A Review of Use of Augmented Reality in Surgery
Medical Image Analysis

Pamir Ghimire, Gopikrishna Erabati, Poorna Naga Avinash N.
Master Computer Vision, M1, UBourgogne, Le Creusot Antenna
Supervisor : Dr Alain Lalande

May 2017

Summary: Minimally invasive surgeries are currently performed under limited view of the surgical field acquired through an endoscope. This presents difficulties in locating the target tissue, visualizing the surgical tool, and making fast decisions regarding maneuvering of the tool in inside the body. A view of the surgical field augmented with information acquired pre-operatively as well as intra-operatively using instruments other than the endoscope can provide the surgeon a better representation of the surgical field, thereby potentially increasing his/her speed, accuracy and confidence in the procedure. The augmented reality (AR) of the minimally invasive surgical field can thus make it more effective.

We present in this report the science behind AR, the technologies used for implementing it, and its use-cases in some types of surgeries.

Chapter 1

Introduction to Augmented Reality

1.1 What is Augmented Reality?

Augmented reality can be defined as a sensation of the actual state of things together with non-existent states ascribed to them. The non-existent states arise from virtual processes, and comprise the virtual component of augmented reality, henceforth called AR. The augmentation can be applied to the sensation of light, as well as other stimuli like temperature, touch, etcetera [1] . Here, we concern ourselves with augmentation the sensation of light through the sense of vision.

Augmented Sensation = $f(S_{real-processes}, S_{virtual-processes})$, a function of hybrid stimulus.

According to the most widely used definition of AR, it must meet two requirements: it must combine information from real and virtual environments while being interactive in real-time and registered in 3D [1]. The extent to which information from reality and virtuality is present in an augmented reality determines its position on the Milgram's scale. Milgram also defined augmented reality as 'a technique of augmenting natural feedback to the operator by use of simulated cues'. However, not all implementations of 'AR' today are interactive.

Figure 1.1: Milgram's Continuum of reality. Both augmented reality and virtual reality are instances of a larger class called mixed reality.

1.2 The Computer Vision Perspective

Augmented reality is the perspective projection of a virtually augmented 3D scene. Image points correspond to points that exist as well as don't exist in reality.

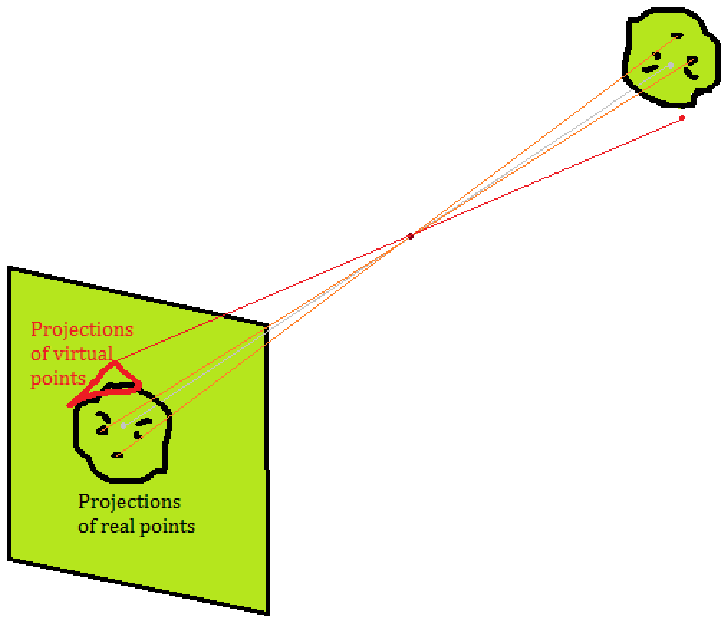


Figure 1.2: The red hat on top of the face does not exist in reality. The image, therefore, is an augmented reality.

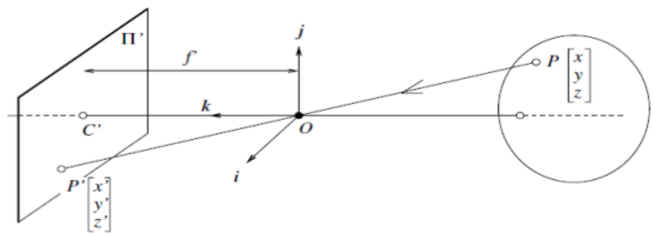
To create AR, it is necessary to have 3D understanding of the scene, since rendering the augmented scene requires computing projections of 3D points represented in scene coordinates. The virtual objects that are to be rendered in an image are created as a set of related 3D points, first in an arbitrary coordinate system, with optical properties such as color, texture, opacity, and so on. In order to be rendered with elements of the scene , these 3D points need to be translated, rotated and scaled (and transformed in other ways in case of non-rigid scene) to be registered correctly with the world elements by the system creating the AR. The system has to render the augmented 3D scene as a perspective projection from the desired view-point.

Hence, the knowledge of the pose of the viewer (which may or may not be coupled with a camera) is also fundamental to composition of AR.

1.2.1 Camera Calibration:

In order to acquire 3D understanding of the scene, it is necessary to know the parameters of the cameras that capture the scene.

The process of estimating camera parameters, external ones being pose (location and orientation) of the camera relative to a world coordinate system, and internal ones being parameters like focal length, is known as camera calibration. There are several methods in the Computer vision literature for calibrating a camera, a popular one being DLT (Direct Linear Transform) which takes as input pairs of corresponding 3D (world) and 2D (image) points.



$$\begin{cases} x' = f' \dfrac{x}{z}, \\ y' = f' \dfrac{y}{z}. \end{cases}$$

Figure 1.3: Pin-hole model of a camera. In calibration, we estimate the location and orientation of the camera in the scene, together with its focal length.

To know the locations of some image points in the world to calibrate a camera, we may add fiducial markers to the world at known locations and find their projections in the image. If not, other techniques, notably SLAM (Simultaneous Localization and Mapping) can also be used.

1.2.2 Tracking:

In order to represent real objects in AR, it is necessary to know in real time their location in the world. If the object of interest is not static, its position and orientation needs to be tracked. This also implies that we need to track the surfaces we want to augment.

