

# Augmented Reality in Radiofrequency Ablation of the Liver Tumours

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**Abstract**— Minimally Invasive Surgery is a surgery technique that provides evident advantages for the patients, but also some difficulties for the surgeons. In medicine, the Augmented Reality (AR) technology allows surgeons to have a sort of “X-ray” vision of the patient’s body and can help them during the surgical procedures. In this paper we present two applications of Augmented Reality that could be used as support for a more accurate preoperative surgical planning and also for an image-guided surgery. The AR can support the surgeon during the needle insertion for the Radiofrequency Ablation of the liver tumours in order to guide the needle and to have an accurate placement of the surgical instrument within the lesion. The augmented visualization can avoid as much as possible to destroy healthy cells of the liver.

**Keywords** - *Augmented Reality, medical images, minimally invasive surgery, RF ablation*

## I. INTRODUCTION

The actual trend in surgery is the transition from open procedures to minimally invasive interventions. Using this surgery technique visual feedback to the surgeon is only possible through the laparoscope camera. Furthermore direct palpation of organs is not possible. Minimally Invasive Surgery (MIS), such as laparoscopy or endoscopy, has changed the way to practice the surgery. It is a promising technique and the use of this surgical approach is nowadays widely accepted and adopted as a valid alternative to classical procedures.

The use of MIS offer to surgeons the possibility of reaching the patient’s internal anatomy in a less invasive way. This reduces the surgical trauma for the patient. The diseased area is reached by means of small incisions made on the patient body called ports. Specific instruments and a camera are inserted through these ports. The surgeon uses a monitor to see what happens on the surgical field inside the patient body.

With the use of MIS the patient has a shorter hospitalizations, faster bowel function return, fewer wound-related complications and a more rapid return to normal activities. These advantages have contributed to accept these surgical procedures. If the advantages of this surgical method are evident on the patients, these techniques have some limitations for the surgeons. In some systems, the

imagery is in 2D. With this limitation the surgeon needs to develop new skills and dexterity in order to estimate the distance from the anatomical structures. We have to consider that he had to work in a very limited workspace. Modern systems use two cameras to offer a 3D view to the surgeon but this technology is useful when the working volume is not too small.

Medical images (CT or MRI) associated to the latest medical image processing techniques could provide an accurate knowledge of the patient’s anatomy and pathologies. These informations can be used to guide surgeons during the surgical procedure to improve the patient care.

The Augmented Reality (AR) technology has the potential to improve the surgeon’s visualization during the MIS surgery. This technology can “augment” surgeon’s perception of the real world with the use of information gathered from patient’s medical images.

AR technology refers to a perception of a physical real environment whose elements are merged with virtual computer-generated objects in order to create a mixed reality. The merging of virtual and real objects in an AR application has to run in real time. Virtual objects have to be aligned (registered) with real world structures. Both of these requirements guarantee that the dynamics of real world environments remain unchanged after virtual data has been added [1].

The use of AR technology in medicine makes possible to overlay virtual medical images of the organs on the real patient. This allows the surgeon to have a sort of “X-ray vision” of the patient’s internal anatomy.

In order to obtain a correct alignment of virtual and real objects a registration procedure is needed. This procedure requires the real time position tracking of the objects in the real world. This task can be accomplished with the camera, recognizing in some way the position and alignment of some objects in the scene, or with special devices called tracker. In surgery using a tracker usually improves the system uncertainty.

Using AR in surgery produces a better spatial perception and a reduction in the duration of the surgical procedure.

The aim of this paper is to present an AR system that could be used as support for a more accurate surgical preoperative planning and also for image-guided surgery.

The application can support the surgeon during the needle insertion in the radiofrequency ablation of the liver tumours. We modified the library on which our application is based to support an optical tracker that could improve the performance of the system.

## II. PREVIOUS WORKS

Many research groups are now focusing on the development of systems that assists surgeons during the minimally invasive surgical procedures.

