Multimodal Feedback Cues To Aid Veterinary Training Simulations

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ABSTRACT
This paper describes the concept of multimodal cues to aid training in a medical simulator. These cues aim to provide guidance and performance feedback to the user in the form of haptic, graphic and auditory feedback presented during the simulator training. The paper describes current implementations of the cues and their integration into the Horse Ovary Palpation Simulator (HOPS) developed at Glasgow University.

Keywords
Medical Simulation, Force Feedback, VR training

INTRODUCTION

Providing training to novices in any safety-critical application can present risks to those involved, but particularly in medicine where a mistake can permanently damage a patient or can even be fatal. The question remains as to the safest method to provide experience to medical personnel without endangering a patient. Traditionally, training in both human and veterinary medicine has taken the form of the apprenticeship model - trainees would perform the procedure under the supervision of an experienced doctor several times before they are considered qualified to perform the operation by themselves. Clearly there are risks to the patient particularly when the trainee may lack the necessary cognitive or psychomotor skills. This system also relies on subjective assessment of the performance level of the trainee by the supervisor. Virtual Reality (VR) simulators are now widely thought to offer the potential of providing a new medical training paradigm. As such, commercial as well as research systems are being developed worldwide. One of the major considerations in building a training simulator is how to provide performance feedback to the user. Higgins *et al.* [12] state;

"it is pointless to build a training simulator that doesn't provide useful feedback on performance to the trainee"

One of the disadvantages of physical simulations is that it can be difficult to extract performance feedback from the model. The majority of the virtual medical training simulations developed do address this issue of feedback by analysing the procedure data and presenting it to the user after he/she is finished. This paper describes the concept and development of a simulator that guides the user through the environment by providing multimodal cues.

General Overview

Virtual medical simulations are becoming more common, and as the fidelity increases, they are expected to become more widely accepted as a training aid. Flight simulations are often used as an analogy in that they provide training in a multi-dimensional, safety-critical task. Although not widely accepted for many years, improved technology has lead to more realistic simulations that have proved useful in developing, maintaining and assessing pilot skill. They have been successfully used to simulate a wide range of conditions and emergencies, while reducing the learning curve for trainee pilots by providing a safe, controllable learning environment [16].

Simulation training is not a new idea in human and veterinary medicine. Students gain experience in certain techniques through use of plastic or rubber models, but these often lack realism and provide no useful feedback to the trainee. Surgical skills can also be improved in the anatomy labs that are incorporated into the medicine and veterinary medicine courses. Again, there are problems since cadavers are a scarce resource, and are not generally reusable. Living tissue can also have noticeably different haptic properties than cadaver tissue [12]. VR medical simulators have the potential to present anatomical and physiological information to the user simultaneously on reusable models. Simulations currently developed can be divided into those that provide training for minimally invasive surgery (MIS), surgery, or palpation procedures. MIS simulators are by far the most common [4, 13, 15, 17]. In a MIS procedure, surgeons view their interaction with the patient through a monitor, and hence, it lends itself to a virtual simulation. The Preop endoscopic simulator [4] developed by HT Medical Systems is one example of a system combining a force feedback MIS training system with anatomical and physiological models. Other systems exist to simulate other MIS procedures such as arthroscopy or laparoscopy. SKATS [1] and VE-KATS [17] present knee arthroscopy training systems.

Surgery simulations cover a wide range of techniques using different surgical instruments. Cathsim [2] is an example of a commercially available training system for venipuncture. Berkley *et al.* [3] present a simulation for training in wound suturing. Simulation for cutting procedures in particular present problems as models need to be dynamically adjustable, to allow incisions. Delp *et al.* [7] have developed tissue cutting and bleeding models for this purpose.

The development of a palpation simulation presents different problems than development of a surgery simulation. During surgery, a medical practitioner interacts with the patient through surgical instruments, so the haptic feedback from the tissue to the surgeon is mediated by the instruments. Palpation, however, involves the medical personnel interacting directly with skin or tissue. The development of palpation simulators tends to be less common, although palpation is an important technique for the diagnosis of many conditions. Two recent examples come from the Human Machine Interface Laboratory at the CAIP Center at Rutgers University. They have developed a simulation using the Rutgers Master II for training in palpation for the detection of sub-surface tumours using experimentally based force-deflection curves [8]. They also present a prostate simulator developed using the PHANToM [5], which can model several different prostate conditions.

One of the most important aspects of a virtual training system is that a user can be given an objective performance rating for the procedure performed. Determining the performance in a medical procedure is difficult however, since it can be a complex, multi-dimensional task with many different outcomes – not just success or failure. Metrics will depend on the training task performed. Gorman *et al.* [11] suggest the following metrics for a task involving driving a simulated needle through a target overlaying a blood vessel: time on task, accuracy, peak force applied, tissue damage, surface damage, and angle error. However, they note the difficulty in calculating tissue or surface damage accurately. For a palpation simulator where the user may wish to examine the whole of an object for specific shape or surface properties, accuracy and angle error may not be so relevant. Particularly in training for diagnosis, metrics can be very high level. For example, in Glasgow University's horse ovary simulator [6], users palpate the ovaries for a follicle to diagnose the stage of ovulation of the horse. The users might be asked "Does a follicle exist on either ovary, and if so, what size is the follicle". Systems exist to allow user performance to be stored over time [4], such that any trends of improvement or otherwise can be noted. This could eventually lead to an objective method of certification of medical trainees [12].