Similarly, if the AR is to be rendered from the perspective of a moving viewer, like an endoscope or a head mounted display, its pose also needs to be tracked. The camera's pose may not be the same as the viewer's pose.

1.3 A Taxonomy for Mixed Reality Visualization

DVV, short for Data, Visualization processing, View, defines each of the major components of mixed reality image guided surgery (IGS) system. This paves way for developing a common language that builds the bridge between developers and end users to understand the constituents of visualization system.

In line with this classification, researchers have tried to introduce a syntax and a framework within which mixed reality image guided systems may be discussed, analyzed and evaluated, and its significant components be understood.

For surgeons to effectively plan surgeries, following questions are answered:

- Data is abundant, what to use?
- How the selected data can be effectively merged and visualized
- How it should be displayed and interacted with

1.3.1 Data

Data can be classified as : patient specific data and visually processed data. Significant consideration is given to data because we would have abundant data, and what type of data should be visualized and at what point during the surgery it is useful. A given instance of visualization data may be represented in a different way or in a different view during the surgical procedures. Therefore, visually processed data, should show the user the most appropriate data with more information at each point in the surgery.

1.3.2 Visualization Processing

This component of classification represents the visualization techniques or transformations on the data that are used to provide the best pictorial representation of the data for a particular task at a given surgical step. So, by choosing apt technique it is possible to increase the diagnostic value of original data.

1.3.3 View

The user actually interacts with this component of mixed reality. It provides a description of information presented to user and how the user can interact with the system. The perception location is a significant component of View. It may be the patient, a digital display, or real environment. Display and interaction tools also forms a part of View system.

Chapter 2

AR Environment : Technologies

2.1 Displays

2.1.1 Head-worn displays (HWD)

As the name suggests, this kind of displays are mounted by users on their heads so that display screens imagery is in front of their eyes. There are two types of HWDs:

optical see-through - AR overlay by a transparent display, and
video see-through - uses video imagery from video camera as background for AR overlay on opaque display.

Many renowned electronic and optical companies have manufactured head worn display intended for consumer applications. Although they are light weight they suffer from low resolution and small fields of view.

Another approach for display is the *virtual retinal display* [2] which forms images directly on the retina.it is quite interesting to know that several companies are developing displays that embed the optics within the conventional eyeglasses.

2.1.2 Handheld displays

These are panel LCD displays which use a video camera to obtain video see-through based augmentations.

2.1.3 Projection displays

Here, the virtual information is directly projected onto the physical objects. An interesting approach at projective display is head worn projector which project the information in viewers line of sight onto the object. If the target objects are coated with retro-reflective materials which reflect the light along the angle of incidence, multiple users can access the same object to project their virtual information as projected information can not be seen except along line of projection. An interesting application of such display is in mediated reality if we want to camouflage a device by making it appear semitransparent.[3]

There are certain problems in the displays. In see-through displays, the virtual information can not occlude the real information. Video-through displays suffer from parallax error as camera mounted on device is away from true eye location.

2.2 Tracking

Accurate tracking of viewers orientation and position is significant in registration. Although recent AR systems shows robust registration in prepared, indoor environments, there's still much to work with tracking and calibration. Typically, such systems employ hybrid-tracking techniques such as combination of accelerometers and video tracking for instance. The Single Constraint at a Time (scaat)[4] algorithm improved the tracking performance. Scaat incorporates individual measurements as the exact time they occur, resulting in faster update rates, more accurate solutions, and auto-calibrated parameters.

Effective AR requires, user's location and position of all other objects of interest in the environment. Using of fiducial markers in outdoor AR applications is not practical. Outdoor tracking with hybrid compass/gyroscope tracker in addition to video tracking (not in real time) provides nearly pixel-accurate results on known landmarks features. Although GPS (Global Positioning System) or dead reckoning has their own limitations, they may be used to track the real time position outdoors. Eventually, tracking in outdoor environments rely heavily on tracking visible natural features[5]. Unfortunately, System delays are often the largest source of registration errors. Predicting the motion and careful system design would reduce the effects of delays.

2.3 Input Devices: Interacting with the Augmented Reality

There are two main trends in AR interaction research:

- Using different devices to take the advantage of different displays.
- Integrating with the physical world through tangible interfaces.

2.4 Visualization problems

There are certain fundamental problems of displaying information in AR displays.

- Error estimate visualization
  Registration errors are significant and unavoidable in certain AR systems. Sometimes, visible registration errors may occur due to the unknown accurate measured location of object in the environment. This problem can be solved by knowing expected tracking and measurement errors and there by visually displaying the area in screen space where the object could reside.

- Data density
  If the density of virtual information augmented on real world is high, the display would result in an cluttered and unreadable. Researchers started to use filtering techniques based on a model of spatial interaction[6] to display only the significant information thereby minimizing the amount of information to display.

2.5 Advanced Rendering

High quality renderings aren't currently feasible in real time, researchers are studying about photorealistic rendering and also mediated reality.

- Mediated Reality
  Mediated reality is about removing the real objects from the environment. Here, we need to extract not only the depth information from the scene but also need to segment individual objects in the environment. A method for identifying the objects and their locations in the scene with the help of silhouettes[7] is proposed.

- Photorealistic rendering
  With the help of automatic capture of the environment illusion and reflectance information we can improve the rendering quality of virtual objects in AR application.

2.6 A Design of Head-Mounted Operating Binocular

2.6.1 Introduction

A HMD is used in AR, but due to considerable technical problems related to AR, the intra-operative application of HMD is limited. One of the issues in using HMDs is requirement of common optical focal plane for both the real-world scene and the virtual image. To solve this issue researchers have adapted a Varioscope (Life Optics, Vienna), a miniature, cost-effective head mounted operating binocular, for AR.

The technical problems associated with the clinical application of AR:

- In a conventional HMD, the joint display of virtual and real scenery is difficult to achieve as the only optical element in the viewer's optical path is a simple beam-splitter. As, the virtual object distance reflected on semi-transparent beam-splitter and real object distance varies, a common focus cannot be achieved by viewer's eye, which results in an unfocused view.
- The acceptance of HMD by the surgeons.
- The registration of virtual and real world view which has to be maintained at all times within accuracy limits. So, an accurate calibration and real time tracking of HMD is mandatory.

