# Augmented Reality in Minimally Invasive Surgery

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**Abstract.** In the last 15 years Minimally Invasive Surgery, with techniques such as laparoscopy or endoscopy, has become very important and research in this field is increasing since these techniques provide the surgeons with less invasive means of reaching the patient's internal anatomy and allow for entire procedures to be performed with only minimal trauma to the patient. The advantages of the use of this surgical method are evident for patients because the possible trauma is reduced, postoperative recovery is generally faster and there is less scarring. Despite the improvement in outcomes, indirect access to the operation area causes restricted vision, difficulty in hand-eye coordination, limited mobility handling instruments, two-dimensional imagery with a lack of detailed information and a limited visual field during the whole operation. The use of the emerging Augmented Reality technology shows the way forward by bringing the advantages of direct visualization (which you have in open surgery) back to minimally invasive surgery and increasing the physician's view of his surroundings with information gathered from patient medical images. Augmented Reality can avoid some drawbacks of Minimally Invasive Surgery and can provide opportunities for new medical treatments. After two decades of research into medical Augmented Reality, this technology is now advanced enough to meet the basic requirements for a large number of medical applications and it is feasible that medical AR applications will be accepted by physicians in order to evaluate their use and integration into the clinical workflow. Before seeing the systematic use of these technologies as support for minimally invasive surgery some improvements are still necessary in order to fully satisfy the requirements of operating physicians.

**Keywords:** Augmented Reality, biomedical images, Minimally Invasive Surgery.

## 1 Introduction

In recent years the latest technological developments in medical imaging acquisition and computer systems have permitted physicians to perform more sophisticated as well as less invasive treatments of patients.

One trend in surgery is the transition from open procedures to minimally invasive laparoscopic interventions, where visual feedback to the surgeon is only available through the laparoscope camera and direct palpation of organs is not possible. To successfully perform such sophisticated interventions, the provision of additional intra-operative feedback can be of great help to the surgeon.

These techniques mean a reduction in the amount of unnecessary damage to the patient, by enabling the physician to visualize aspects of the patient's anatomy and physiology without disrupting the intervening tissues. In particular, imaging methods

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such as CT, MRI, and ultrasound scan make the safe guidance of instruments through the body possible without direct sight by the physician.

In addition, the availability of high-speed graphic workstations and medical virtual reality techniques has expanded the possibilities of medicine in the area of diagnosis, treatment, and education.

In traditional open surgery, surgeons often have to cut through many layers of healthy tissue to reach the target of interest, thereby inflicting significant damage on the tissue. This is very traumatic for the patient.

In the last 15 years Minimally Invasive Surgery (MIS), such as laparoscopy or endoscopy, 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 [1].

The diseased area is reached by means of a small incision in the body, called ports, and specific instruments are used to gain access to the operation area. The surgical instruments are inserted through the ports using trocars and a camera is also inserted. During the operation a monitor shows what is happening inside the body. This is very different to what happens in open surgery, where there is full visual and touch access to the organ.

The idea of Minimally Invasive Surgery is to reduce the trauma for the patient by minimizing the incisions and the tissue retraction. Since the incision is kept as small as possible, the surgeon does not have direct vision and is thus guided by camera images. 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 the use of 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. The view of the patient's organs is not as clear and the ability to manipulate the instruments is diminished in comparison with traditional open surgery. The indirect access to the operation area causes restricted vision, difficulty in hand-eye coordination, limited mobility in handling instruments and two-dimensional imagery with a lack of detailed information and a limited field of view during the whole operation. 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.

This situation, where eye-hand co-ordination is not based on direct vision, but more predominantly on image guidance via endoscopes, requires a different approach to conventional surgical procedures.

In Fig. 1 a cholecystectomy carried out in laparoscopic and open surgery is shown.

On the other hand, the quality of medical images and the speed with which they can be obtained, the increasing ability to produce 3-dimensional models and the advanced developments in Virtual Reality technology make it possible to localize the pathology accurately, to see the anatomic relationships like never before and to practice new methods such as surgical navigation or image-guided surgery.

