Highly-Realistic, Immersive Training Environment for Hysteroscopy

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Abstract. The primary driving application of our current research is the development of a generic surgical training simulator for hysteroscopy. A key target is to go beyond rehearsal of basic manipulative skills, and enable training of procedural skills like decision making and problem solving. In this respect, the sense of presence plays an important role in the achievable training effect. To enable user immersion into the training environment, the surrounding and interaction metaphors should be the same as during the real intervention. To this end, we replicated an OR in our lab, provided standard hysteroscopic tools for interaction, and generate a new virtual scene for every session. In this setting, the training starts, as soon as the trainees enter the OR, and ends when they leave the room.

Keywords. surgical simulation, immersive environment

1. Background

Therapeutic hysteroscopy has become a common technique in gynecological practice [5]. Nevertheless, a number of potentially dangerous complications exist - the most common being uterine wall perforation, intra-uterine bleeding, and mismanagement of distension fluid. Therefore, specialized training is necessary to reduce the rate of complications. Virtual Reality based surgical simulation [6] is one option to provide a corresponding learning environment. In contrast to existing systems and products [7,8,9,10], our work aims at achieving the highest possible realism. A key target is to go beyond rehearsal of basic manipulative skills, and enable training of procedural skills like decision making and problem solving.

In this respect, the sense of presence [1] plays an important role in the training effect, which can be achieved. Therefore, a user should feel emotionally and cognitively present in the simulated environment [12]. In order to achieve suspen-

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Figure 1. View of the complete OR.

sion of disbelief, a multi-sensory, first-person experience has to be provided [13]. Especially, if actions could lead to negative consequences in reality, it is vital, that the learning environment engages the trainee and seems real.

To enable user immersion into the training environment, the surrounding and interaction metaphors should be the same as during the real intervention. To this end, we replicated an OR in our lab, including standard hysteroscopic tools and surgical devices, and we provide multi-sensory feedback. Moreover, individualized problem cases are presented, by generating new virtual scenes for every session. In this setting, the training starts, when the trainee enters the OR, and it ends, when she leaves the room.

2. Tools and Methods

The first element of our immersive setup is the training environment. We outfitted our OR with real tools and equipment (Figure 1). These tools are actually needed to access the surgical site. For instance, the first step of an intervention is to enable access to the cervix with the specula, and then fixate it with surgical forceps.

The female pelvic region is represented by a Limbs&Things model [2]. It has been modified to our needs in order to be able to house the haptic device. It mainly provides the tissue models for vulva, vagina, and cervix. The latter are directly connected to the haptic device, thus hiding the mechanism from the user. Moreover, the model contains the bony structures of the pelvic region, as well as the abdominal wall. For further realism, two legs obtained from a patient model from Ruediger Anatomie [3] were added.

Since interaction should be carried out with real tools instead via a mouse, we use an original resectoscope, which has been equipped with sensors to interact with the simulation. Valves for controlling in- and outflow of the distension fluid

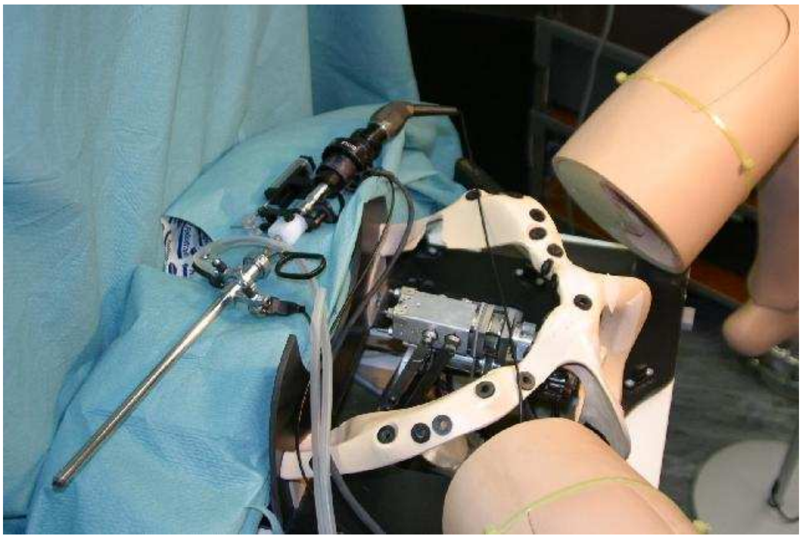


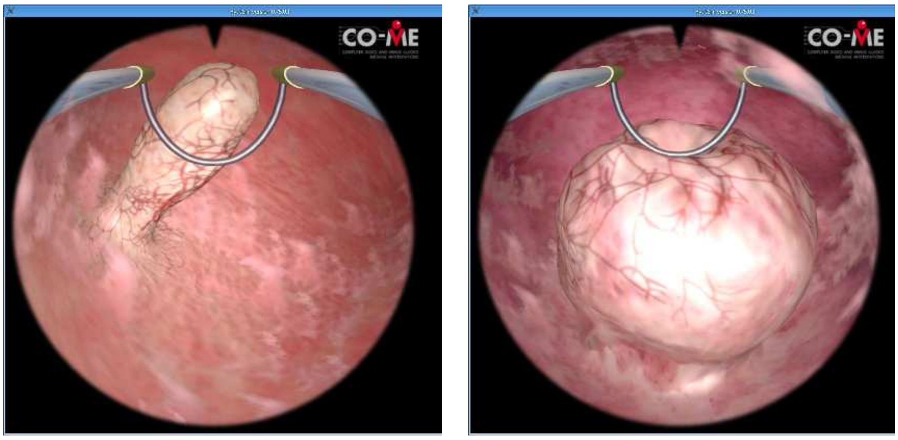
Figure 2. Haptic mechanism inside dummy.