Researchers proposed to introduce HMD in the operating theater by integration into the operating microscope which solves the above problems. But the use of an operating microscope has limitations as it is not available in all operating rooms and introducing bulky operating microscope for the purpose of AR, appears infeasible economically.

In order to solve all the afore mentioned problems, researchers designed a stereoscopic AR visualization by adapting a miniature head-mounted operating binocular.

2.6.2 Methodology

By the insertion of image rectification prisms into the optical path, we provide a convenient way to add the beam-splitters for merging the virtual and optical view as captured by the lens of the device. One face of image rectification prism is covered with a thin semi-transparent layer acting as a beam-splitter. Due to this there is a loss of 20% of incident light. Inspite of loss of image brightness, the perceived image remains almost same due to the low focal ratio of Varioscope.

The projection optics is designed in such a manner that the eye lens of the Varioscope magnifies both the image from the objective lens and from the projection , both of which provide an image in the focal plane of the objective lens as shown in Fig. 2.1. By this the problem of providing a commonly focused view of real and virtual scenes is solved. The computer generated images are displayed on two miniature LCD displays with VGA resolution. The displays have high brightness which allowed projecting of image without additional background illumination. The prototype can be seen in Fig. 2.2.
The photogrammetric calibration for relating the 3D position information to the 2D coordinate system of the HMD's display is done [8] and experiments were carried out resulting a very low mean calibration error of 1.24 ± 0.38 pixels or 0.12 ± 0.05 mm for a 640 x 480 display.

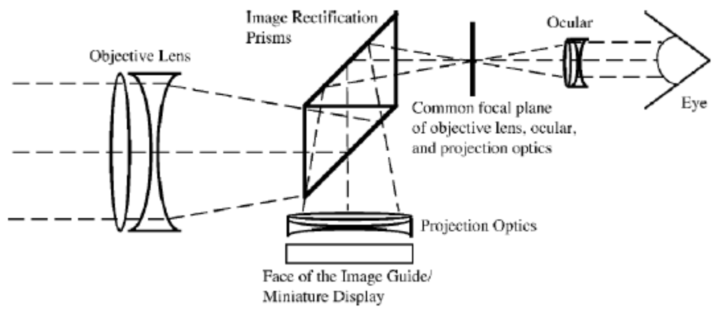


Figure 2.1: The principle of image overlay in Varioscope AR

Figure 2.2: Prototype of Varioscope AR (a) the base instrument (b) the housing for the projection optics with the miniature displays

Chapter 3

Use-Cases in Surgery

3.1 Introduction

Why use AR: In minimally invasive surgeries, the surgeon's field of view is limited. Augmented reality can help surgeons to see anatomically important information that is occluded. This can lead to shorter operative time, and less collateral damage since the surgeon can be certain about the location of the occluded target tissue. AR and VR are being used today for diagnosis and treatment planning, surgical training, pre- and intra-operative visualization, and intra operative navigation. [13]

Goal of AR in MIS: The goal of AR in MIS is to effectively integrate pre- and intra-operative medical images and surgical navigation into a common environment. Intra-operative images currently come from modalities like CT, intra-operative MRI, XMR (combined X-ray and MRI imaging), ultrasound, and X-ray fluoroscopy. These modalities are studied in detail in the field of interventional radiology, whose standard now is x-ray fluoroscopy.[13]

Preparing data for AR: : Pre-operative image data is usually incorporated into a model instead of being used directly. These models are generally surfaces described as polygonal meshes. Decimation is a technique used to compress such models by replacing several small polygons in areas of low curvature with a single large one. Segmentation is necessary to extract the surface model, and manual segmentation is the current gold standard. Models generated through volume rendering can be more descriptive than surface models, since they don't discard bulk of the volumetric data. [13]

Representation of Surgical Instruments: Surgical instruments are tracked by using either optical methods, which require line of sight between the surgical device and the tracking sensor, or magnetic methods, which can track instruments inside the body but in a limited tracking volume and require absence of

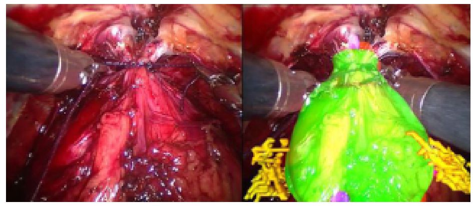


Fig. 8. Example of an augmented reality overlay onto the prostate, showing the position of the prostate itself and the nerve bundles that need to be preserved to maintain urinary and sexual function.

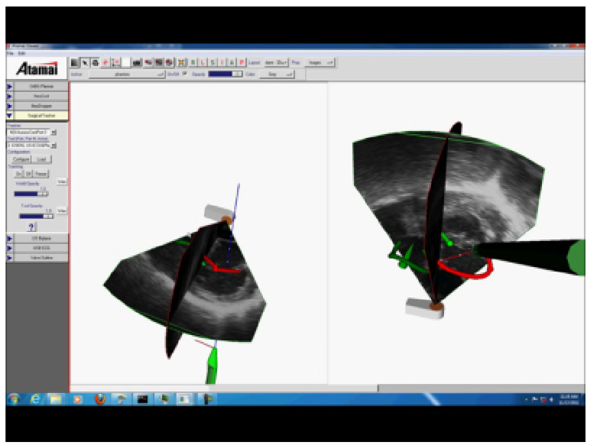


Fig. 9. Mixed reality guidance platform for intracardiac mitral valve repair showing real-time trans-esophageal echocardiography data combined with geometric models for trans-esophageal probe, NeoChord tool, mitral and aortic valve annuli.