Given that a great deal of the difficulties involved in MIS are related to perceptual disadvantages many research groups are now focusing on the development of surgical assistance systems, motivated by the benefits MIS can bring to patients. Advances in technology are making it more and more possible to develop systems which can help surgeons to perform their tasks in ways which are both faster and safer.

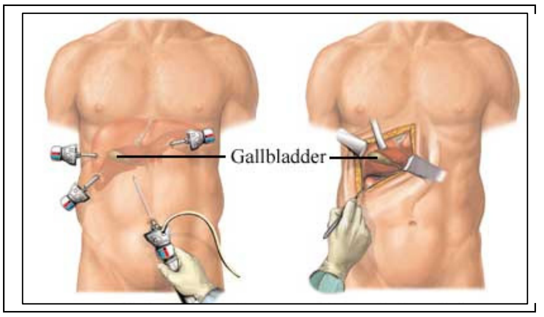


**Fig. 1.** Cholecystectomy in laparoscopic and open surgery

Appropriate visualization tools and techniques are playing an important role in providing detailed information regarding human organs and pathologies and realistic 3D models of the organs for the specific patient. The utilization of this visual information in combination with the operation techniques can help the surgeon during the surgical procedure and provide a possible solution to the problems associated with the practice of minimally invasive surgery.

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

The use of the emerging Augmented Reality technology shows the way forward in bringing the direct visualization advantage of open surgery back to minimally invasive surgery and can increase the physician's view of his/her surroundings with information gathered from patients' medical images.

Augmented Reality can avoid some drawbacks of MIS and can provide opportunities for new medical treatments.

## 2 Augmented Reality Systems and Technologies

### 2.1 Introduction to AR

Augmented Reality (AR) research aims to develop technologies that allow the real-time fusion of computer-generated digital content with the real world. With the help of Augmented Reality, a user can see hidden objects and, for this reason, AR enhances the users' perception and improves their interaction with the real world.

The virtual objects, displaying information that they cannot directly detect with their own senses, help them to perform real-world tasks better.

In contrast with Virtual Reality technology which completely immerses a user inside a synthetic environment and where he cannot see the real world around him, Augmented Reality technology allows the user to see 3-dimensional virtual objects superimposed upon the real world.

Therefore, AR supplements reality, rather than completely replacing it. The user is under the impression that the virtual and real objects coexist in the same space.

Azuma [2] presents a survey of AR and describes the characteristics of AR systems, registration and sensing errors with the efforts to overcome these. Using the Azuma's definition, an AR system has to fulfil the following three characteristics:

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

In Fig. 2 an example of Augmented Reality is shown where a virtual lamp and two virtual chairs are visualized with a real desk.

**Fig. 2.** Real desk with virtual lamp and two virtual chairs

Milgram and Kishino defined 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" [3].

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 and includes elements of both, virtual objects and real-world elements, where the surrounding environment is real.

In Fig. 3 Milgram's reality–virtuality continuum is shown.

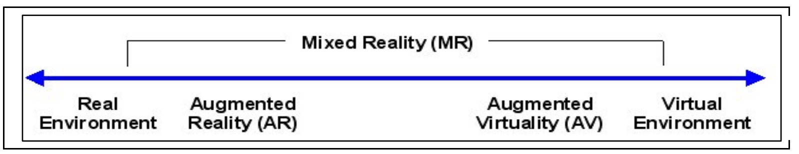


**Fig. 3.** Milgram's reality–virtuality continuum

Several research studies carried out have shown that Augmented Reality technology can be applied in a wide range of areas including education, medicine, engineering, military and entertainment.

It is possible to identify several research directions in:

- *tracking techniques*: how to achieve robust and accurate overlay of virtual imagery on the real world;
- *visualization technologies*: head mounted displays, handheld devices and projectors for AR;
- *interaction techniques*: methods for interaction with AR content;
- *novel AR applications* in fields which are not jet analyzed.

### 2.2 Tracking Systems

One of the most important tasks in developing Augmented Reality applications is to continuously determine the position and orientation of surgical instruments with regard to the patient's virtual organs and to estimate the physician's viewpoint.

For this reason tracking systems are integrated in the scene and attached to surgical instruments and to the patient's body.