Furtado and Gersak [1] present some examples of how AR can be used to overcome the difficulties inherent to MIS in the cardiac surgery.

Samset et al. [3] present some decision support tools. These tools are based on concepts in visualization, robotics and haptics and provide tailored solutions for a range of clinical applications.

Bichlmeier et al. [4] 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.

Navab et al. [5], [6], [7] present 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.

De Paolis et al. [8] present an AR system that can guide the surgeon in the operating phase. The main goal of the system is to prevent erroneous disruption of some organs during surgical procedures. They provide distance information between the surgical tool and the organs and they use a sliding window in order to obtain a more realistic impression that the virtual organs are inside the patient's body.

Nicolau et al. [9] present a real-time superimposition of virtual models over the patient's abdomen in order to have a three dimensional view of the internal anatomy. The authors have used the developed system in an operating room and to reduce the influence of the liver breathing motion they have tried to simulate the patient's breathing cycle.

LiverPlanner [10], [11] is a virtual liver surgery planning system developed at Graz University of Technology that combines image analysis and computer graphics in order to simplify the clinical process of planning liver tumor resections. The treatment planning stage enables the surgeon to elaborate a detailed strategy for the surgical intervention and the outcome of pre-operative planning can then be used directly for the surgical intervention.

Maier-Hein et al. [12] present a system developed for computer-assisted needle placement that uses a set of fiducial needles to compensate for organ motion in real time; the purpose of this study was to assess the accuracy of the system in vivo.

Stüdeli et al. [13] present a system that provides surgeon, during placement and insertion of RFA needle, with information from pre-operative CT images and real-time tracking data.

## III. AR FOR THE RF ABLATION OF THE LIVER TUMOUR

Hepatic cancer is one of the most common solid cancers in the world. Hepatocellular carcinoma (HCC) is the most common primary hepatic cancer. The liver is often the site of metastatic disease, particularly in patients with colorectal adenocarcinoma.

The use of chemotherapy for malignant form of liver cancer rarely led to good results in long-term survival rate. Surgery led to the best results for hepatic cancer care. Unfortunately only from 5 to 15 percent of patients with liver cancer can undergo to a potentially curative resection of the liver cancer [23].

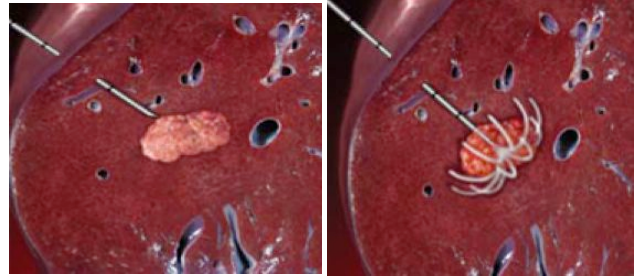


Figure 1. The effect of the RFA technique at the liver tumour

Patients with confined disease of the liver could not be candidates to resection because of multifocal disease. Another factor that could preclude surgical treatment is the proximity of tumor to key vascular or biliary structures. This preclude a margin-negative resection potentially unfavourable in case of presence of multiple liver metastases. Very often the tumor is associated to a pre-existent cirrhosis that can further reduce resection margins.

Liver transplant is the only radical therapy that eliminates the risk of recurrence. Unfortunately it can't be always used. So, since most of patients with primary or malignancies confined metastatic at the liver are not candidates for surgical resection, different approaches to control and potentially cure liver diseases were developed.

The Liver Radiofrequency Ablation (RFA) is a minimally invasive treatment for liver cancer used since 1980's. It consists in the placement of a needle inside the liver parenchyma in order to reach the centre of the tumor lesion. When the lesion center is reached, an array of electrodes is extracted from the tip of the needle and it is expanded in the tumor tissue. From these electrodes is injected in the tumor tissue a radiofrequency current that causes tumor cell necrosis for hyperthermia (the local temperature is higher than 60 °C and cancer cells are more sensitive to heat than normal cells).