Figure 3.1: Examples of augmented intra-operative views with 3D surface model (top) and multi-plane US view with tool localization (bottom). [13]

ferromagnetic materials. A representation of the tracked instrument is placed in the composition of mixed 3D scene, together with the model from pre-operative images, and intra-operative images. Image registration is used in this composition to fuse the information from different sources. Iterative Closest Point, a rigid-body registration algorithm is popularly used for this today.[13]

Visualization: For visualization, the most commonly preferred 2D views are orthogonal and oblique planar; a particular oblique plane can be defined by choosing 3 points in a volume. Similarly, an axis can be defined by choosing 2 points and be used as the normal for generating planar views. 3D visualization is obtained through volume rendering and ray casting methods. It is possible to combine data from morphological and functional modalities in creating these visualizations, for example, electro-physiological model of the heart. The display platform may be one of the technologies explained in the previous chapter. Here, choice of a stationary viewpoint can reduce complexity of implementation since tracking the viewpoint is not necessary.

What to track: For composing AR for MIS, it is necessary to track the location and orientation of the surgical tool, the surgeon's head (when a Head Mounted Display is being used, refer chapter 2), and the endoscopic camera. In case a see through display is used, it is also necessary to track the position of the pupil. [16]

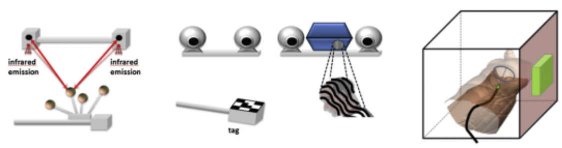


Figure 3.2: Different methods for tracking surgical instrument and surgeon's head. [16]

In order to augment the right surfaces on the patient, it is necessary to track them. In MIS, the practice is usually to track markers on the skin of the patient being operated on.

What not to show: It is important to constrain the information presented to the surgeon, so that it is not distracting or overwhelming. One possible method is to model the surgical workflow, identify the information required in th current stage of the surgery, then compose the augmented display to be presented to the surgeon.

Synchronization: A key challenge is to achieve spatial and temporal synchronization between different data sources. Complex systems can have a high end-to-end latency which means lag between the augmented view and the reality. Any motion that occurs during the time taken for composing AR then results in misalignment of the AR with reality.

3.2 Augmented Reality in Liver Surgery

We review here augmented realities (AR) for minimally invasive hepatic surgery under different methods.

Non invasive techniques commonly used for diagnosis and therapy include laparoscopic surgery and endoscopic surgery. While both approaches can be used for the treatment of hepatic tumors, laparoscopy is by far the most commonly used. However, hepatic resection and tumor removal using a laparoscopic approach remains a major challenge. Besides the requirement for advanced technical skills, the main issue is the transfer of the planned resection strategy (performed on the pre-operative data) into the operating field. While resection planes, vascular structures and tumors are identified in the preoperative CT or MR scan, and reconstructed in 3D, they cannot be visualized during the procedure. To overcome this issue, a number of research groups are developing augmented reality techniques to overlay vessels, tumors and cutting planes onto the laparoscopic video. Some current techniques use real time deformable liver model based on bio-Mechanical approach. The objective is to develop an automatic, real-time, non-rigid registration and tracking of the intra and pre-operative liver data.

3.2.1 Augmented Reality in Laproscopic Liver Surgery

The topic of non-rigid Registration and Augmentation is actively researched today. According to the context, non-rigid registration and augmentation can be realized directly from 2D images [14] or advantage of a 3D model can be taken. The computational flow of the method in [14] is shown in Figure 3.3.

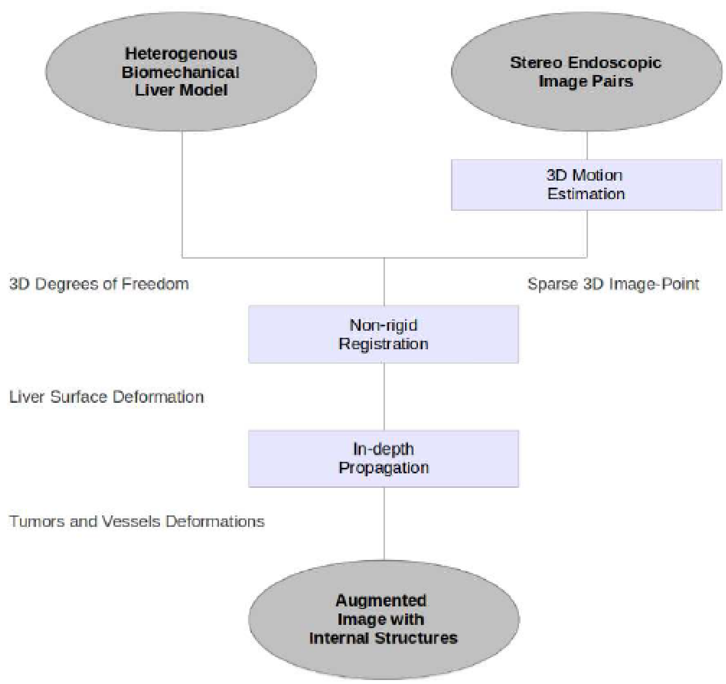


Figure 3.3: Computational Flow for creating AR with deformable liver model. [14]

3.2.2 3D Motion Estimation.

In [4], stereo endoscope is used to recover 3D information from the liver intraoperatively. A set of sparse 3D points are required, and feature-based tracking is used. Salient landmarks are detected in each image pair using the Speeded-Up Robust Features (SURF) descriptor [14] and are tracked over time thanks to the Lucas-Kanade optical flow [14] . This combination has proven to be robust to track heart motion in laparoscopic images [14] . Feature correspondences between stereo images are obtained with a nearest neighbor criterion on feature descriptors coupled with the epipolar constraint to filter out outliers. After triangulation, a sparse set of m 3D points is obtained, denoted by 3xm coordinate vector y. Examples of point correspondences and reconstructed 3D points from laparoscopic images are shown in Fig. 3.4.

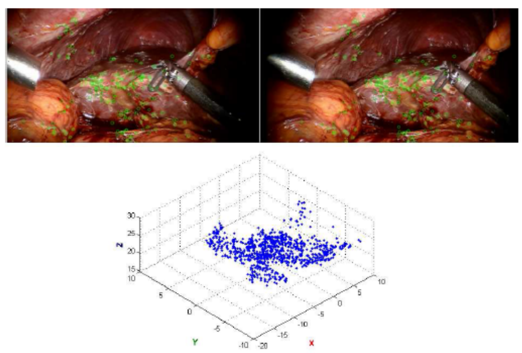


Figure 3.4: Reconstructed 3D points.