are included. Displacement of the loop electrode is done with a standard handle, while current for tissue cutting or cauterization is controlled by foot pedals. The endoscopic camera is attached to the end of the tool and provides rotational Degrees-of-Freedom (DOF), as well as adjustment of focus. Thus, all typical manipulations of the original tool can be performed in the immersive setup and the simulation appropriately controlled. Moreover, the resectoscope itself can be completely dis- and reassembled from its individual components. All of the above allows the trainee to also get acquainted with the full complexity of tool handling.

The hardware allows insertion and complete removal of the surgical tool. After cervix fixation with the forceps, the hysteroscope is inserted into the uterine cavity, where it connects seamlessly with the haptic mechanism inside of the pelvic dummy, without any noticeable mechanical constraints. Triggered by the insertion of the tool, the visual display of the virtual scene starts automatically with a view obtained after passing the cervix. This permits a smooth transition into the fully immersive scenario instead of the well known simulation on/off experience.

The haptic device provides 4-DOFs for hysteroscopy [14]. Two DOFs for spherical displacement around a virtual pivot point are possible, as well as tracking and force-feedback for tool translation along and rotation around the tool axis. Friction and inertia from the haptic device are compensated by closed-loop control. During the simulation session, all gestures of the surgeon are tracked, permitting not only simple playback, but also making evaluation of the recorded session possible. The components inside of the mock-up (without the tissue elements) are depicted in Figure 2. During simulation the mechanical hardware remains completely hidden from eye-view.

A further element in the immersive environment is the auditory feedback. Characteristic sound sources are the electrocardiogram, hysteroscopy pump, artificial respiration, warning sounds for electrotomy and coagulation. These provide important cues to a gynecologist, and thus have to be integrated into a training



(a) Scenario with polyp. (b) Scenario with myoma.

Figure 3. Individual training scenes with different pathologies.

system. To this end, a hysteroscopic intervention has been recorded with studio microphones and a highly sensitive sound level meter (room size 6 x 4 x 3 m). Measured sound pressure levels have been in general between 57 - 65 dB(A). The rhythmic beep of the ECG was by far the most audible source. Based on these data, sound samples were extracted, which are synthesized in real-time stereo during the simulation and adapted to the actual surgical action, e.g. regulating in-/outflow of the hysteroscopy pump.

The final element of the system is a complete process for creating individual training scenes [4]. Based on real data (i.e. 3D ultrasound and MRI datasets, intra-uterine videos acquired during interventions, and in-vivo tissue measurements), statistical models were generated, enabling the creation of new instances of surgical scenarios. This includes the variability of healthy anatomy, modeling of pathology growth, incorporation of vascular structures, attachment of textures, and specification of deformation parameters. Thus, just like in real life, no two (virtual) patients will be the same. In Figure 3 two training scenarios are depicted, showing a polyp and a myoma inside the uterine cavity.

Screenshots, movies of sample interventions and further descriptions of the simulator modules can be found one our project web (http://www.hystsim.ethz.ch).

3. Conclusions

In order to increase the sense of presence, and thus improve the training outcome, we created an immersive environment for hysteroscopy simulation. This includes the surroundings, surgical tools, haptic, visual, and auditory feedback, and a virtual training scene generation process. Further modules of the simulator include real-time collision detection and response, tissue deformation, and fluid models. The complete system is depicted in Figure 4.

In future work, we will focus on further enhancement of the surgical suite. In order to increase realism, real surgical devices, e.g. fluid pump, electrocardio-

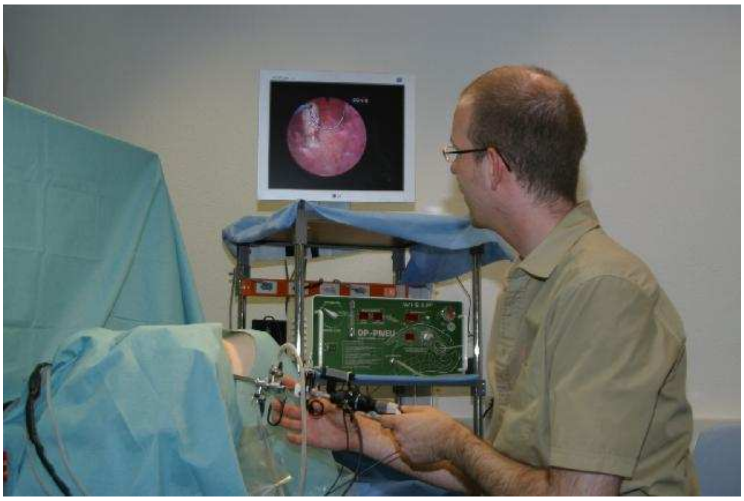


Figure 4. Close-up of the system.

gram, will be connected to and controlled by the simulation. Additionally, we will integrate real management of distension fluid with the simulation. Finally, an extension of the setup to team training possibilities will be examined.

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