A VISUAL GRAPHIC/HAPTIC RENDERING MODEL FOR HYSTEROSCOPIC PROCEDURES

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Abstract

Hysteroscopy is an extensively popular option in evaluating and treating women with infertility. The procedure utilises an endoscope, inserted through the vagina and cervix to examine the intra-uterine cavity via a monitor. The difficulty of hysteroscopy from the surgeon's perspective is the visual spatial perception of interpreting 3D images on a 2D monitor, and the associated psychomotor skills in overcoming the fulcrum-effect. Despite the widespread use of this procedure, current qualified hysteroscopy surgeons have not been trained the fundamentals through an organised curriculum.

The emergence of virtual reality as an educational tool for this procedure, and for other endoscopic procedures, has undoubtedly raised interests. The ultimate objective is for the inclusion of virtual reality training as a mandatory component for gynaecologic endoscopy training. Part of this process involves the design of a simulator, encompassing the technical difficulties and complications associated with the procedure. The proposed research examines fundamental hysteroscopy factors, current training and accreditation, and proposes a hysteroscopic simulator design that is suitable for educating and training.

Key Words: Surgical Simulation, Virtual Reality, Hysteroscopy

Introduction

The focus on constructing a hysteroscopic simulator in this review is essentially an extension to the Virtual Kylie system[1], a laparoscopic-based training simulator. While there may be similarities in the manoeuvring of instruments between laparoscopy and hysteroscopy, surgeons not only operate in a vastly different environment in hysteroscopy, but they also need to acquire different skill sets to perform hysteroscopic specific procedures. Although certain functions such as the algorithms for the deformation and cutting of tissues may be mutual, many elements involving both hardware and software need to be redesigned and created specifically for the hysteroscopic environment. The hysteroscopy extension of the Virtual Kylie system would then be integrated via a graphic user interface (GUI). Practicing surgeons or trainees using the system will be given the option of selecting the desired task through the simple GUI. Furthermore, the GUI will function as a database, so that progress of assessment can be monitored.

The selection of utilising a high-end PC as the platform over a graphics workstation has the advantage of immense cost savings. However, the difficulty in accomplishing this task now depends on the limitation of computing power. A balance must be attained between the computation of complex algorithms for instrument interaction with the virtual environment, force feedback calculations, and realistic modelling of the virtual environment in order that real-time visual display may still be achieved. These considerations and a proposed hysteroscopy simulator system suitable for both education and training are elaborated in this article.

Hysteroscopic Instruments and Procedures

The rapid advancement of surgical tools has allowed hysteroscopic procedures to be performed in an outpatient setting and thus increasing its popularity in gynaecological practice. With this technique, it is feasible to view the intra-uterine cavity, and is used as both a diagnostic and operative tool. With around 25% of women with abnormal bleeding found to have intra-uterine pathology growth, such as polyps or fibroids[2], and accounts for the widespread use of this procedure. Although the development in non-invasive imaging techniques may contest hysteroscopy as a diagnostic tool, operative hysteroscopy will remain the preferable treatment method for intra-uterine pathologies over open surgery or the blind procedure option of dilatation and curettage (D&C)[3].

For hysteroscopic diagnostic procedures, a hysteroscope is inserted through the vagina and cervix to view the uterine cavity. The hysteroscope, a long thin rod with a 3-4mm diameter that utilises fibre optic technology, essentially acts as a video camera transmitting live pictures to the connected monitor from which the surgeon makes observations. Gradual cervical dilation is required before the hysteroscope is inserted, and the narrow cervical canal is the fulcrum point of the inserted instrument. An electrolyte-free liquid medium is pumped into the uterus to distend it via the hysteroscope, with the control of the inflow and outflow of the liquid being an important factor in maintaining clear video images. Depending on user preferences and the type of procedure being carried out, the scopes used have different tip inclinations, varying from 0° to 75°, with 12° and 30° being commonly used. The slight inclination allows the user to view the roof and floor of the cavity simply by rotating the scope.

