Virtual Endoscopy; an Application of Virtual Reality in Medicine

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ABSTRACT

Virtual reality is an exciting technology that is evolving rapidly within the field of medicine. Over the years, several researchers and developers have investigated and created advanced technologies to enable three-dimensional computer generated models, with the objective of assisting within a variety of medical sectors from basic training through to practising surgical procedures.

The approach taken for this paper involved researching previously published papers from journals and conferences on the developments of virtual reality, focusing on an application known as virtual endoscopy. The findings illustrate the birth of virtual reality was in the back-end of the last century, and since then, it has grown considerably. Virtual endoscopy incorporates the technologies haptics, computed tomography and magnetic resonance imaging. It has also been recognised that virtual endoscopy can benefit not only surgeons but patients as well. However, there are still several issues with using current virtual technology, for which researchers are exploring solutions.

Keywords
Virtual reality, medicine, virtual endoscopy, haptics, computed tomography and magnetic resonance imaging,

1. INTRODUCTION

Virtual reality is a three-dimensional (3D) computer generated simulation/model that provides users with the opportunity to interact and change it [1]. It involves three different aspects; visual, auditory and tactile.

Virtual reality in medicine aims to present views or virtual objects to all human senses as if the environment was real. As a result of numerous motivations, it has been implemented in several areas of medicine including surgical training and planning, surgical instrument prototyping, telemedicine, rehabilitation and medicine education [2].

Changes in patient awareness and safety, high costs to teach in clinical environments and the impracticality of supervised clinical practise, due to the risk it involves, are strong motivations to include virtual reality within medical training [3].

This paper aims to consolidate research on virtual reality in medicine, focusing on the application virtual endoscopy and the technologies it uses. The history of virtual reality is discussed in section 2. Haptics, a technology that has enabled virtual reality to advance considerably is described in section 3. Virtual endoscopy, an application of virtual reality, is described in section 4 highlighting its developments, with examples of projects that have taken place, and the different technologies it makes use of including computer tomography. The paper also aims to summarise the benefits of virtual endoscopy for both the surgeon and patient, which can be found in section 5. The final sector, section 6, recognises issues with current virtual endoscopy technology and potential future advances that may solve them.

2. HISTORY

Virtual reality evolved in medicine in the late 1980’s when other methods for surgical procedures of the lower leg were investigated. In the 1990’s virtual reality was recognized to be a good training tool [3].

In 1991 a simulator for surgical procedure practice was developed, which in 1995, was improved by incorporating a haptic device, enabling training to take place as if it were real [4]. Haptics; feedback provided through touch, were originally derived in the 19th Century [3].

Further developments of virtual reality were seen in 1998. These included the use of high fidelity haptics and visuals in simulators [4].

An application of virtual reality is virtual endoscopy. This has been a major focus for development in medicine since 1994, when it was first recognised that computed tomography could be employed [5]. Indeed, many applications of virtual reality, including virtual endoscopy, have incorporated computed tomography since its development by Hounsfield and Cormack, in 1979 [6].

3. HAPTICS IN VIRTUAL REALITY

Haptics, a method of providing touch feedback, are used in virtual reality to enhance the environment, creating a more realistic effect [1]. They provide the opportunity for surgeons to train, practice and plan, known as virtual surgery. Users of virtual surgery can carry out processes such as cutting and grasping soft tissue as if it were real. They will also receive physical feedback by exercising the technique titled force-feedback [7].
Figure 1 illustrates a virtual environment that includes a haptic device (left) and shows the visual that is displayed to the user (right).

Haptic force-feedback commonly operates by detecting a connection made between a user and a virtual object. It then replicates a force back through a hand controller device. To identify tactile information between a virtual surgical instrument and virtual organ/tissue, virtual sensors are used [7]. Therefore, there are three components that make up the virtual surgery; an operator (the person using the virtual surgery), manipulator and virtual environment (see Figure 2). In [7] the authors describe the manipulator’s job as sending the operator’s movement and location details to the computer in real time and creating tactile, which is sent back to the operator. From the data received by the manipulator, the virtual environment produces the graphics that are presented to the operator and creates the force-feedback signals using an “algorithm of contact state detection” [7].

4. VIRTUAL ENDOSCOPY
This section will describe an application of virtual reality in medicine known as virtual endoscopy.