AR applications require accurate knowledge of the relative positions of the camera and the scene; when either of them moves, it is necessary to keep track in real-time of all six degrees of freedom that define the camera position and orientation relative to the scene and the 3D displacements of the objects relative to the camera [4].

Many technologies have tried to achieve this goal. Typical tracking devices used in medical applications are mechanical, optical and electromagnetic systems.

Mechanical trackers are quite accurate, but the accuracy degrades with the length of the mechanical link; however, the mechanical link can be obstructive and the tracking volume is limited to the length of the mechanical linkage. Magnetic trackers are vulnerable to distortions by metal in the environment and limit the range of displacements. The optical trackers track both wired active tools with infra-red light-emitting diodes and wireless passive tools with reflective markers; the position sensor receives light from marker reflections or emissions and the system provides precise, real-time spatial measurements of the location and orientation of an object or tool within a defined coordinate system.

Computer vision technology has the potential to yield non-invasive and accurate solutions [5]. It is desirable to rely on naturally present features, such as edges, corners or texture, but this approach makes tracking much more challenging. In some case it requires the addition of fiducials, as special markers, to the scene or target objects to aid the registration task. This means that one or more fiducials are visible at all times and, if the markers are tracked, the virtual object will be blended in the real scene. However, in some applications it is not possible to place fiducials.

Planar square fiducials are used in ARToolKit, a video tracking library that calculates the real camera position and orientation relative to physical markers in real time [6]. ARToolKit software has become popular because it yields a robust, low-cost solution for real-time 3D tracking and it is publicly available.

In Fig. 4 an application in medicine based on ARToolkit is shown. The virtual environment is built using the real patient's CT images of the abdominal area and markers are used to overlap the virtual organs onto the real scene and to provide visual information which is not visible by means of normal senses [7].

Tracking technology has already entered operating rooms for medical navigation and provides the surgeon with important help to further enhance performance during the real surgical procedure.

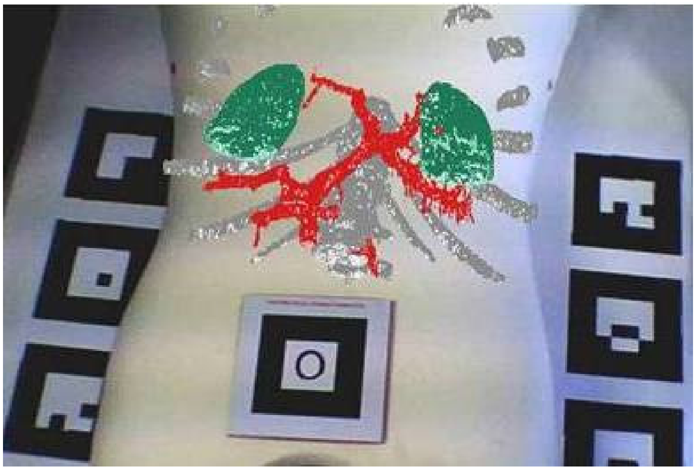

**Fig. 4.** An ARToolKit application in medicine (from [7])

The prevailing method in medical procedures is currently optical tracking using infrared light. The advantages of this kind of tracking are high accuracy and reliability; the use of infrared light can easily be explained by the fact that light conditions can be controlled for optimal measurements without disturbing human vision. Accuracy degradation is mainly caused by line-of-sight issues, which can be detected easily during measurement.

### 2.3 Visualization Devices and Modalities

Medical Augmented Reality takes its main motivation from the need of visualizing medical data and the patient within the same physical space. This would require real-time visualization of co-registered heterogeneous data and was probably the goal of many medical augmented reality solutions proposed in literature.

Augmented Reality systems often involve the use of a Head Mounted Display (HMD). A high resolution HMD is preferred for a dexterous manipulation task and is crucial in medical 3D visualization; stereoscopic view is also important for accurate operations.

There are mainly two types of see-through approaches in AR: optical and video [4].

With an optical see-through display, real and synthetic imagery is combined with a partial transmissive and reflective optical device and the synthetic imagery is overlaid on the real image. Advantages of optical see-through HMDs include a natural, instantaneous view of the real scene and simple and lightweight structures.