A resectoscope (or operating hysteroscope), as shown in, is similarly used for operative procedures, but the instrument includes a shaft below the endoscopic camera that allows for surgical tools to be attached. The attached surgical tool is controlled via a spring-loaded mechanism which when pushed, extends the tool. The tools commonly used in hysteroscopy include graspers, scissors, electrocautery loops for resection, and roller balls for endometrial ablation. The tools requiring an electric current for operation i.e., the electrocautery loop and roller ball is only activated with the depression of a floor pedal switch. For safety precautions, the surgical tools are only activated when it is fully extended, as using a pull motion rather than pushing reduces the likelihood of uterine perforation. Operative procedures undertaken in hysteroscopy include the resection of polyps (polypectomy) or fibroids (myomectomy), endometrial ablation and metroplasty.

Figure 1. *Typical resectoscope[4].*

Polyps and fibroids are often the cause of abnormal uterine bleeding causing infertility, abnormal uterine bleeding and chronic pain, and are reportedly the most common abnormalities. The absence of menorrhagia after hysteroscopic myomectomy, defined as the desired outcome, has been reported in approximately 80% of women[5]. Hysteroscopic resection is performed for submucosal and intramural pathologies, which intrude into the intra-uterine cavity. The removal of such pathologies is usually accomplished using an electrocautery loop which has the advantage of coagulating the tissue during resection preventing bleeding.

Endometrial ablation is a technique that completely removes the endometrial lining using the electrocautery loop or roller ball. This therapeutic procedure which significantly reduces menstrual flow is an alternative to hysterectomy, a major operation to remove the uterus, and is offered as an option for women experiencing menorrhagia – excessive menstrual flow, in the absence of uterine pathologies. The reports of high success rates (>80%) along with the avoidance of major surgery, fast recovery rate, shorter hospitalisation and the preservation of uterus have made endometrial ablation the preferable treatment option[5].

Hysteroscopic metroplasty is a procedure which involves the removal of a uterine septum. The presence of a septum in the uterine cavity is usually associated with infertility, recurrent pregnancy loss and the abnormality formation of the foetus. The diagnosis can be confirmed by both hysteroscopic and ultrasound examinations. Again, an electrocautery loop is used to perform the removal of the septum. This procedure is often assisted by laparoscopy in order that immediate actions can be taken in cases of uterine perforation. Although this risk is present, reported morbidity rates are low and subsequent successful baby deliveries of up to 90% have deemed hysteroscopic metroplasty as the superior treatment for uterine septum [5].

In hysteroscopy, surgeons are not only required to overcome the fulcrum effect associated with the set-up, but also deal with a liquid-filled environment and operability is limited by the use of only a single instrument.

Current Training Recommendations

According to the Royal Australian and New Zealand College of Obstetricians and Gynaecologists (RANZCOG) training guidelines[6], gynaecology registrars are required to undertake a six year training programme. Registrars in their first year of the training programme are required to attend a 2-3 day basic surgical skills course which includes hysteroscopy. In the first four years of the integrated training programme, registrars are expected to have a minimum level of experience in performing 100 hysteroscopic examinations or procedures. Assessment and approval of competence is based on observing the registrar performing the relevant procedure once. Furthermore, assessments to advanced hysteroscopic procedures are currently optional. Members are expected to understand the fundamental principles of these procedures without the need of being able to perform them.

With no recommendations or further compulsory training for a registrar prior to performing live procedures, the current norm for registrars is first observing the procedure, then assisting an experienced surgeon and gradually gaining independence to perform the procedure. The assessment for initial competence is clearly subjective and the need for objective assessment and training prior to registrars performing on patients should be more clearly established so that the quality of procedure and patient safety is not compromised. Surgeon-specific factors play an important role in the speed with which a surgeon acquires competence and needs to be more accurately assessed[7]. The lack of standardisation in both assessing and educating needs to be addressed. The proposed hysteroscopic simulator provides a mean of objectively assessing trainees and also hands-on experience without the risk of compromising patient safety.