In Figure 1 is shown the needle insertion and array expansion of the RFA technique on the liver tumour.

One problem in using radiofrequency tumor ablation technique is the correct placement of the needle. To ensure a maximum efficacy of the treatment the needle has to reach the center of the tumor.

Today surgeons use ultrasound, CT or MNR images acquired during the needle placement in order to correctly

direct the needle towards the center of the tumor. The use of these two-dimensional images makes the insertion procedure very difficult and requires sometimes more than one insertion.

In addition, the surgeon, in order to destroy all tumoral cells, applies the RFA on an extended area of the liver. In this way a large number of healthy cells are also destroyed. This practice can cause to the patient a number of other different consequences. To reduce this problem is of primary importance to reach the center of the tumor.

A guidance system of the needle in tumour ablation procedures can be obtained using Augmented Reality technology. With the superimposition of the virtual models of the patient's anatomy (liver, vessels, biliary ducts, cancer, etc) exactly where are the real ones, it is possible to make the needle placement task less difficult. In this way the surgeon has a sort of x-ray 3D vision of the patient internal anatomy.

The purpose of this AR application is to provide a guidance system that can help the surgeon during the needle insertion in liver RFA. The position and orientation of the ablation tool are measured using some reflective spheres attached to. These spheres are detected by an optical tracker that measure the position and orientation of the real ablation tool. These measure permits to orient the virtual ablation tool in the virtual world where virtual models of the patient anatomy are placed.

To achieve a correct augmentation it is necessary to have a perfect correspondence between the virtual organs and the real ones. This is very important in an image-guided surgery application because a very small error in the registration phase can cause a serious consequence on the patient due a bad alignment of the virtual organs on the real ones.

The tracking system is also used in order to permit the overlapping of the virtual organs on the real ones. The registration phase is one of the most delicate step in an AR system for surgery. An accurate registration is necessary to obtain a correct alignment of virtual models on the real ones. The registration is obtained using fiducial points. These points were defined on the patient body and identified on the patient tomographic images. During the registration phase the surgeon is asked to touch on the patient body with the tracker measure tool the point that the application shows on patient 3D models. In this way the application can establish the transformation between the "real" world and "virtual" world. Once registered the patient should not be moved. If the patient position can change during surgery it is necessary to fix to the patient body a tracker tool that permits to measure its position and orientation.

The novel aspect of our application is the use of an optical tracker that should decrease the guidance uncertainty in needle positioning.

#### IV. DEVELOPED APPLICATION

The application is provided of an user interface designed to be simple and functional at the same time. In the left side of that interface we placed the application control

panel. On the right-top window we show 3D models and the augmented reality scene. On the right-bottom there are the three smaller windows where axial, coronal and sagittal views of CT dataset are placed.

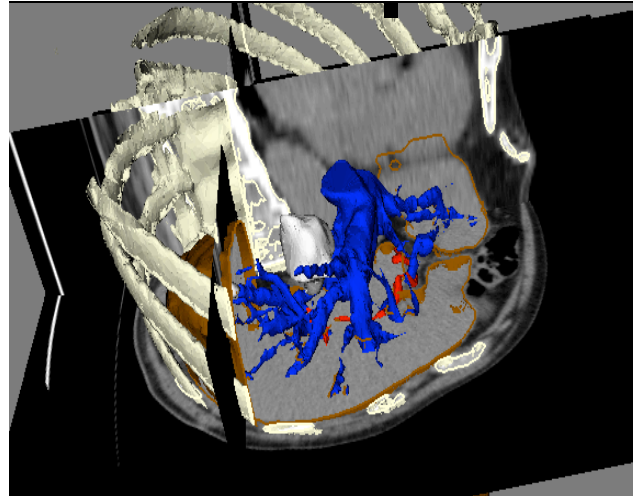


Figure 2. Clipping visualization applied to the liver and thoracic cage

The application offers to surgeon the possibility to study the case study before going in operating room. There is the possibility to apply a clipping modality that permits the surgeon to dissect the model and study its internal structure changing the opacity of the organs (Figure 2,3). The dissection could be made along the three principal axes of tomographic images.