With a video see-through display, the real world imagery is first captured by a video camera then the captured image and the synthetic imagery are combined electronically and presented to the user.

Advantages of video see-through HMDs over optical see-through HMDs include pictorial consistency between the real and the synthetic view and the availability of a variety of image processing techniques. With appropriate vision-based tracking and synchronous processing of the captured and the rendered images, geometric and temporal consistencies can be accomplished.

Fig. 5 shows typical configurations of an optical and a video see-through display.

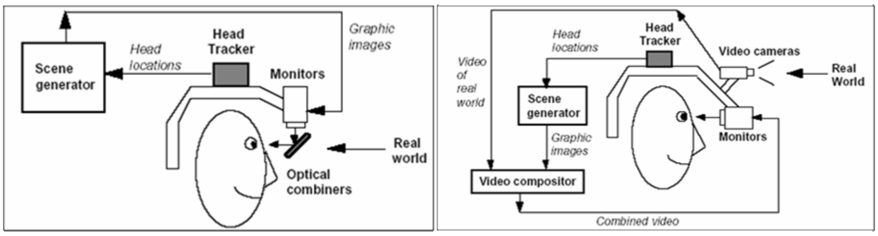


**Fig. 5.** Configurations of an optical and a video see-through display

Operating microscopes and operating binoculars can be augmented by inserting a semi-transparent mirror into the optics. The mirror reflects the virtual image into the optical path of the real images [8].

A drawback of augmented optics in comparison with other augmented technology is the process of merging real and computed images. As virtual images can only be added and may not entirely cover real ones, certain graphic effects cannot be realized.

It is possible to augment video images on ordinary monitors using an additional tracked video camera. As an advantage of augmented monitors, users need not wear an HMD or glasses.

Since endoscopy has been successfully introduced into many surgical disciplines, the use of augmented endoscopes is very interesting [8]. These devices require a tracking system for augmentation but, since the endoscopic setup already contains a camera, the integration of AR techniques does not necessarily introduce additional hardware into the workflow of navigated interventions.

Several research groups have investigated in order to find appropriate solutions, but for a helpful endoscopic augmentation the issues of calibration, tracking and visualization have not been completely solved.

In some applications the projection of the virtual images directly onto the patient can be used. These systems provide augmented vision without looking through additional devices such as glasses, HMDs, etc.

The simplicity of the system introduces certain limitations as a compromise, but this modality presents a beneficial feature when visualization on the skin rather than beneath it is required [8].

## 3 Building an AR Application for Surgery

The aim of an AR application for minimally invasive surgery is the development of a system that can help a surgeon to see in a non-invasive way the patient's internal anatomy during a minimally invasive surgical procedure.

To develop such a system, different technologies must be integrated:

- generation of the 3D model;
- calibration of the camera;
- registration;
- stereoscopic visualization and depth perception.

In order to obtain an AR environment which is as realistic as possible and, therefore, to provide information on the location and visualization of the organs, it is possible to visualize the internal organs of the patient by means of 3D models of the anatomy built from the medical images of the patient. The 3D models of the patient's organ have to be overlaid on the real patient's body and have to coincide with the real organs.

Through non-invasive sensors like Magnetic Resonance Imaging (MRI), Computed Tomography scans (CT) or ultrasound imaging it is possible to collect 3D datasets of a patient and an efficient 3D reconstruction of his/her anatomy can be provided in order to improve the standard slice view by the visualization of 3D models of the organs.

The geometric models are reconstructed by means of specific segmentation and classification algorithms in order to obtain information about the size and the shape of the human organs [9]. The grey levels in medical images are replaced by colours allocated to the different organs.

There are different software toolkits currently available for use in medicine for the visualization and analysis of scientific images and the 3D modelling of human organs; among these tools Mimics [10], 3D Slicer [11], ParaView [12] and OsiriX [13] play an important role.

Fig. 6 shows an example of the segmentation and classification results applied to CT images of the abdominal region of a human body.