Proposed Simulator

Although this project is an extension to the current laparoscopic project and certain functions of the simulation may be shared, there are many unique aspects of the hysteroscopy environment requiring many parts of the simulation to be independently created. The non-convex nature of the uterus cavity subsequently requires a new collision detection algorithm. Furthermore, the liquid distension medium used in hysteroscopy creates an environment that is totally dissimilar to the laparoscopic environment. This not only alters the visual simulation requirements, but ineffectively promotes haptics to be an important inclusion to the simulator. The instrument handle also needs to be designed and created to include haptic feedback on the push-pull mechanism controlling the surgical attachment tools. *Figure 2* shows a flow chart of all aspects of the project and how they are interrelated.

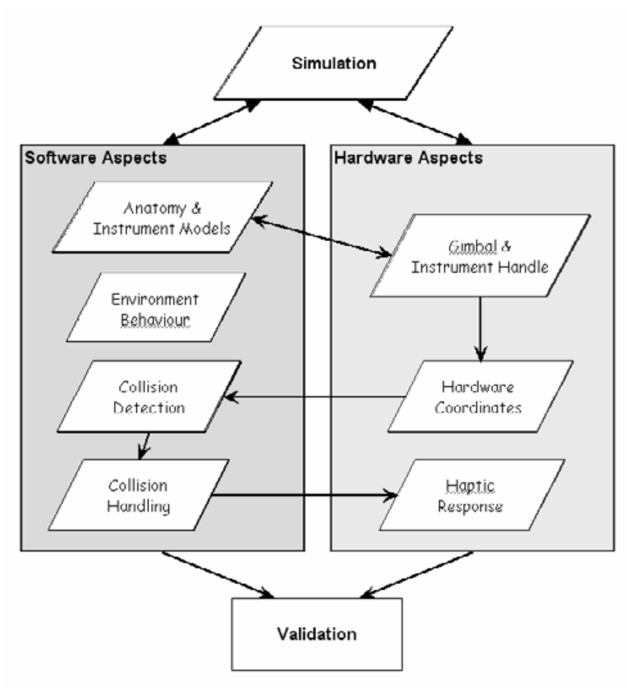

Figure 2. *Flowchart encompassing all aspects of the project.*

Research Objectives

The ultimate objective when all parts of the project have been incorporated is a training simulator that not only familiarises users to the dexterity skills required, but also exposes them to a wide array of cases encountered in hysteroscopy. It must be emphasised that the aim is not intended for users to be completely accustomed to the simulator setup, but to become familiar with the task and procedures. The following lists the outcomes to be accomplished at the conclusion of this project:

- Software models of hysteroscopic-related objects
- Collision detection and anatomy deformation
- Algorithm for cautery-loop resection of pathology
- Hardware construction of gimbals and instrument handle
- Implementation of force feedback on gimbals and instrument handle
- Incorporation of quantitative assessment tools
- Validation of system as a training simulator

Software Aspects

The priority of this aspect of the project is initially not in visual realism, but rather, the focus is placed primarily on simulating behavioural realism because the algorithms used will need to be performed at real-time while maintaining sufficient accuracy. In simulations the outcome is always a trade-off between visual realism and of real-time performance.

Object and Environment Modelling

Before any simulation can be initiated, the relevant objects must first be modelled. The hysteroscopy environment involves a uterine cavity, surgical attachment tools that are visible on-screen, and any pathology the cavity might contain. The models were created using the software modelling package 3DS Max 7, which is a package commonly used for animation, games and special effects.

Dimensions of the uterus model created are an approximation as uteri sizes vary, and the uterus under hysteroscopic examination is further distended by a liquid medium. An exact sized uterus model is further irrelevant as different models can simply be generated specific to the training requirements. The pathology models are similarly created based on task specifications, and integrated with the uterus. The completed uterine cavity model created for this project includes an integrated pedunculated submucosal fibroid, a simple construction by sculpting NURBS spheres and then converted into a triangular mesh. *Figure 3* shows screenshots of the completed model.

