

An Endoscope Interface for Immersive Virtual Reality

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Abstract

This is a work in progress paper that describes a novel endoscope interface designed for use in an immersive virtual reality surgical simulator. We use an affordable off the shelf head mounted display to recreate the operating theatre environment. A hand held controller has been adapted so that it feels like the trainee is holding an endoscope controller with the same functionality. The simulator allows the endoscope shaft to be inserted into a virtual patient and pushed forward to a target position. The paper describes how we have built this surgical simulator with the intention of carrying out a full clinical study in the near future.

CCS Concepts

• *Human-centered computing* → *Virtual reality*; • *Software and its engineering* → *Virtual worlds training simulations*;

1. Introduction

Minimally invasive surgery (MIS) results in smaller incisions, faster recovery times, reduced pain, and reduced scarring. As well as these patient benefits, using MIS provides significant cost savings for the healthcare provider. Training for MIS to obtain the required level of competency and accreditation is an ongoing challenge, however, and opportunities continue to evolve. Training opportunities can include an intensive experience during residency, postgraduate short courses and/or full time fellowship programs. Incorporation of large animal surgery or specialist mannequins/patient models may also help shorten the necessary learning curve. The goal is to provide an intense hands-on experience to trainees in all aspects of MIS [PA09] enabling both skills acquisition and measuring competency.

Commercial simulators from companies such as 3D Systems Inc (USA) - formerly Symbionix Ltd (Israel) - CAE Healthcare (Canada) and Mentice AB (Sweden) have been available for the last two decades. Their products have proven to be effective in training a wide variety of MIS procedures [TLD14]. There are other sophisticated endoscopy simulators from academic groups, such as NOViSE, which supports flexible endoscopy with haptic feedback [KBS*16]. Such systems are expensive, however, and rarely found outside of specialised training hospitals. More recently there has been a surge in the development of immersive Virtual Reality (VR) hardware with affordable Head Mounted Displays (HMDs) and tracking sensors from Oculus (Facebook Technologies, USA) and HTC Corporation (Taiwan) aimed at the entertainment market. This paper reports on how we have used such hardware to develop one of the first *affordable* and *immersive* VR interfaces for training endoscopy procedures. In particular we describe a novel tangible

interface that "feels" like a real endoscope when being manipulated by the trainee in VR. Our goal is to provide an *accessible* training tool that can easily be deployed at any hospital.

The next section summarises the current background in surgical simulators based on virtual reality technologies and identifies the need for using such an approach in MIS for gastrointestinal (GI) procedures. We then describe the clinical procedure selected for our prototype design in more detail. This is followed by the methods and tools used for our implementation and we end the paper with conclusions and an outline of the future work that is planned.

2. Background

Surgical training simulators that use VR technologies can have different fidelity in terms of how close the experience resembles the procedure being trained. A good example of a low fidelity tool is the tablet-based app that we previously developed for a neurosurgery application [JPC*15]. The user interface consisted of finger gestures on the tablet screen. The app takes the trainee through all of the steps of a neurosurgery procedure using an interactive 3D rendering of a patient. Despite its low fidelity the app was shown to be effective. We have also developed much higher fidelity training simulators that combine the sense of touch with the sense of vision. Together with our collaborators we have produced interventional radiology training simulators ([LZJ*13], [CJGC11]). These use haptic feedback devices so that the user feels a biopsy needle penetrate soft tissue, and feels the forces exerted on a guide-wire as it is inserted into the vascular network of a virtual patient. The challenge is to blend these haptic devices into the simulation so that the trainee believes they are using the real tools.

None of the above examples used a HMD. It is only recently that these devices have become readily available at an affordable price. Their main advantage is that they can give a user a far more immersive experience i.e. they can present a virtual environment that replaces the real-world surroundings convincingly enough so that a user is able to suspend disbelief and fully engage with what they see. To still take advantage of the sense of touch, however, the user must be able to hold a tool that feels just like the tool that they see in the virtual environment and receive an appropriate response as they use that tool and this is the focus of this work. The only other system that we are aware of that uses a HMD for endoscopy is the system developed by Hann et al [HWMM19]. It uses head movements to allow the user to zoom into the endoscopy image which is then displayed on the HMD. They are still using a conventional endoscope but mount a VR hand held controller onto it so that it can be tracked. The procedure is carried out on a physical training model.

Any endoscopic procedure could be addressed by our approach but the initial investigation has been in the domain of gastrointestinal (GI) procedures such as Endoscopic Retrograde Cholangio-Pancreatography (ERCP) that is used to treat diseases of the bile and pancreatic ducts. A recent UK survey on GI endoscopy argues that without changes to the delivery and provision of training, future clinicians will not be able to perform essential endoscopic assessment of patients [JSR*15]. Poor performance of novice endoscopists can lead to patient injury and failed procedures. Training on a virtual patient is important to enhance patient outcomes, yet currently no simulators are widely adopted due to the deprecated technology used and notably high price, and there is currently insufficient evidence to suggest that VR training can replace conventional training [KPJ*18]. To be able to exploit the latest generation of affordable VR technology and investigate its effectiveness is therefore timely [MSKG18].