4.1 What is Standard Endoscopy?
In medicine, endoscopic procedures are continuously a main focal point [8], and do not require the need for surgery. The process involves looking inside a human body using a medical instrument known as an endoscope [2]. An endoscope is a fibre optic that provides a source of light and is a camera, which captures images that can be displayed on a screen [9] (see Figure 3). This can be very invasive and uncomfortable for the patient as well as being a risky procedure and expensive to carry out [9].

4.2 What is Virtual Endoscopy?
Virtual endoscopy uses a mixture of virtual reality and medical imaging as an alternative to standard endoscopy [10].

The objective of virtual endoscopy is to transform images of the human body, into something more than just a photo; a 3D model, which can be operated by physicians as if they were carrying out a real endoscopic procedure. The user can view the visual model on a screen, as they would when conducting a standard endoscopic procedure.

The process can be used for training, surgical practice and surgical planning and the working model can be based upon patient-specific data [2].

To construct the model, the physical properties of the body part that is of concern need to be captured [11] and transformed into the virtual environment. This can be achieved by using either of the medical imaging methods; Computed Tomography (CT) or Magnetic Resonance Imaging (MRI). CT involves the use of X-ray’s and MRI uses strong magnetic fields and radio waves.

There are two versions of Computed Tomography; Sequential CT and Spiral CT [6]. Sequential CT, the original approach used, involves the production of cross-sectional images achieved by scanning from different angular positions. Spiral CT, established in 1989, enables the production of 3D images as it gathers the volume element of the datasets [6].

Patients would be required to undergo a CT or MRI scan, as this provides the ability to form the model tailored specifically to the individual.
4.4 Developments of Virtual Endoscopy

Virtual endoscopy has been developed for different areas of medicine including virtual colonoscopy (examination of the bowel), virtual bronchoscopy (inside of airways) and virtual angiography (interior of blood vessels) [14]. Three projects, described in the following sections, have been researched and published illustrating the developments of virtual endoscopy. Each includes one or more of the technologies described; CT, MRI and haptics.

4.4.1 Virtual Endonasal Transspheriodal Pituitary Surgery

Endonasal transspheriodal pituitary surgery is a procedure used to remove pituitary tumours, which entails high risk. (The Pituitary gland is found at the base of the brain). In [8] a virtual endoscopy system, Simulation of Transspheriodal Endonasal Pituitary Surgery (STEPS), is discussed. It offers the ability to plan prior to operating, intraoperative support and training for the surgeon. The simulation is mainly for assisting users with training. Haptics are used to provide instant reactions. This employs the use of force-feedback, using a joystick, with the aim of guiding the user when inside the virtual soft tissue. The intensity and direction of the force feedback varies with the use of an algorithm that was generated for this system. The STEPS model also provides additional features including split screens known as linked views, angled endoscopes, surface rigidity, depth shading and simulation of surgical instruments [8].

4.4.2 Virtual Bronchoscopy

Virtual Bronchoscopy is used to examine inside airways. It is beneficial as it increases confidence in diagnostics and improvement in surgical planning. However, an issue with this virtual procedure was recognized; using computer tomography images to carry out airway segmentation is challenging [15]. Exploiting virtual reality, three-dimensional reconstruction of potential airway sections on two-dimensional axial images can be formed by a variety of methods. The authors of [15] proposed a new method to construct the 3D airway sections. The solution involves using a Bronchial Tree, which accurately maps the inner airway wall, illustrated in Figure 6. A CT image of bronchi is shown on the left and the virtual bronchoscopy that was developed from the CT image is on the right.
4.4.3 Virtual Colonoscopy
Colonoscopy is defined as the procedure for finding pulps, which can then lead to the identification of colon cancer [9]. Virtual Colonoscopy uses computed tomography to collect axial images, which can be transformed into a 3D model. For a patient, this is a less invasive method of colon evaluation. The authors of [16] state that this virtual method has the potential to eliminate the real endoscopic colonoscopy procedure, however it still requires the need for bowel cleansing prior to examination; an unpleasant process to undergo.

A new virtual colonoscopy method was proposed in [16] that doesn’t require the bowel cleansing procedure. Instead, faecal tagging and electronic bowel cleansing can take place by using morphological and convolution-based image processing (see Figure 7).

![Figure 7 – Images of Electronic Bowel Cleansing](image)

5. ADVANTAGES OF VIRTUAL ENDOSCOPY
There are general advantages to virtual endoscopy and many benefits to both surgeons and patients.

Overall it can be cost effective [10] and can increase diagnostic confidence [15]. This is beneficial for patients as well as surgeons as they will feel comforted in the knowledge that their surgeon is giving them a diagnosis they are more certain of.

