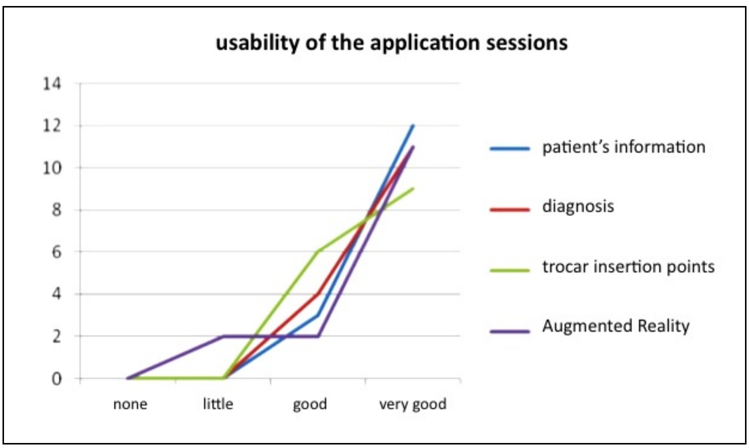

Fig. 6. Test answers about the usability of the application sessions

5 Conclusion and Future Work

The developed application offers a tool to visualize the 3D reconstructions of the patient's organs, obtained by segmentation of a CT slices, and to simulate the placement of the trocars in order to verify the correctness of the insertion sites. A complete user interface allows a simple and efficient utilization of the developed application.

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 patient's body during the real 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.

The developed platform can support the physician in the diagnosis steps and in the pre-operative planning when a laparoscopic approach will be followed. This support could also lead to a better communication between physicians and patient's parents in order to obtain their informed consent.

The platform has been tested on study cases already operated by the surgeon; the future work will be the validation of the developed application on a new study case by following all the steps from the diagnosis to the pre-operative planning and to the first phase of the real surgical procedure.

The building of a new Augmented Reality system that could also help the surgeon during the other phases of the surgical procedure has been planned as future work.

The acquisition in real time of a video of the patient and the development of an application able to overlap the virtual organs on the real patient's body is in progress; the changing of the surgeon points of view and the positions of medical instrument will be taken into account.

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