3. Design and Task Analysis

A task analysis of the actions carried out when using an endoscope for ERCP was conducted with clinical experts at the Countess of Chester hospital in the UK. We observed the procedure being carried out on patients and then in more detail using the training model shown in Figure 1. We also made extensive use of Lee *et al*'s guide to the technical skills and training of upper gastrointestinal endoscopy for new beginners [LPC*15].

3.1. The Endoscopy Procedure

For the ERCP procedure, a special type of endoscope is used called a duodenoscope that has a unusual visual system. Most endoscopes have a forward facing camera; in contrast the camera in the duodenoscope faces the side. This arrangement creates many challenges especially for trainees in advancing the duodenoscope into the duodenum as some manoeuvres are done "almost blindly". The trainee must first learn how to carefully feed the endoscope via the oropharynx into the oesophagus, crossing the stomach to negotiate the pylorus (the opening from the stomach into the duodenum). This is the step that we implement in this paper. The endoscope then continues into the first part of duodenum, the superior duodenal angle, to obtain a stable position in the second part of the

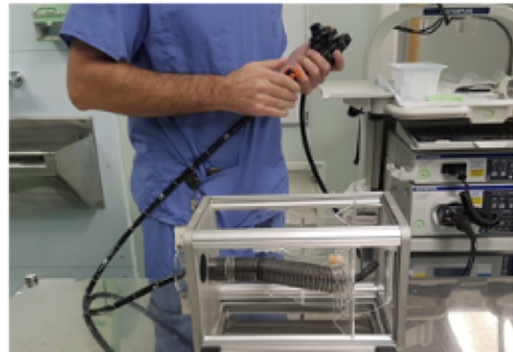


Figure 1: A task analysis of the ERCP procedure was conducted with clinical experts using this training model with an endoscope as well as observing the procedure performed on actual patients.



Figure 2: The view from an endoscope tip as it traverses down a healthy oesophagus (source: Society of American Gastrointestinal and Endoscopic Surgeons).

duodenum opposite the papilla through which the bile and pancreatic ducts empty. The further steps in the procedure are for future work.

As the endoscope moves inside the patient, a small camera mounted on the endoscope tip will send a video image to a monitor (see Figure 2). The endoscope also has a channel through which water can be squirted to clean the camera and the gut lining; and either air or CO₂ can be pumped into the stomach and duodenum, making them easier to see. In addition, the duodenoscope has an operating channel through which instruments can be passed to do the relevant procedures.

3.2. The Endoscope Controller

The duodenoscope comprises a control section that is connected via one tube to a light source, pump and water supply; and another



Figure 3: The duodenoscope used at the Countess of Chester Hospital. Note the rotatable knob controllers that need to be modelled in VR.

tube that is inserted into the patient. The control section has two rotatable knobs used for tip deflection, a bridge, two valves and an operating channel (see Figure 3). The larger, outer control knob is used for the vertical (up or down) movement of the tip and the smaller, inner knob is used for the lateral (left or right) movement of the tip. There is also a lever adjacent to the large angle control knob that is attached to a bridge at the end of the operating channel as it emerges at the tip of the duodenoscope. The bridge allows instruments to be moved over 90 degrees.

3.3. Advancing the Endoscope

Push forward is the action of advancing the endoscope forward into the patient through their mouth or other orifice, whereas pull back is the action of withdrawing the endoscope. Push forward is essential for advancing the endoscope. However, pull back is also important in some cases: when the endoscopist loses direction especially when normal anatomy is adversely affected by diseases; or when the endoscope is adjacent to the gut lining (mucosa) and all that can be seen is redness. This is referred to as a red-out sign. The right hand holds the distal end of the endoscope shaft at the correct distance from the tip. If held too far from the tip, the shaft will bend, and force is not transmitted to the tip. If held too close to the tip, there is less flexibility in advancing the endoscope.

The movements of the duodenoscope can be summarised as: advance or withdraw; tip up or down, tip left or right, clockwise or anticlockwise rotation of the tip, bridge up or down. Very rarely are these movements used in isolation. When teaching ERCP the technique is deconstructed to individual movements to aid learning and skill acquisition.