The Glasgow Horse Ovary Palpation Simulator

Using a medical simulator allows trainees to make mistakes while learning, without their mistakes adversely affecting a patient. To provide training however, they must be aware of their mistakes, and learn from them. Providing performance feedback to the user after the simulated procedure is an important step, but this guidance does not affect performance during the procedure. This will allow users to correct their behaviour during the simulation. Feedback cues can also be used to guide users through an unfamiliar procedure, particularly during the initial stages of training where they may not possess the necessary psychomotor skills.

A horse ovary simulation has been developed in collaboration with Glasgow University Veterinary School [12]. It was developed to train veterinary students in equine ovary palpation techniques, and in particular, in diagnosing the stage of ovulation of a horse. This is not only a difficult procedure for students to learn but can be fatal for the horse if performed incorrectly. Veterinarians perform an examination by locating the ovaries, and palpating them. The ovary shape and surface properties indicate the stage of ovulation of the horse.

Users interact with the environment through the PHANToM force feedback device from SensAble Technologies [14], which allows 6DOF input and 3DOF translational output. The model itself consists of two horse ovaries fixed in space (Figure 1), that were developed iteratively with help from experienced horse vets at Glasgow University Veterinary School. An initial experiment showed no significant difference in performance between students trained by traditional methods and those trained on the simulator. However, the results also showed there was potential for improvement in traditional training methods of ovary palpation [6], as an equally low percentage of ovaries were diagnosed correctly for both training groups.

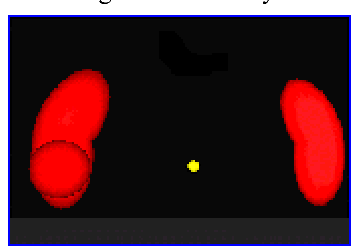

Figure 1: The Glasgow Horse Ovary Palpation Simulator. The model consists of two ovaries, (on the left and right) with the cursor shown in the centre. A follicle can be seen on front left ovary.

Current work is concentrating on two different areas: Integrating multimodal cues into the environment and improving the fidelity of the models. The feedback suggested can take the form of haptic, audio or graphical cues.

Multimodal Cues

Haptic Cues

Haptic cues provide a method to directly affect the user's path through the environment. We have considered two different forms of guidance that haptic cues could provide:

- Guidance through pre-recorded movements
- Interactive guidance.

Guiding a user using pre-recorded movements can be broken down into 2 stages - record and playback. During the record stage, both positional and force information of a user must be stored at specific regular sample intervals. Playback of the procedure would drive the user's interaction point along the path recorded. At each stage, the driving force would equal the force recorded for the current position. By this method, a student could feel the techniques and forces involved in a correct procedure by playing back a recording of an experienced doctor or veterinarian performing the same procedure. Alternatively, a doctor could assess the performance of a student by playing back a recording of their movements.

Interactive guidance can be thought of as a tutor-trainee model. In this situation two interaction points would exist in the same environment. The first is controlled by the trainee, and can be used to explore freely the environment as in a single user simulation. The second is controlled by the tutor, who can influence the student at any time. This could take the form of grabbing the student’s interaction point and dragging it through a series of motions. The trainee could then practice the procedure as normal, while the tutor could guide him/her if and only if help is required. This would serve to reinforce the apprenticeship model currently in use, while allowing the tutor to have a more active role in guiding the student.

An initial attempt has been made to integrate pre-recorded haptic guidance into the training environment. During the recording stage, the position of the PHANToM can be sampled at a rate of between 100 and 1000 Hz. The PHANToM's position sensors provide a representation of the current cursor position that can be used to accurately recreate the path recorded. However, recording force information at the sample points presents problems, as the PHANToM device does not have force sensors. The system implemented attempts to estimate the applied force through the reaction force from objects or effects within the scene. By introducing viscosity throughout the scene, a reaction force to any movement can be detected through the device. Playback also presents problems, as even a passive user can affect the path of the cursor, and applying the recorded force vector will not generally move the cursor along the recorded path. The PHANToM drags the user’s finger through a series of movements. Resistive forces from the user will combine with the driving force to produce deviations from the path. The current system calculates the magnitude of the recorded force and applies it towards the next sample point on the path. This however can cause instabilities when contacting objects in the scene, demonstrated in Figure 2.

When touching an object the user will apply a force to counteract the reaction force from the object. Even if the user is moving perpendicular to the surface of the object, he/she is still applying a force to counter this reaction force. However, the playback force will not take account of this and will drive the user directly towards the next sample point. The reaction force will combine with the playback force to produce a net force vector that is not in the direction of the next sample point. A more complex algorithm must be developed to adapt the playback force direction depending on the reaction force from the contacted object.