3.2.3 Bio-Mechanical Model

A bio-Mechanical Model is used to compute the deformation of the liver model. This model is derived form the pre-operative CT data.

3.2.4 Non Rigid Registration

A proper initial registration is an important step in the framework since it can significantly impact the estimated position of the tumor. For that purpose, special care must be taken during the initialization phase. The initialization in [4] is done manually through a Graphical User Interface:

- The real camera parameters acquired from camera calibration are loaded on the virtual camera.
- The 3D model of the liver is manually aligned on the first pair of laparoscopic images based on salient geometrical landmarks such as liver

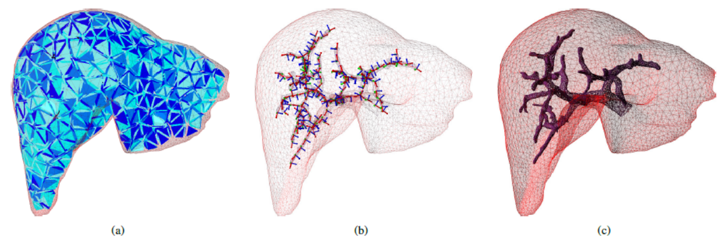


Figure 3.5: 3D heterogeneous Bio-mechanical model of the liver:a)The volumetric mesh composed of tetrahedra,b)The beams generated along the vessels,c)the heterogenous liver including the vascular network in wireframe.[14]

contours or surrounded ligaments (the first pair is chosen so that a large part of the liver is visible).

- The biomechanical model (including the vessels and the tumour) is deformed to better fit the laparoscopic stereo images and the 3D reconstructed point cloud.
- The boundary conditions are set by fixing correct degrees of freedom of the biomechanical model.
- The set of three-dimensional points reconstructed using this initial stereoscopic pair of images are projected onto the liver model surface. This is done using a ray casting method, followed by a computation of barycentric coordinates describing the position of these points with respect to adjacent degrees of freedom of the Bio-mechanical model.

3.2.5 Results

The final result is the superimposition of biomechanical model onto the liver's view in endoscope's feed and can be seen on displays of respective screen.

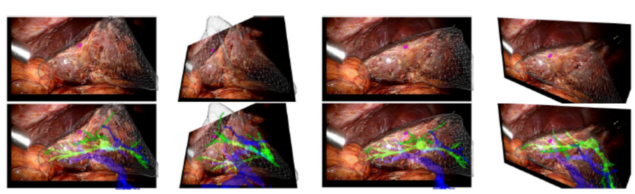


Figure 3.6: The superimposition of the real-time biomechanical model onto the human liver undergoing deformation due to surgical instrument interaction during MIS. The liver is represented in wireframe, the tumor in purple, the hepatic vein is shown in blue and the portal vein in green.[14] .

3.3 Long-Term and Accurate Augmented-Reality for Monocular Endoscopic Videos [15]

The major contribution of this study is the ability to automatically recover from the system failures caused by occlusions, endoscope retraction and organ deformation in order to obtain long term and accurate augmented Reality.

To preserve long term Augmented reality, the following pipeline was presented.

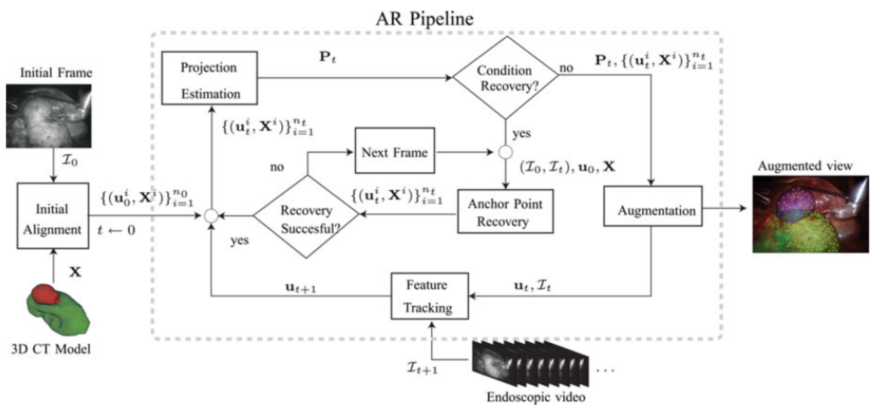


Figure 3.7: Pipe Line for AR[11].

In order to maintain the augmented reality, a set of anchor-points (i.e., matches between the 3-D CT model and the endoscopic image) are used which can be seen in the figure below.

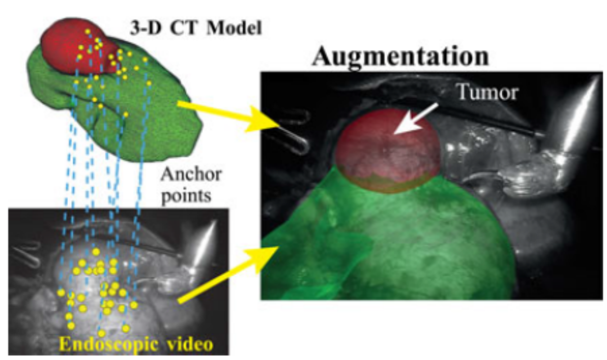


Figure 3.8: AR Display [15].

The system uses correspondence-search methods, and a weighted slidingwindow registration approach, to automatically and accurately recover the overlay by predicting the image locations of a high number of anchor points that were lost after a sudden image change. The system can thus maintain the AR for over 2 minutes. In case of loss of tracking, it goes into a tracking-recovery mode. If the recovery is successful, the new set of anchor points are used to compute P_t . Otherwise, the system does not render the virtual model on the current frame and tries to recover the anchor-point pairs at the next frame. These stages are iterated for each new frame of the video.