The application features described till now are part of what we consider the pre-operative planning task. During this task the surgeon can use the application to study the pathology in a more simple and natural way than that provided by simple CT slice visualization.

For the navigation and augmentation task are devoted to the surgery room. Here the surgeon needs to use the optical tracker and to carry out the registration task. When the registration process is complete, a virtual ablation tool is shown in 3D view. It is coupled with the real ones and follows its movements.

In Figure 5 is shown the augmented visualization of the 3D virtual model over the patient's body (a dummy) during a preliminary test in the operating room. In the image is shown also the model of the needle used for RFA. This visualization should guide the surgeon during the needle insertion in the radiofrequency ablation of the liver tumour.

#### V. USED TECHNOLOGIES

A reconstruction of the 3D model of the anatomical structures of the patient is required in order to improve the standard slice view.

An efficient 3D reconstruction of the patient's organs is generated by applying some segmentation and classification algorithms to medical images (CT or MRI) of the patient.

The image segmentation consists in the identification of the pixels that belong to a specific anatomical structure. This process can manual, semi-automatic or fully automatic. The grey levels in the medical images are replaced by colours that are associated to the different anatomical structures [14]. After the segmentation of each slice of the dataset the software can reconstruct the 3D model using a model maker. This algorithm combines the results of segmentation of each slice and the slice tickness parameter to build a tri-dimensional model.

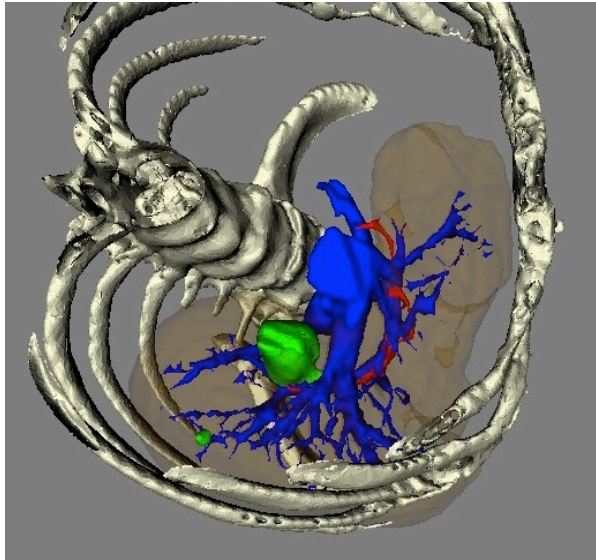


Figure 3. 3D model from the CT dataset

Nowadays there are different software used in medicine for the visualization and the analysis of medical images and the 3D modelling of human organs. Mimics [15], 3D Slicer [16], and OsiriX [17] play an important role among these

tools. Some of them are also open-source software.

In our application we have used 3D Slicer for the building of the 3D model of the patient’s organ. 3D Slicer is a multi-platform open-source software package for visualization and image analysis. It has many builtin segmentation algorithms and also a model maker module. Fig. 1 shows a 3D model built from CT scan of the patient with the liver tumors models in green.

The AR guidance application was developed using Image-Guided Software Toolkit (IGSTK) framework [18]. It is a set of high-level components integrated with low-level open source software libraries and application programming interfaces.

In the developed AR platform we use an optical tracker. This tool is able to detect some retro-reflective spheres intentionally introduced in the surgical scene. These spheres are placed on the surgical tools. They provide within a defined coordinate system the real-time spatial measurements of the location and orientation of the surgical instruments used during the surgical procedure.

In the first prototype of the system we have used the Polaris Vicra optical tracker [19]. After the test in the operating room we changed the tracking system to ensure surgeons more freedom of movement. For this reason we decided to use the Bonita Vicon tracking system [20]. This tracking system uses a variable number of separated cameras that can be better positioned in the operating room.