4. Methods and Tools

Software development has used the Unity real-time 3D development platform (Unity Technologies, SF, USA). Unity has native support for the latest HMD technology enabling us to support either the Oculus HMDs, or the HTC Vive HMD. When wearing a HMD, the trainee will not see the real world and will be immersed in a virtual scene. In this case it will be an operating theatre environment with a monitor that displays the view from the endoscope

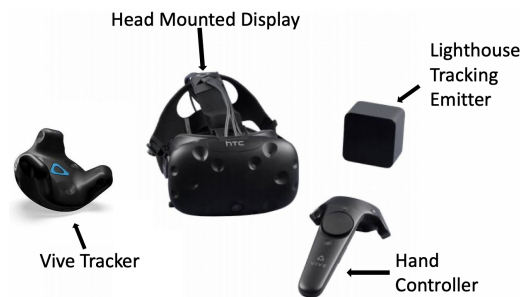


Figure 4: The HTC Vive consists of a Head Mounted Display, two hand held controllers and the Lighthouse tracking system. The latter emits timed infrared pulses that are then picked up by the headset and controllers with sub-millimeter precision. The Tracker is an optional peripheral that can be attached to other objects to be tracked by the Lighthouse system.



Figure 5: Example view from the HMD. The endoscope has been advanced into the patient and the view from the endoscope camera displayed on the monitor. The scene will be enhanced once the operating theatre furniture has been included.

camera. However, we want to make using the endoscope feel as realistic as possible. The HTC Vive's hand controller (see Figure 4) is closer to the look and feel of an endoscope than the Oculus Rift's controllers and so we have used the HTC Vive for our implementation. However, it still needed to be adapted as described below.

4.1. The Virtual Scene

The virtual operating room is seen from the perspective of the trainee who will use the endoscope (Figure 5). The main Unity camera is positioned at the location of the HMD. The HMD is tracked by the Lighthouse system (the emitter shown in Figure 4) is mounted on a tripod or fixed to the wall) and all movements of the trainee's head will be captured. The scene is rendered onto the HMD screens accordingly.

A second Unity camera is positioned at the tip of the virtual endoscope shaft. To render a view from the inside of a mesh representing anatomy such as the oesophagus, the surface normals of

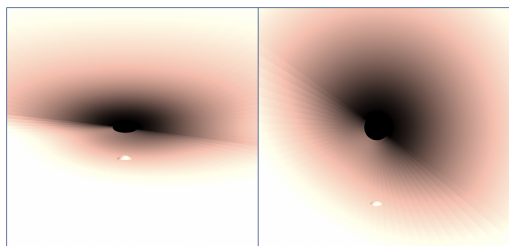


Figure 6: A simulated endoscopic view from the inside of a tube geometry representing the oesophagus. A small polyp can be observed. The image on the right is from the same endoscopic position after gentle air pressure has been used to inflate the tube (scaling it in the y-direction).

the mesh first have to be flipped to point inwards. Otherwise the shading algorithm performed within Unity fails and everything inside the mesh appears black. We used the invert faces orientation filter within the MeshLab software [CCC*08] to pre-process the mesh geometry in this way. Next a texture map is applied to the mesh using an image of the interior surface of the relevant anatomy to obtain the correct colours. As with a real endoscope, a light source is positioned at the location of the camera so that an appropriate illumination is obtained. We use a high intensity point light source with all shadow effects due to this light disabled. Figure 6 is an example of the virtual endoscope renderings that are obtained when the endoscope is inside a simple tube (here representing the oesophagus). The option of inflating the anatomy by increasing air pressure has been added by programming one of the controller buttons to gradually scale the mesh while it is being pressed. The monitor in the main operating theatre scene displays these endoscopic views in real time.

4.2. The Endoscope Controller

The Microsoft Surface Dial is a hockey puck-shaped device that can be used with any Windows 10 PC that supports Bluetooth connectivity. It can be used to navigate menus, control volume and other similar tasks that involve rotating the dial, or clicking it like a button press. We have attached the Surface Dial to the end of the HTC Vive controller using heavy duty Velcro as can be seen in Figure 7. It is used to replicate the functionality of the endoscopes control knobs. However, as we only have a single knob on the Surface Dial, you have to "click" it by depressing the top slightly to toggle between the actions of the outer and inner control knob. The rotation of the Surface Dial is mapped in its software driver to emulate keyboard presses, which can be picked up by Unity's event manager and mapped to appropriate movements of the endoscope camera.

