Hysteroscopic Simulator for Training and Educational Purposes

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Abstract— **Hysteroscopy is an extensively popular option in evaluating and treating women with infertility. The procedure utilizes 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 organized 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 gynecological endoscopic 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 hysteroscopic factors as well as current training and accreditation norms, and proposes a hysteroscopic simulator design that is suitable for educating and training.

I. INTRODUCTION

The rapid advancement of surgical tools has allowed hysteroscopic procedures to be performed in an outpatient setting and thus increasing its popularity in gynecological 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 [1], this 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 [2].

The emergence of virtual reality as a surgical training tool for hysteroscopy and other endoscopic-type procedures has been well published. However, the acceptance of such purpose-built simulators as part of any mandatory medical training requirement has been non-existent. Criticisms of current commercially available simulators are the lack of reliable haptic feedback, the inability to reproduce full and complex procedures, and high costs associated with setting up such systems [3]. There is also a reported separation

between the use of the simulators in research and the wider clinical use for training and education [4]. Furthermore, the lack of studies demonstrating positive effects of surgical skill acquisition through virtual reality training fails to provide sufficient incentive for the simulators to be added to the training curriculum.

The proposed hysteroscopic simulator has been designed to account for the stated negative factors surrounding VR training. As such, a high-end PC is utilized as the processing platform and has the advantage of immense cost savings over a graphics workstation. However, the limitations of available processing power must be taken into consideration while maintaining real-time visual realism and accurate user interactions. The focus on constructing a simulator for hysteroscopic procedures is essentially to extend the scope of the current laparoscopic-based training simulator – Virtual Kylie [5]. While certain aspects may be shared between the simulators, the hysteroscopic environment is significantly different. In addition, a completely unique skill-set is required to perform certain hysteroscopic procedures. Ultimately, the hysteroscopic extension of the simulation system will be integrated via a graphic user interface and will complete a training simulator for all gynecological endoscopic procedures.

II. PROJECT OBJECTIVES

The ultimate objective is for the inclusion of the completed simulator as part of a mandatory training requirement for gynecological surgeons. As such, selection of the system configuration and the current focus remains sensitive to achieving this. Minimizing system costs is justified by the necessity to provide greater accessibility to surgeons using the system. The processing power of the current system for both visual and haptic loops is:

- Intel® Xeon™ 2.80GHz (dual) CPU,
- 1GB RAM, and
- 128MB DDR nVidia® video card

An important point to state is that the simulator will not be used solely to familiarize users to the required dexterity skills, but also to impart knowledge and expose them to a wide array of cases, particularly rare occurrences. Furthermore, the advantage of a virtual simulation is the ability to take objective measurements. This will be used as an attempt to gauge user progress.

Although certain aspects of the simulator utilize a similar setup with the current laparoscopic simulator, the visual simulation is completely unique. The non-convex nature of

the uterus cavity subsequently requires new collision detection and handling algorithms. Furthermore, the liquid distension medium used in hysteroscopy creates an environment that is completely dissimilar to the laparoscopic environment. This not only alters the visual simulation requirements, but ineffectively promotes haptic-feedback to be an important inclusion to the simulator.

III. HARDWARE INTERFACE

The hardware is primarily necessary to relay instrument movement information and synchronizing movement of the instrument 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 synchronize both hardware and software aspects of the simulator needs to be established. Thus, a fixed mounting point that holds the instrument in place has been incorporated and accurately calibrates 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 currently used in the simulator is shown in Fig. 1, and is further defined in [6].

Fig. 1. Gimbal setup serves as the fulcrum point at the cervical canal allowing 4-degrees of movement.

IV. SOFTWARE SIMULATION

The priority of this aspect of the project is initially not in visual and texture realism. Rather, the focus is placed primarily on simulating behavioral realism because the algorithms used will be executed in real-time and maintaining interactive accuracy is important as not to detract realism. In VR simulations, there is always an inherent trade-off between visual or haptic realism and real-time performance. Techniques for accurate virtual interaction are computationally far too exhaustive for the processing power available and have been redesigned accordingly.