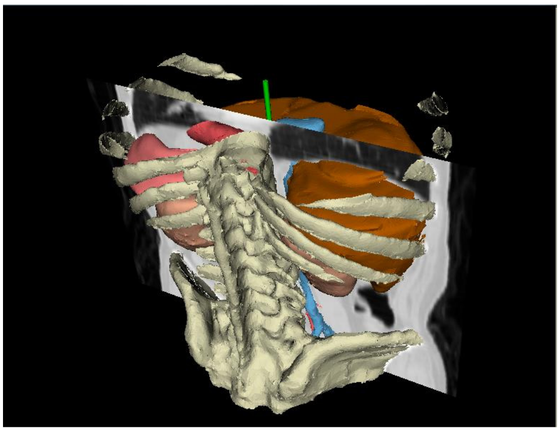

**Fig. 6.** A 3D model of the abdominal region obtained from CT images

In order to have an effective AR application, the real and computer generated organs must be accurately positioned relative to each other. For this reason it is necessary to carry out an accurate registration phase, which provides, as a result, the correct overlapping of the 3D model of the virtual organs on the real patient [14], [15], [16].

In medical applications it is very important to have correct detection and overlapping of the fiducial points because even a very slight error could have very serious consequences for the patient.

The integration of the registration algorithm into the surgical workflow requires a trade-off between complexity, accuracy and invasiveness. The process of registration can be computed using tracking data after an initial calibration step that provides the registration of a certain pose. For the pose determination of the real view, optical (infrared) tracking systems are currently the best choice; 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 that are fixed on the skin or implanted. These fiducials are touched with a tracked pointer and their positions have to match with the corresponding 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, visually they are overlapped with all real objects, creating a situation which is not sufficiently realistic. This situation is shown in Fig. 7.

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, to ensure correct visualization.

Some solutions have been proposed [17], but the issue of a correct depth visualization remains partially unsolved.

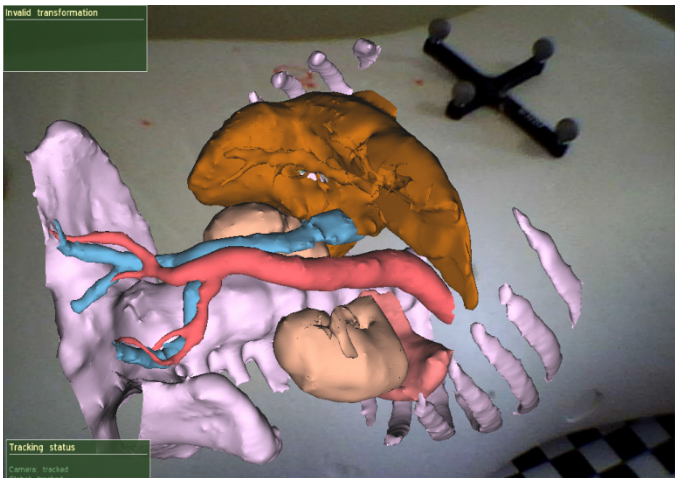


**Fig. 7.** Issue of the correct depth visualization

## 4 AR Applications in Minimally Invasive Surgery

Augmented Reality provides an intuitive human-computer interface and in surgery this 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 a view of the patient’s anatomy.

Augmented Reality technology has the potential to bring the visual advantages of open surgery back to minimally invasive surgery; increasing the physician’s visual knowledge with information gathered from patients’ medical images.

The patient becomes transparent and this virtual transparency will therefore make it possible to find tumours or vessels not by locating them thanks to touch, but simply by visualizing them thanks to 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.

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

To successfully perform minimally invasive interventions, highly trained and experienced specialists are required.

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

- training purposes;
- pre-operative planning;
- 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.[18] 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 the fact that, because of the narrow field of view, it is sometimes quite difficult to locate the objects that can be seen through the endoscope. This is especially true in cardiac surgery, where it is difficult not to confuse two coronary arteries on a beating heart. The narrow field of view of the endoscope may lead to misidentifying the coronary or the position of the stenosis on the coronary. The information coming from the 3D anatomical model of the patient extracted from MRI or CT-scan and the position of the endoscope with respect to the patient are not sufficient since the organs (in particular the lungs and the heart) 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, by indicating the position of the coronaries with respect to the field of view. The proposed method involves five steps: making a time-variant 3D model of the beating heart using coronarography and CT-scan or MRI, calibrating the stereoscopic endoscope, reconstructing the 3D operating field, registering the operating field surface with the 3D heart model and adding information on the endoscopic images using Augmented Reality.