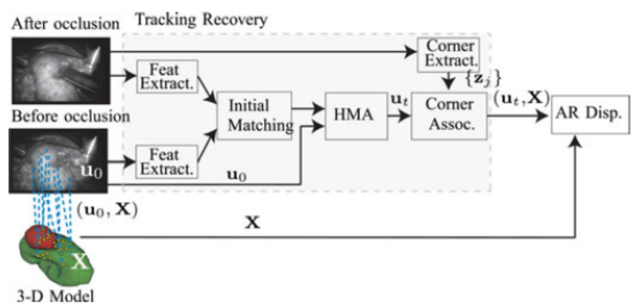


Figure 3.9: Pipe Line for Tracking Recovery [15].

3.3.1 Augmentation:

In this stage, the projection matrix estimated from the previous stage, is used to overlay the entire 3-D organ's model onto the endoscopic view.

3.3.2 Feature Tracking Stage

The feature-tracking stage updates the anchor point every time a new frame is acquired. In order to track image features (corners) among consecutive endoscopic video frames, a feature-tracking algorithm is adopted[15] which is robust to changes in illumination.

3.3.3 Tracking Recovery Stage

In order to accurately recover a high percentage of anchor points after a complete occlusion, we adopted a tracking recovery stage (see Fig. 3.9).Here it compares the image before occlusion with the current one after occlusion.Feature-matching strategy [15] to compute an image transformation that predicts in I_t(current frame) the position of those anchor points from I_m(last recovered frame). This procedure is repeated for each image in the buffer, and the solution that leads to the largest number of recovered features and lowest re-projection error is selected.Due to uncertainties in the estimated transformation, these predicted points u_t might not correspond exactly to the original tracked features.

For this reason, a corner-association stage has been introduced to ensure that the recovered features are of the same kind of the original tracked ones in this way we can preserve the long term accurate augmentation.

3.4 AR in Laparascopic Surgery

Port Placement: Laparascopic surgery is the surgery of abdominal parts. Instruments are inserted through incisions in the abdominal wall. It is hence important to decide where to place incisions in order to reach the target organ effectively. AR can be used to facilitate this by displaying on top of the abdominal skin a projection of the internal/target organs obtained through preoperative imaging. Markers can also be placed in virtualization of the anatomy, for example virtual screws in the MRI of spine, and this information can be projected on the surface of the skin to augment its informativeness during the surgery. [16]

To display the projection of the internal organs on accurate locations on the skin, it is necessary to register the projections with the view of the skin. For this, we can use artificial fiducial markers as well as anatomical landmarks like ribs, the clavical bone and other prominent structures. Abundant a priori knowledge of anatomical landmarks (such as the ribs) is an important advantage for AR in surgery over AR in other environments. Currently, in interactive AR, registration requires the surgeon to adjust the augmentation to align it well with landmarks in reality.

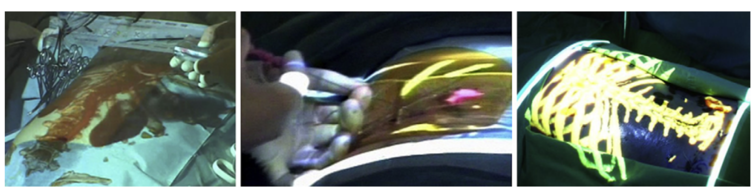


Figure 7. This figure shows different examples of projection-based augmented reality from Sugimoto (left), Osorio (middle) and IRCAD Taiwan institute (right, courtesy of Dr. Pei-Yuan Lee, chief of Orthopedic Dept. ShowChwan Chang-Hua Hospital).

Figure 3.10: Internal anatomy visualized on skin, so that it effectively becomes 'transparent'. Needles and probes inserted beneath the skin can also be visualized and guided using the projection on the skin. [16]

Augmenting view of the endoscope: To augment the images from an endoscope, we first estimate the current pose of the endoscope and use this to render a view of the internal organs that a virtual endoscope would see from the same pose in the pre-operative image. The pose information is then also used to initialize the registration of the rendered view with reality. The registration can then be fine tuned manually or automatically.

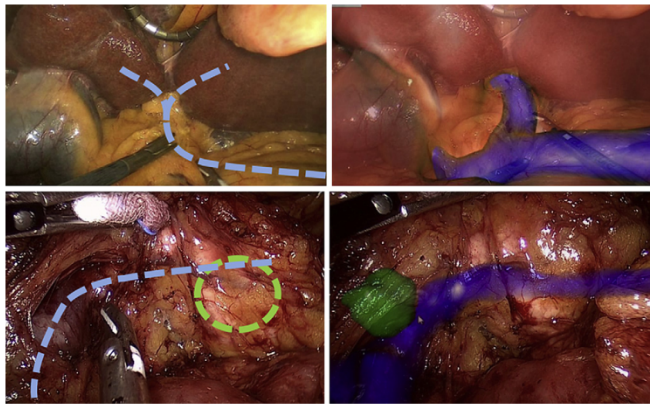


Figure 9. Two examples showing a correct estimation of vessels (blue) and tumour locations of the IAR (right views) validated by an endoscopic US, against an initial erroneous estimation by the surgeon (dash lines in the left views). The first line shows a surgeon error of 45° in the orientation of right and left portal branch, the second line shows a surgeon erroneous location of the tumour (over 1 cm). In both cases IAR provides the correct location.

Figure 3.11: Augmentation of view of the endoscope for visualization of invisible blood vessels. In this case, the system's estimate of vessel positions was more accurate than that of surgeons. [16]

Rigid registration is incorrect: Position of organs in the patient body changes (slightly) during surgery, and the organs may also become deformed (The organ displacement can be over 2 cm). Further, in laparascopic surgery, the abdomen is insufflated (inflated) with gas to increase the maneuverable space. The pre-operative image based information of the organs thus quickly becomes obsolete once the surgery begins. It is therefore necessary to update this information interactively, possibly by the use of intra-operative imaging, or simulation of deformations of organs in real time. In [16], real time measurement of skin motion is used to infer organ deformation.