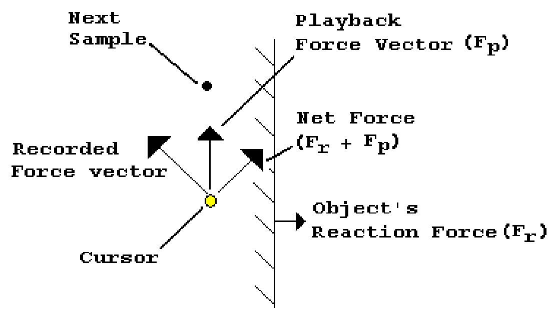

Figure 2: Demonstration of the problems of playback when the cursor and next sample point lie inside an object. The direction of the playback force will be affected by the object’s reaction force and resultant force will push the cursor away from the sample point.

Audio Cues

Audio cues can be used to convey state information about a system to the user. Gaver presents Arkola [10], a system in which continual auditory feedback can be used to monitor the running of a simulated factory, and in particular alert the user when an error occurs. Audio feedback to present state information has also been demonstrated in a medical context to augment a surgical procedure [18]. Surgical instrument position and optimal path information are passed to the surgeon through audio, allowing the surgeons to use the information while keeping their visual focus on the patient. Similar concepts of supplying users with auditory position and path information can also apply to medical simulators. Incorporating audio warnings into a simulation can provide immediate feedback to users that the current action they are performing is incorrect, or dangerous. Unlike haptic cues, audio cues do not directly affect the cursor position, but allow users to correct their actions themselves. In this manner, they can build confidence as they progress through the procedure that their actions are not damaging the patient.

A simple audio warning cue has also been incorporated into the Glasgow ovary simulation. One of the dangers when performing an ovary examination is damage can be caused by palpating an ovary too firmly. An obvious solution is to alert the user when they are applying too much pressure to an ovary. Each of the objects in the environment can be assigned a threshold force value. If more than this threshold force is applied to an ovary during palpation an audio warning is sounded. In the current implementation, the pitch of the audio warning is linked to the force applied above the threshold, so a higher pitch of sound indicates a greater danger.

Graphical Cues

Graphical cues can be most easily used to highlight a specific area of the screen. The user's attention can be drawn to a particular object by colouring it differently from the surroundings. In this way, an area of interest, for example an incision point, can be highlighted. Other possibilities exist however. A training system might include a path following mode where, much in the same way as haptic cues, a pre-recorded procedure is played back the user. During a correct examination, cursor position could be recorded at regular time intervals and a representation of this position can be played back in a subsequent examination for a student to follow. The pre-recorded cursor would provide no direct guidance, but a user could follow the movements with his/her own cursor, performing the same actions as the recording.

Improvements to the models

The ovary models are being developed to increase the fidelity of the simulation. This is a particularly important issue for a simulator relying on palpation, where the users are directly interacting with the virtual objects that must feel realistic. Currently, the ovaries are based on the combination of geometric shapes, and while this was judged to be effective by veterinarians, methods to build anatomically accurate models exist. The "Lucky the Virtual Dog" project generates anatomically accurate models of a dog through the composition of MRI and CT scans [9].

The ovary firmness is modelled with a linear force model. We are trying different non-linear soft tissue models, although their realism will still be decided subjectively by veterinarians.

The next stage in the project will be to integrate two PHANToM devices into the same environment. Users can then use their thumb and forefinger to grasp objects in the scene. This will provide a more realistic simulation in that vets performing an ovary exam will cup the ovary with one or more fingers and palpate it using their thumb. It should also allow the ovaries to become moveable. The ovaries were moveable in our initial simulation, but proved difficult to palpate. With two interaction points, one can provide a reaction force to movement while the other can be used to palpate the ovary. An experiment is currently being developed to test object identification when using two PHANToMs instead of one. This experiment will be performed on the ovary simulator, but will involve a group of novice users with no veterinary knowledge. The users will be trained and then asked to find and identify soft spheres (representing follicles) on the ovary models using touch alone. It is expected that the two PHANToM simulation will allow users to find and identify the size of follicles with more accuracy than the one PHANToM simulation. A similar experiment will also be run using experienced horse veterinarians as the user group, to attempt to validate the ovary models.

Conclusion

Presenting performance feedback to users is an essential feature of a simulator, as it will allow them to learn from their simulator experience. Current research has concentrated on providing post procedure performance analysis, but little work has been done on guiding a user during the simulation. Providing users with multimodal cues has the potential to both guide them, and present them with performance feedback during the simulation. However, both the simulator and the cues themselves require further work before a useful system can be developed.

ACKNOWLEDGMENTS

This research was funded by the Faculty of Veterinary Medicine at Glasgow University. Thanks must also go to the SHEFC REVELATION Project, SensAble Technologies and Virtual Presence Ltd.

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