Samset et al. [21] 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.

Demonstrators were developed with the aim of providing a seamless workflow for the clinical user conducting image-guided therapy. The presented solutions are the results of the multidisciplinary ARIS*ER project.

Bichlmeier et al. [19] 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 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 transparency of the video images depends on the topology of the skin surface of the patient and the viewing geometry of the observer and the modified video image of the real scene is then blended with the previously rendered virtual anatomy. The presented method allows for an intuitive view on the deep-seated anatomy of the patient providing visual cues to correctly perceive absolute and relative distances of objects within an AR scene.

In addition, they describe a method for integrating surgical tools into the medical AR scene resulting in improved navigation. The effectiveness has been demonstrated in a series of experiments at the Chirurgische Klinik in Munich, Germany with a cadaver study and a thorax phantom, both visualizing the anatomical region around the spinal column, and an in-vivo study visualizing the head.

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

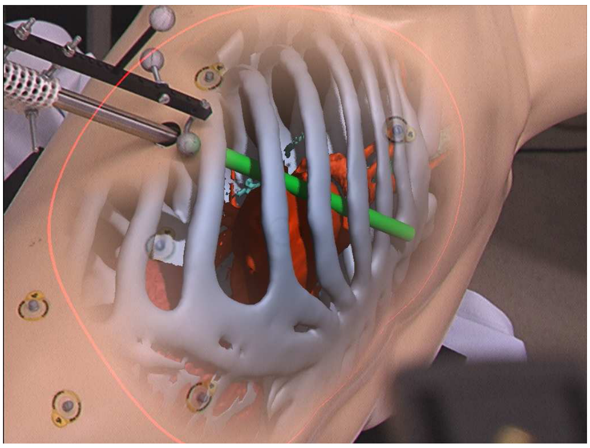

**Fig. 8.** The medical AR scene using an "AR window" (from [20])

Navab et al. [22] introduce an interaction and 3D visualization paradigm, which presents a new solution for using 3D virtual data in many AR medical applications. The problem becomes more evident when a single camera is used in augmented laparoscopic surgery. When augmenting a monoscopic laparoscope, which is the usual case, the 3D volume is projected onto the laparoscope's image plane, so one dimension is totally lost, leading to even more limited perception of 3D shape and depth during superimposition. However, particularly for interventions targeting the inside of organs, shape information is crucial, for instance for identifying blood vessels to be clipped during liver resection.

To recover this lost shape information they 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. The Laparoscopic Virtual Mirror is able to virtually reflect the 3D volume as well as the laparoscope or any other modelled and tracked instruments. This enables the surgeon to observe the 3D structure of, for example, blood vessels by moving the virtual mirror within the augmented monocular view of the laparoscope.

By combining this visualization paradigm with a registration-free augmentation system for laparoscopic surgery, a powerful medical augmented reality system becomes possible, which could make such minimally invasive surgeries easier and safer to perform.

To demonstrate the full advantage of this new AR interaction paradigm, the system is integrated into a medical application, which was desperately in need of such interactive visualization. Fig. 9 shows the Laparoscopic Virtual Mirror used in an experimental setup.

A clinical evaluation investigating the perceptive advantage of a virtual mirror integrated into a laparoscopic AR scenario has been carried out [23].

Kalkofen et al. [24] 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.

Careless augmentation with synthetic imagery may occlude extremely relevant information presented in the real world imagery. They solve the problem of augmentations occluding useful real imagery, with edges extracted from the real video stream. The extracted edges provide an additional depth cue and since they come from the real imagery, they are also able to preserve important landmarks.