Soft organs can deform as a result of interaction with surgical tools. Hence, rigid registration of the model obtained from pre-operative imaging with intra-operative organ view is inaccurate for deformable organs. However, deforming the pre-operative model and non-rigid registration are not practiced popularly.[16]

3.5 AR for Needle Guidance

Biopsy is the process of removing a sample of tissue or fluid (like blood, cerebrospinal fluid, etc.) from a person's body to assess it for the presence of a disease or guage the extent of a confirmed one.

To acquire samples from a suspected tissue inside the body, the modern practice is to use a needle inserted into the body through a small incision, instead of by making a big incision. A small incision minimizes the injury to the patient for diagnosis purpose, allowing quick recovery.

Because target tissues often lie deep within the body, it is necessary for the surgeon to know the position of the needle with respect to the target tissue and other anatomical structures as s/he guides it. This is usually done by using ultrasound (us). However, AR can provide a richer feedback. [17]

The idea here is to first model the anatomy and the target tissue using pre-operative imaging such as CT, then use this model to augment the view of the surgeon when s/he guides the needle. The augmented view can include the current position of the needle beneath the skin, it's projected trajectory, and the position of the tumor.

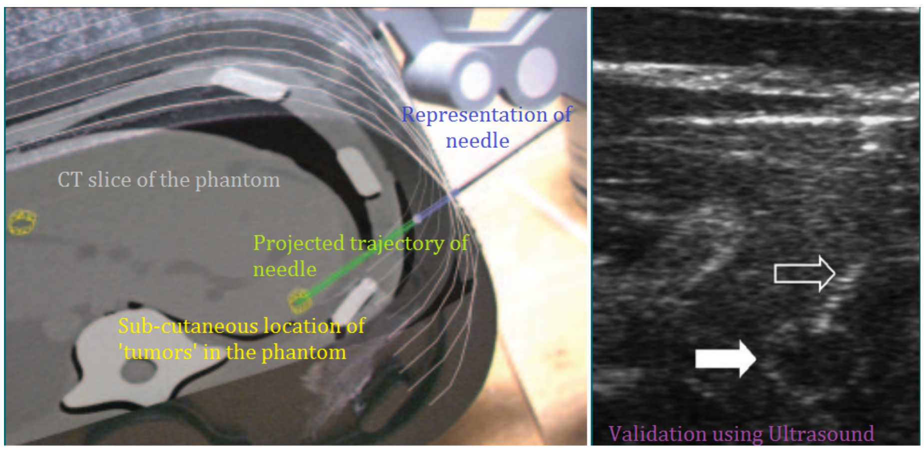


Figure 3.12: The phantom is made transparent by using AR as a needle is guided to a 'tumor' inside it. That the needle was actually placed in the visualized location is validated using Ultrasound.

To do this, the needle's pose (location and orientation) is tracked, using optical markers in [17], or magnetic tracking. The view-point of the surgeon is tracked if it is a dynamic one, like in [17] where the surgeon views the surgical scene through a video see-through head mounted display, and if not (stationary viewpoint), view-point tracking is not necessary. The augmented 3D scene is built by adding to the real image of the scene a representation of the needle under the skin, together with the models obtained from pre-operative imaging, and this scene is rendered for the surgeon's (or a stationary camera's) viewpoint.

Authors in [17] report that the difference between the position of the needle in the virtual patient space (where the AR showed the needle to be) and reality (where the needle actually was) was about 2 mm in their experiments using a phantom.

3.6 Virtual Reality-Enhanced Stroke Rehabilitation

3.6.1 Introduction

One of the major causes of adult disability is Stroke. The people who have survived stroke are living with minor to severe impairments. So, the stroke survivor's capacity for independent living is affected by the deficits in motor control caused by the impairments. Many conventional therapeutic interventions have been used in rehabilitation to recover the functionality of the motor control but the outcome is inconsistent[9]. It is evident from research that intensive massed and repeated practice is necessary to modify neural organization and to recover the functionality of motor control. But in this practical world, a patient is not given intense practice for recovery due to the service-delivery model which we are currently living in because of time, economic or similar practical concerns. So, a virtual reality based intense practice at the convenience of the patient is most required. Robot training using a virtual environment has been shown to enhance stroke rehabilitation[10].

By using virtual reality in rehabilitation we can create an environment where the training can be made systematic and introduce the feedback in system to improve the performance of the patient. The key advantages of this type of system are: we can increase the duration, frequency and intensity of practice to the patient by partial autonomous programs.

Taking the advantage of advances in the technology, we can make use of a personal computer connected to an internet to create VR environment for the practice of patient and the internet can be used to data transfer, allowing a therapist to monitor improvements of patient and change the plan of practice remotely. The VR-based rehabilitation can also be made interesting to the patient and engage the patient fully into the practice such that the patient feels immersed in simulated world. Thanks to the VR sensor technology,which can also be used to quantify the progress made by patient.

We should also consider the issue of whether the practice gained by the patient in virtual environment transfers to real world. Patients made a progress in the virtual environments but the learning always did not transfer to real world[11]. These conflicts should be further deeply studied to make use of VR as an enhancement to conventional therapy.

3.6.2 Experimental System

The VR-enhanced stroke rehabilitation system comprises of a personal computer running VR simulation exercises and database and some sensors for feedback. The researchers used two types of gloves where each of them was suited for certain exercises. The CyberGlove is used that mainly involve position measurement of patient's fingers, and the Rutgers Masters(RM) II glove is used for force-exertion exercises.

3.6.3 Rehabilitation Exercises

The designed system consists of four exercises where each of them concentrates on one particular parameter of hand movement: range, speed, fractionation and strength. The range-of-motion exercise is designed to improve patient's finger flexion and extension.In speed-for-motion exercise patient is asked to fully open and then close it as fast as possible. the fractionation exercise is performed by all fingers except thumb individually where the goal of exercise is to flex one finger as much as possible whether others kept constant. the strength exercise is designed to improve patient's grasping. The process of rehabilitation is divided into sessions, blocks and trials. A session is a group of blocks, each of different exercise. A block is a group of trials of same type of exercise.

The exercise parameters are estimated on-line during each trail in order to drive the display graphics and provide feedback to patient.

The researchers implemented target-based exercises which requires an initial test to evaluate patient's baseline movement. The set of targets for the first session is made from the normal distribution around mean and standard deviation given by the initial evaluation baseline test.the targets are changed according to the performance of the patient.