For surgeons, virtual endoscopy offers education, training and surgical planning [8]. The model can be adapted to patient-specific data [7], facilitating the ability to explore areas that are precarious to carry out on a real human or are too small to access with real instruments [4]. For example, endoscopes are unable to be used within blood vessels, as they are too large [9]. It can eliminate some restrictions that classical endoscopy entails. For example, there aren’t any restrictions on viewing internal structures that would be impossible to view in real life [17]. Using virtual endoscopy, procedural techniques can be learnt quickly and effectively, as it is interactive and makes use of haptics [11].

Virtual endoscopy also provides benefits for patients. It allows an assessment to take place that reduces the likelihood of side effects such as infection [10] and is believed to be non-intrusive [7].

6. THE ISSUES AND THE FUTURE OF VIRTUAL ENDOSCOPY
There are many concerns with the use of virtual endoscopy as there are several factors that have the potential to cause an error. The data collected to form the virtual environment must be current and accurate to gain the best results. This puts pressure on the datasets as, if they are too small or incorrectly gathered, false connections within the visual could be made, as well as the potential for holes to be formed. Motion artefacts, such as a fast moving body part, are also a concern as they could misrepresent the images. Speed is another requirement that is vital to produce an effective virtual environment; delays are not acceptable [9].

Navigation is a general problem of virtual endoscopy, which involves issues with controlling the camera and offering users better intraoperative support. It is a concern as a physician could not be sure they have seen all abnormalities. Studies have taken place to solve this issue, and now there are different methods of navigation that can be offered to the users; automatic or manual and free; the user can roam freely within the application or guided; the user has to follow specific steps [9]. An example of this is illustrated in [10], as the authors proposed and constructed a reliable path algorithm that can be followed by users when conducting the virtual endoscopic procedure [10]. However, this doesn’t resolve the concern completely as there is still the difficulty of camera control, which is also vital in achieving reliable navigation [18].

Virtual endoscopy is a wide field itself, with issues and future technologies being specific to the different endoscopy domains. Three practices; Sinus Endoscopy, Virtual Bronchoscopy and Virtual Intravascular Endoscopy are described to illustrate more specific virtual endoscopic issues and proposed future developments in an attempt to solve them.

6.1 Sinus Endoscopy
Sinus endoscopy uses computed tomography to obtain data for establishing a diagnosis and planning prior to operating however, it is very difficult to process data with swollen structures/nearly closed airways [19]. Virtual endoscopy has been used to integrate a new image rendering technique that includes realistic visualisation, texturing and shading, advanced usability by avoiding image segmentation, and customisation with changes of level of density. In [19], proposals are given for other ideas to develop this technique, by investigating its application to other areas of virtual endoscopy such as virtual bronchoscopy. However, research on the topic of adapting textures to enhance the realistic representation is now required.

6.1.2 Virtual Bronchoscopy
Virtual Bronchoscopy uses computed tomography images. Due to the high amount of data required and complexity of human organs, an issue with this application is segmenting airways without losing the quality of the images produced. The authors of [20] have proposed an algorithm, which was successful in segmenting the upper airway. However, improvements are required. In the near future research will be conducted in improving the segmentation results to enable discovering and presenting even smaller airway branches [20].

6.1.3 Intravascular Endoscopy
Multislice computed tomography is a recent development of computed tomography to aid virtual intravascular endoscopy. It has been evaluated by the authors of [21] and was proved successful. However this has only been assessed using small comparisons with other technologies, thus it is not certain to be a valuable tool for analysis and risk assessment of coronary artery disease. Therefore further studies are required.
7. CONCLUSION
Since the 1980’s when virtual reality was first developed, it has drastically advanced and has become a popular tool for numerous reasons including training, educating, surgical planning and practise within the field of medicine. Along with the technologies of computed tomography and magnetic resonance imaging, the development of haptics has enabled the advancement of virtual reality. An application that has received great focus in medicine is known as virtual endoscopy and it is hoped that one day, it will eliminate the need for endoscopic procedures. This is because of the many benefits that virtual endoscopy provides for both surgeons and patients, including the ability to improve training and conduct less invasive procedures to establish a diagnosis. Currently there are still several concerns with the use of virtual endoscopy as it is fundamental the datasets used to create the virtual environments are accurate and up-to-date. However, the future holds the potential for even greater developments in the field of virtual endoscopy as research continues and techniques evolve. Virtual reality will become an invaluable medical tool, utilised for diagnosis, current and new surgical procedures, education and training.

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9. REFERENCES