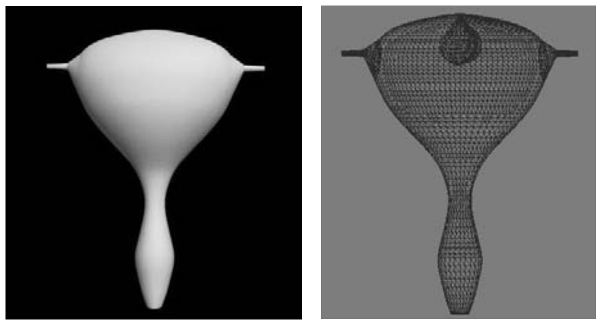

Figure 3. *Screenshots of completed uterus model.*

The software representation of the instrument was simplified as the shaft and handle of the instrument would never be displayed in the simulation. The two types of surgical attachment tools that have been modelled include a cautery-loop and an electro-ball, both of which are used extensively in hysteroscopic operative procedures. For collision detection purposes, the shape of the cautery-loop is represented by twelve separate parts. The electro-ball is similarly modelled, but can be represented by a single sphere. Screenshots of the modelled instruments are shown in *Figure 4.*

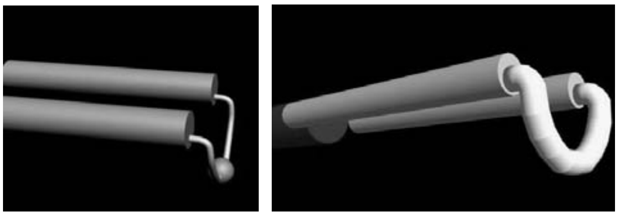

Figure 4. *Model of cautery-loop and electro-ball.*

Collision Detection

Determining the point of collision between two objects plays an important role in a virtual reality simulation as it is the foundation upon which other algorithms rely. More specifically, the visual collision responses such as deformation or ablation effects and haptic feedback control rely on the information obtained from the collision detection phase. The information acquired in this phase includes the affected vertices involved in the collision and the direction of movement. There are obvious trade-offs in that speed of performance and accuracy of detection are both important factors, and since the processing load should be saved for the collision response and haptic stages. The accuracy of this stage however remains crucial for the outcome of those latter stages. Furthermore, many basic collision detection algorithms are restricted to convex polytopes, and are not efficient for real-time applications when applied to non-convex polytopes [8].

As hysteroscopy examines the intra-uterine cavity, this effectively deals with a non-convex polygon, and is further complicated by the fact that simple polygons cannot be used to represent the cavity with sufficient accuracy. To add to this complexity, the instrument is constantly at close proximity to the anatomy, and has a camera view that is centred on the instrument. The functioning of objects at close proximity with each other means detailed collision checks must constantly be carried out, while the close camera view requires collision handling to be detailed as inaccuracy will be noticeable and will detract the realism of the simulator. Accurate and efficient collision detection algorithms utilised in this application can further be applied to other simulations involving non-convex environments, while any novel intersection tests can be applied to any environment.

Collision Handling

This project also proposes to include two aspects of collision handling – deformation of anatomy and the resection of tissue with a cautery-loop. This deformation algorithm utilises a simple surface model and is computationally advantageous over physically-based algorithms [9]. However, most important is that this algorithm can be applied to the hysteroscopic models by obtaining the required parameters.

Simulating the resection of tissue with a cautery-loop is especially important for hysteroscopy as it is extensively used in the removal of pathologies. The action can simply be described as peeling a layer off an object following the contours and movement of the peeler. The project emphasis is on achieving this simulation without modelling the pathology as a volumetric model. Modification of the surface vertices in real time to simulate part of an object being peeled off is a major part of the project. Although the application seems specific to cautery-loop resection, the dynamic surface modification of objects also have potential applications in gaming and computer model sculpting.

Hardware Aspects

The hardware is primarily necessary to relay instrument movement information and synchronising movement of the instrument handle with the software simulation. The gimbal used to relay this information also serves as the fulcrum point of the narrow cervical canal. The information received from the gimbal will determine instrument movement in the three-dimensional space, and an additional degree-of-freedom being introduced to determine rotation of the instrument about its axis. It is important to note that an initial calibration point to synchronise both hardware and software aspects of the simulator needs to be established. Thus, a fixed mounting point that holds the instrument in place needs to be manufactured and incorporated accurately with the software.