The exercises are designed to attract the patient's attention and to challenge him to execute the task as in form of games.The range of motion is planned as moving a wiper by patient to reveal an attractive wallpaper hidden behind the fogged window. The speed of motion is designed as to catch the ball game. the fractionation exercise is designed for the patient to play the piano by playing one key at a time. the strength of movement is designed as a virtual model of RMII glove where the strength applied on each finger is virtually seen by the patient as filling of a piston with different color[12]. The database is also maintained to provide quick access to the data for the therapist.

3.6.4 Designed Rehabilitation in Practice

The significant advantage of using VR-based rehabilitation in therapist point of view is the wealth of objective measures of patient's performance. For each trail or each block or for session the performance data can be visualized in appropriate way for the analysis of the therapist. Researchers have studied many case studies on this VR-based rehabilitation environment as in [12].

As we discussed first, the transfer of improvements from virtual environment to real world, the case studies showed good improvements in the real world. The VR-based rehabilitation involved exercise with force exertion, there are significant improvements in the grasping power of patients after this exercise. Although the cases were studied with parallel conventional and VR-based rehabilitation, we can consider that VR-based rehabilitation has quite reasonable contribution to some degree in improvements. We can also consider that, VR-based rehabilitation as an innovative way of improvement of patients conditions.

Chapter 4

AR : Challenges

4.1 Technological Limitations

The technologies used in AR systems need to become more accurate, lighter, cheap and less power consuming. The issues with the displays are of significant importance to explore the AR area to all sort of applications. The displays are not very bright and completely washes out in bright sunlight. The image has a fixed focus and it may not match the outdoor landmarks. The AR equipment is not portable. As always tracking in unprepared environments remains an enormous challenge. On par with tracking the issues with calibration still holds its limitations for end user as it is complicated. The connecting interfaces of different components involved also needed to be rugged.

4.2 User Interface Limitations

This is always a good area of research as we need a better understanding of what type of data to show, in which representation the data visualized would be apt to user and how the user interacts with the system. For instance, a user might want to look into a store, and query the availability of required items in the store with AR experience, so not all that can be shown might be relevant.

4.3 Social Acceptance

The end challenge is social acceptance, as how the AR becomes a part of user's everyday life. thanks to films which made many people aware of AR experience. Several issues regarding the social acceptance are needed to be addressed for instance the privacy concerns. These issues must be addressed before AR becomes widely accepted.

Bibliography

[1] Carmigniani, Julie, et al. "Augmented reality technologies, systems and applications." Multimedia Tools and Applications 51.1 (2011): 341-377.

[2] H.L. Pryor, T.A. Furness, and E. Viirre, "The Virtual Retinal Display: A New Display Technology Using Scanned Laser Light," Proc. 42nd Human Factors Ergonomics Soc., Santa Monica, Calif., 1998, pp. 1570-1574.

[3] M. Inami et al., "Visuo-Haptic Display Using Head-Mounted Projector," Proc. IEEE Virtual Reality 2000, IEEE CS Press, Los Alamitos, Calif., 2000, pp. 233-240.

[4] G. Welch and G. Bishop, "Scaat: Incremental Tracking with Incomplete Information," Proc. ACM Siggraph 97, ACM Press, New York, 1997, pp. 333-344.

[5] U. Neumann and S. You, "Natural Feature Tracking for Augmented Reality," IEEE Trans. Multimedia, vol. 1, no. 1, Mar. 1999, pp. 53-64.

[6] S. Julier et al., "Information Filtering for Mobile Augmented Reality," Proc. Int'l Symp. Augmented Reality 2000 (ISAR 00), IEEE CS Press, Los Alamitos, Calif., 2000, pp. 3-11.

[7] V. Lepetit and M.-O. Berger, "Handling Occlusions in Augmented Reality Systems: A Semi-Automatic Method," Proc. Int'l Symp. Augmented Reality 2000 (ISAR 00), IEEE CS Press, Los Alamitos, Calif., 2000, pp. 137-146.

[8] Wolfgang Birkfellner et al., "A Head Mounted operating Binocular for Augmented Reality in Medicine - Design and Initial Evaluation," IEEE trans. on Medical Imaging, vol. 21, no. 8, Aug. 2002.

[9] P. Duncan, "Synthesis of intervention trials to improve motor recovery following stroke," Stroke Rehab., vol. 3, no. 4, pp. 1–20, 1997.

[10] H. I. Krebs, N. Hogan, M. L. Aisen, and B. T. Volpe, "Robot-aided neurorehabilitation," IEEE Trans. Rehab. Eng., vol. 6, pp. 75–87, Mar. 1998.

[11] J. Kozak et al., "Transfer of training from virtual reality," Ergonomics, vol. 36, no. 7, pp. 777–784, 1993.

[12] David jack et al., "Virtual Reality-Enhanced Stroke Rehabilitation," IEEE trans. on Neural systems and Rehabilitation Engineering, vol. 9, no. 3, sept. 2001.

[13] Linte, Cristian A., et al. "On mixed reality environments for minimally invasive therapy guidance: Systems architecture, successes and challenges in their implementation from laboratory to clinic." Computerized Medical Imaging and Graphics 37.2 (2013): 83-97.

[14] Haouchine, Nazim, et al. "Impact of soft tissue heterogeneity on augmented reality for liver surgery." IEEE transactions on visualization and computer graphics 21.5 (2015): 584-597.

[15] Puerto-Souza, Gustavo A., Jeffrey A. Cadeddu, and Gian-Luca Mariottini. "Toward long-term and accurate augmented-reality for monocular endoscopic videos." IEEE Transactions on Biomedical Engineering 61.10 (2014): 2609-2620.

[16] Nicolau, Stéphane, et al. "Augmented reality in laparoscopic surgical oncology." Surgical oncology 20.3 (2011): 189-201. APA

[17] Das, Marco, et al. "Augmented Reality Visualization for CT-guided Interventions: System Description, Feasibility, and Initial Evaluation in an Abdominal Phantom 1." Radiology 240.1 (2006): 230-235.