A specific library has been developed and tested for interfacing with the Bonita Vicon tracker. This library was integrated inside IGSTK framework.

At the base of the functioning of IGSTK there is the use of a state machine that allows to increase the safety and robustness of the toolkit [21].

The use of a state machine, in fact, allows to limit and control the possible behaviors of application in order to ensure that it is always in a formal state planned in the

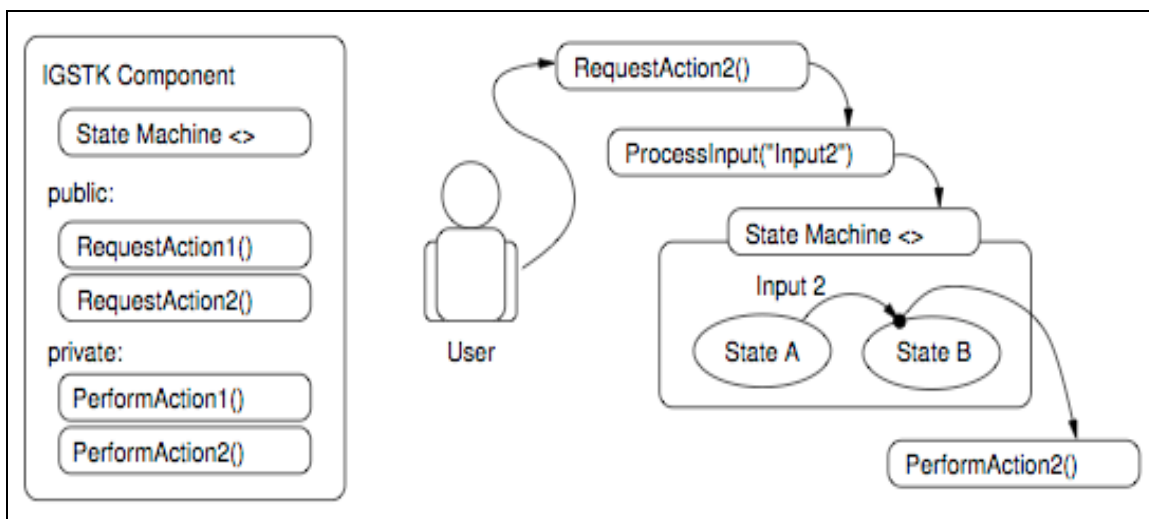


Figure 4. Working modality of IGSTK library components

design phase. This guarantees a reproducible and deterministic behavior that eliminates the risk of application design formal errors.

The separation between public and private interface of a IGSTK component (object) is shown in Figure 4.

When a user send a request for an action through a call of a public method, this request is translated into an input for the state machine. The state machine taking into account the current state and the sent input changes its state as expected in the design phase. In any case, the object will always be in a known state because each type of behavior has been programmed.

The IGSTK Tracker component communicates with the tracker to obtain the position and orientation relative to each tool that is present in the acquisition volume. This information is then transmitted to other IGSTK components who request it.

The two classes of IGSTK framework that provide for trackers management are:

- “igstk::Trackers” that serves to manage the status information of the tracking system;
- “igstk::TrackerTool” that manages the information associated with each tool present on the scene.

The “igstk::Trackers” class uses the interface of the “igstk::Communication” class for the management of communications. This allows to prevent blockage of the application in the case of any lack of connection with the tracker. In this case an error event is generated in a non-blocking mode. The tracker acquired data are stored into a memory buffer.

The class “igstk::PulseGenerator” generates the clock used by the application in order to synchronize all events. In this way, reading and updating of the data are asynchronous operations and this allow high standards of safety and performance.

To calibrate the instrument used in the surgical application and obtain the transformation elapsing between the tool and the point of interest has been implemented the PivotCalibration algorithm. This algorithm permits to store the position and orientation of the tracker tool holding fixed the position of the instrument tip and moving the tool in the space [22].