As observed first-hand in the operating room, hysteroscopy often requires the surgeon to rely on their sense of touch through the instrument. This is because the attached surgical tool is often extended behind pathologies, where it is hidden from camera view, before resection is commenced. As such, the inclusion of haptic feedback as part of the simulation is vital.

The gimbal, as shown in *Figure 5* should then also provide three-degrees of force feedback in moving the instrument, with an additional degree of feedback required in hysteroscopy when the surgeon uses the push-pull mechanism controlling the surgical attachment tool. This is an extremely important feature which is lacking in current commercial hysteroscopy simulators, and is vital as surgeons often rely on this feedback to operate.

Validation Studies

Validation forms a very important part of the project and is necessary if the simulator is to be used either in a research or training situation. The medical collaboration involved with this project will be the primary source of validation. The feedback given by surgeons who perform hysteroscopy daily is necessary to ensure that the

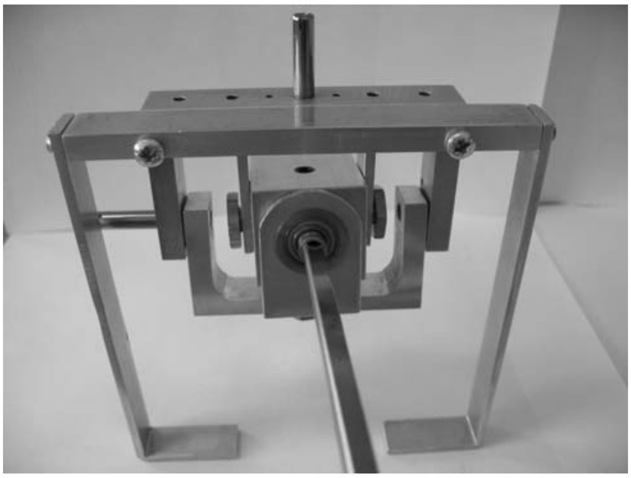

Figure 5. *Constructed gimbals.*

simulation is in line with real procedures. Besides validating the visual and haptic aspects of the project, validation is further required in determining the benefits of virtual reality training. As such, there is a need to incorporate quantitative assessment tools which cannot be easily measured in real procedures, and determine which factors are important in judging the quality of a surgeon's performance.

Inconsistencies of training procedures in endoscopic surgery linger due to the lack of a standardised and systematic objective assessment tool. The unique psychomotor skills required to accomplish the task are not innate behaviour [10], and is a void in which VR simulations can adequately fulfil. There are two main concerns in relation to the validation of VR training:

- Transfer of skill from using the simulator to the operating room [11], and
- Effectiveness of the assessment tools in differentiating the level of skill of a user [12]

The validity of these two factors can be combined in a single study involving both qualified and training hysteroscopist. It is important to note that when designing controlled assessment tasks, one particular quantitative measurement (such as time taken to complete the task) does not necessarily provide enough information to gauge the user's level of skill. However, it is the culmination of many measurements, and how much each factor contributes to the skill of the user that needs intensive investigation. Ideally, this project will initiate a study involving a control group of training surgeons that undergo the normal training programme with additional VR training, while another group solely trains under the normal curriculum. At the same time, the effectiveness of the assessment tools can also be gauged by comparing the outcomes of the training group with qualified surgeons.

Conclusion

The completion of this project will fabricate a flexible hysteroscopic simulator with software and hardware algorithms suitable for full procedures to be performed. These algorithms will be optimised to operate real-time simulations and haptic feedback utilising high-end PCs. This system will also be incorporated with the current laparoscopic simulator to complete a gynaecological endoscopic training unit.

The ultimate objective is for the inclusion of virtual reality training as part of a recommendation in the RANZCOG training guidelines [6]. Research plans have included validation studies to verify the role of virtual reality training. Part of this success will heavily depend on the ability of the system to objectively assess the user.

As such, objective measurements will be incorporated into the system through a database for results to be stored, analysed and means of gauging progress. This would greatly enhance the current norm of assessing a trainee's competence and also greater access for trainees to practice specific tasks and procedures in a safe environment.

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