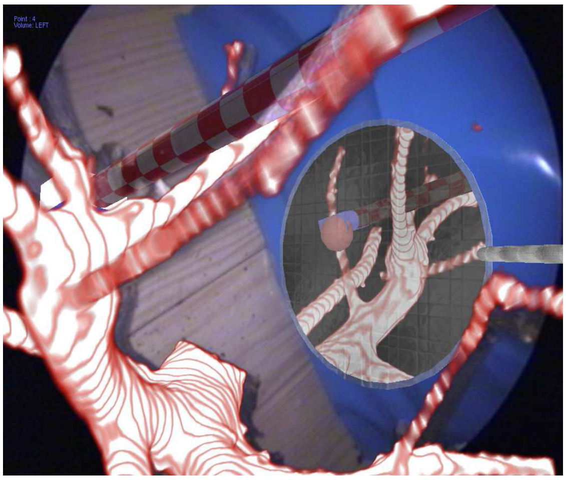

**Fig. 9.** Laparoscopic Virtual Mirror in an experimental setup (from [23])

De Paolis et al. [25] 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. It is possible to slide the visualization window and to locate it in a precise position which provides a view of the organs of interest; only through this window can the internal organs be seen.

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, the frequency of which increases as the distance decreases between the surgical instrument and the organ concerned, are provided.

Fig. 10 shows the visualization of the organs with the box reporting the distance information.

In minimally Invasive Surgery a new original technique, called Natural Orifice Transluminal Endoscopic Surgery (NOTES), could replace traditional laparoscopic surgery for a large set of procedures. By replacing the rigid optic that is introduced through the skin by a flexible optic that is introduced through a natural orifice such as stomach, vagina or colon, this technique should eliminate all visible incisions.

On the other hand, such minimally invasive techniques present new difficulties for surgeons, such as a loss of their gesture capacity due to the length of surgical instruments and the gesture complexity due to the loss of orientation and inversion of movement because of the flexibility of the endoscope.

Such difficulties can be solved thanks to AR technology combined with instrument tracking that can provide information about the location and internal orientation of surgical instruments.

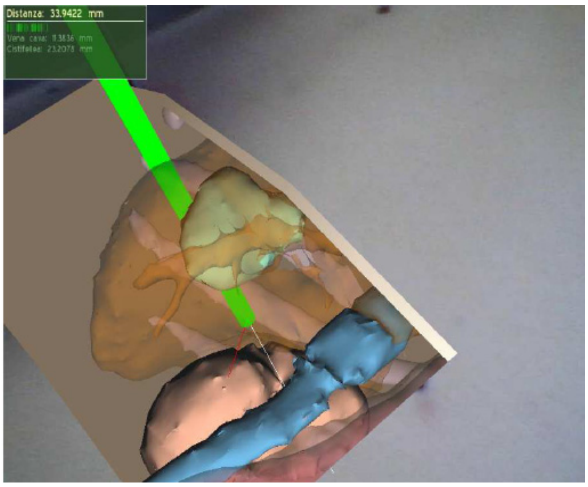


**Fig. 10.** Visualization of the organs with the distance information box (from [25])

Soler et al. [26] present the results of their research into the application of AR technology in laparoscopic and NOTES 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.

## 5 Conclusions and Future Work

Minimally Invasive Therapy (MIT) is a major step forward in interventionist therapy, capable of offering quality of life to patients and decreasing costs for health care systems, the two most important considerations as well as the future of modern medicine.

This new approach, however, also brings limitations to surgeons that can only be compensated for by means of the massive use of innovative technologies in order to have MIT widespread and optimally implemented.

The challenge is related to the actions necessary to bridge the gap between the new surgical methods which are already available and the new emerging technologies, like Virtual Reality and Augmented Reality, which can provide improvements and benefits in the practice of these advanced medical treatments.

After two decades of research on medical Augmented Reality, these enabling technologies are now advanced enough to meet the basic requirements for a large number of medical applications. It is feasible that medical AR applications could be accepted by physicians in order to evaluate their use and integration into the clinical workflow.

Of course, before AR technologies can be used systematically as support for minimally invasive surgery, some improvements are still necessary in order to fully satisfy the requirements of operating physicians. For instance, a perfect medical AR user interface would be integrated in such a way that the user would not notice its existence while taking full advantage of additional in situ information it provides. Also the visualization systems still need hardware and software improvement in order to allow the surgeons to take full advantage of the augmented virtual data.

It seems likely that the superimposition of data acquired by other emerging intraoperative imaging modalities will have a great impact on future surgical interventions and will be applied to further advanced image-guided surgery in the operating rooms of the future.

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