A. Object and Environment Modeling

Before any simulation can be initiated, the relevant objects must first be modeled. The hysteroscopic 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 modeling package 3DS Max, 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 to be included in simulations are similarly created based on task specifications, and seamlessly integrated with the uterus. The completed uterine cavity model created for testing purposes includes an integrated pedunculated submucosal fibroid, a simple construction by sculpting NURBS spheres, which is then converted into a triangular mesh. Fig. 2 shows screenshots of the completed model.
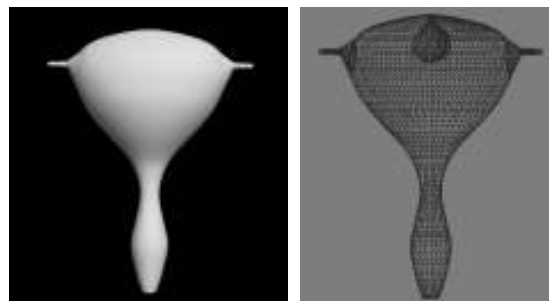

Fig. 2. Rendered and wireframe views of the uterus model with an integrated pathology.

The software representation of the instrument is greatly simplified as the shaft and handle of the instrument will never be displayed during the simulation. The two types of surgical attachment tools that have been modeled include a cautery-loop and an electro-ball, both of which are used extensively in hysteroscopic operative procedures. Screenshots of the modeled instruments are shown in Fig. 3.
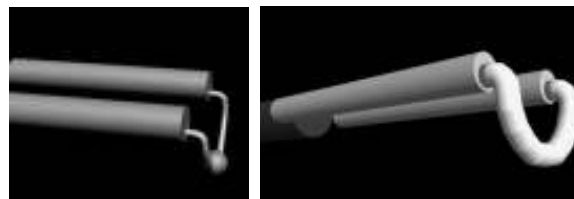

Fig. 3. Modeled surgical attachment tools that are commonly used in hysteroscopic procedures – electro-ball (left) and cautery-loop (right).

B. Collision Detection

Determining the point of collision between two objects plays an important role in virtual reality simulations as it is the foundation upon which other algorithms rely on. 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 between the speed of performance and accuracy of detection, while the processing load should be minimized at this stage 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 [7].

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 centered 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 utilized 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.

One of the challenges of this project is to establish an accurate and effective method of collision detection between the cautery-loop and surrounding tissue. A unique bounding spheres algorithm has been incorporated, and eliminates the computationally expensive need for vertex-vertex checks between the virtual instrument and tissue. The unique and precise placement of two bounding spheres surrounding the cautery-loop is sufficient for collision detection to remain highly accurate, while significantly improving computational efficiency.

C. Collision Handling

The two major aspects of collision handling include deformation of anatomy and the resection of tissue with a cautery-loop. The deformation algorithm utilizes a simple surface model and is computationally advantageous over physically-based algorithms [8]. As interaction in hysteroscopic procedures are limited to the view of the camera, it is sufficient for the affected anatomy to undergo local deformation. Most importantly is that this algorithm can be applied to the hysteroscopic space of concern, or any

other non-convex environment involving interaction between a solid object and a deformable membrane.

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 difficulty in resection is often further complicated by the resected tissue floating in the cavity blocking the view of the surgeon. The project emphasis is on achieving this simulation without modeling 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 separating a single object into two also have potential applications in gaming and sculpting software models.

V. 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 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 standardized and systematic objective assessment tool. The unique psychomotor skills required to accomplish the task are not innate behavior [9], and is a void in which VR simulations can adequately fulfill. There are two main concerns in relation to the validation of VR training:

- Transfer of skill from using the simulator to the operating room [10], and
- Effectiveness of the assessment tools in differentiating the level of skill of a user [11]

The validity of these two factors can be combined in a single study involving both qualified and training hysteroscopic surgeons. 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 program 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.

VI. CONCLUSION

The intrinsic problem with current simulators is the primary focus on research – particularly for accurate software simulations and interactions, which unfortunately does not allow for practical accessibility due to the economic viability of institutions investing in these systems. Addressing the need of properly educating and training surgeons in this procedure is the main focus of this simulator. Even in taking such a stance, there is still substantial research involved if the ultimate objective of having virtual reality simulators as a mandatory training tool for this procedure is to be accomplished. To further take advantage of a simulation system, the ability to objectively gauge user progress is important to overcome the subjectivity currently associated with surgeons assessing trainees.

An important objective to attain is implementing reliable haptic feedback with the current low-cost configuration. Initial tests have shown that reliable haptic feedback is achievable with the current configuration [6]. However, further validation is required in order that the appropriate forces are being exerted and felt through the instrument handle.

The advantages of endoscopic procedures have many uses outside of gynecological practice. As such, the general algorithms developed in this simulator can easily be transferred to function on other endoscopic procedures with the appropriate software models.

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