To allow the virtual endoscope to be able to move and rotate realistically, common animation techniques were employed to enable the 3d model to be deformed and manipulated within the virtual environment. The model was "rigged" and a skeleton was added to allow the shaft of the endoscope to be controlled by the user. Rigging allows techniques such as Inverse Kinematics to be used to create realistic movement by calculating the position of the end of the model, the endoscope tip, and automatically adjusting the

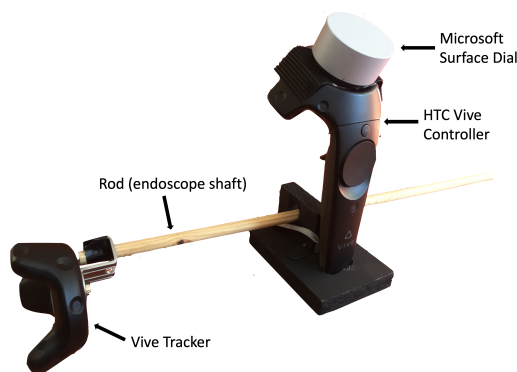


Figure 7: The tangible interface for the VR Endoscope. A Microsoft Surface Dial is used with the HTC Vive hand controller. A rod can be moved backwards and forwards and represents insertion of the endoscope.

position and angles of each bone in the skeleton rig based on the geometry and the surrounding bones to create a realistic behaviour.



Figure 8: A view of the endoscope model used in the prototype (model source: 3d Molier International, TurboSquid) including the bones that we added to the shaft during the rigging process

To dictate how much each bone in the endoscope shaft moves when adjusted using the control knobs, an animation curve was used to control how much each part of the endoscope moves (see Figure 9). This allows the behaviour of the endoscope to be fine-tuned to better represent the movement of a real endoscope. Note, however, that in our current implementation the surface of the anatomy is assumed to be rigid and not deformable.

4.3. Inserting the Endoscope

To enable push forward and pull back of the endoscope shaft we use a rod that is the same diameter as the real endoscope shaft. A Vive tracker has been attached to one end of the rod as can be seen in Figure 7. The tracker makes use of the same Lighthouse system that tracks the HMD and hand-held controller. To constrain movement of the rod to one dimension (forward or back) we fabricated a simple mount for the hand controller that contains a circular hole through which the rod is inserted - see Figure 7 and Figure 10. The hand-controller slots into this holder as well. The length of the rod

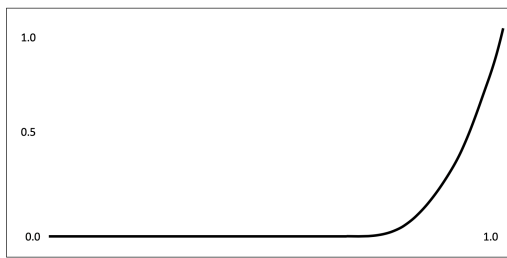


Figure 9: Animation Curve used to dictate how each part of the endoscope moves, allowing the most movement at the tip of the endoscope. X-Axis (0.0 to 1.0) is position on the endoscope, Y-Axis (0.0 to 1.0) is amount of movement

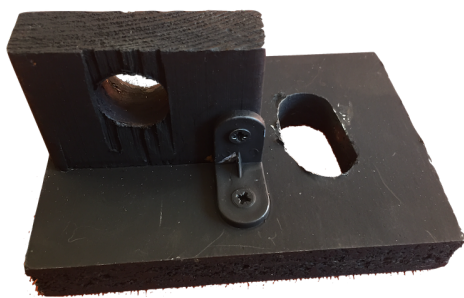


Figure 10: A fabricated wooden holder. The Vive Controller fits into the oval hole. The round hole is for constraining the motion of the rod representing the endoscope shaft to a single dimension.

has been selected so that push forward can be applied until the endoscope tip reaches the target - in this case into the duodenum. Although the rod is rigid and not flexible as the real endoscope shaft is, in the virtual world we only need to know the depth of insertion so that we can map the distance travelled by the virtual endoscope tip to where it would be in the virtual anatomy if moved by that distance.

5. Conclusions and Future Work

Our endoscopy simulator has been built in collaboration with a specialist in diseases of the gastrointestinal tract and an expert in therapeutic endoscopy. We have only addressed the first steps of the ERCP procedure in current work, however, and we do not yet support any therapeutic procedures. Deforming anatomy in response to the endoscope, taking X-Rays and the possible injection of a contrast agent have not yet been simulated. If the procedure is being performed to remove stones from the bile or pancreatic duct, a small cut (sphincterotomy) may be made in the lower end of the bile duct to allow a fine tube to pass through and allow a small basket or balloon to be inserted to grasp a stone. This is also for future work. Before adding more functionality to this simulator we first want feedback on the utility of using a cost effective immersive VR

environment for training diagnostic endoscopy and the basic manipulation of the endoscope. The HTC VIVE provides 110 degrees field of view and a 2160x1200 pixel resolution. We have found this to be adequate for our initial tests but we will evaluate other HMDs as we progress.

We are currently designing a clinical study to assess the level of skill transfer that can be achieved through using our VR simulator. We will investigate the amount of immersion and presence that the trainees achieve as a part of this study. Given the affordability our solution we also intend to look at its use as a warm up tool that the experienced endoscopist can use just before carrying out the real procedure on a patient.

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