## VI. APPLICATION TESTING

The first test of application was made on a dummy. We tried to overlap the 3D models of a real patient on the dummy, as shown in Figure 5. These models were generated from a sample, anonymized CT dataset. This test was not successful because there was a misalignment between the dummy and the virtual models. This is due to a different thoracic girth between patient and dummy.

To overcome this problem we decided to make a preliminary qualitative test of application in the operating theater. This test is designed to evaluate the application uncertainty in the operating room and also all the possible issues related to a live use in the operating room.

A selected case of patient with superficial liver cancer

lesions was found by surgeons. The patient will undergo to a traditional open surgery liver RFA.

After a traditional needle insertion we started the application and made registration. At this moment it was verified if a good overlap with tumor and real organs was obtained. In this case we obtained good qualitative result.

The test doesn't add risks for the patient, if compared with traditional RFA surgery, because the application was not used to guide the needle insertion. Anyway the patient was informed on the nature of the experiment and signed an informed consent form.

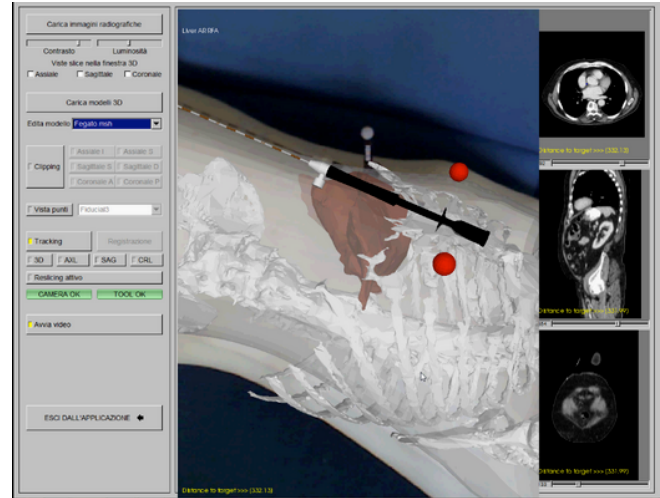


Figure 5. Augmented visualization of the 3D virtual model over the patient's body (a dummy)

## VII. CONCLUSIONS AND FUTURE WORK

In this paper we present a guidance system for needle placement in radiofrequency ablation of the liver tumour.

The application has been tested previously on a dummy and afterwards a first test has been carried out in the operating room during an open surgery procedure for the liver tumour resection.

The laboratory test consists in a simple overlapping of real patient models obtained from a simple anonymized CT dataset on a dummy. The results of this test were not as expected because there was a significantly difference in thoracic girth between patient and dummy.

We decided to move to the operating room to test the application in a qualitative manner on a real patient. The models were built from patient's CT scans. The test in the operating room has also the aim to evaluate all the possible issues of that operating scenario. In Figure 6 is shown a phase of the first test in operating room.

The test on the real patient led to good results. A correct overlap of virtual models on real patient was obtained in this case.

The test in the operating room produced interesting results for all the aspects related to the constraints of the

particular environment. Operating rooms are overloaded of systems and devices and an efficient use of space is mandatory. In this first test the correct position of the devices close to the operating table has been defined and a precise definition of the more appropriate fiducial points used for the registration phase has been decided.

Surgeons judged the tracker volume of interaction to be not sufficient. For this reason we decided to change the model of the optical tracker used in this first test to obtain a bigger volume of interaction. A specific library was developed and tested for interfacing with this new tracker. This library was integrated within the IGSTK framework. This new tracker should be tested in the laboratory to evaluate its measure uncertainty and then in the operating room to evaluate if the new volume of interaction can be sufficient for the surgeons.

Anyway surgeons were excited and think that the AR technology can help them in the needle placement task.



Figure 6. First test in the operating room

The next test will be done on a pig liver in order to measure the precision of the image-guided application. We're planning also to design a quantitative test in operating room to evaluate what is the application guidance uncertainty.

We are also taking into account the possibility to include in the system the simulation of the virtual model deformations due to the breathing of the patient.

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