The Need to Touch Medical Virtual Environments?

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ABSTRACT

Haptics technologies are frequently used in virtual environments to allow participants to touch virtual objects. Medical applications are no exception and a wide variety of commercial and bespoke haptics hardware solutions have been employed to aid in the simulation of medical procedures. Intuitively the use of haptics will improve the training of the task. However, little evidence has been published to prove that this is indeed the case. In the paper we summarise the available evidence and use a case study from interventional radiology to discuss the question of how important is it to touch medical virtual environments?

KEYWORDS: Haptics, virtual environments, touch.

INDEX TERMS: H.5.1 [Information Interfaces And Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; J.3 [Computer Applications]: Life and Medical Sciences

1 INTRODUCTION

Today, more than at any time in the history of medicine, there is unrelenting pressure for changes to accepted medical practice, particularly as a consequence of legislation such as the European working time directive, and the Calman reforms in the UK [1][2]. Some of this is driving surgical management into novel minimal access approaches, in turn raising further challenges of training the increasingly complex skills that are a part of such innovative practices. Safe, effective training of the next generation healthcare professional can benefit by taking advantage of new technologies and approaches emerging from computer science, engineering, psychology and other related disciplines. The use of haptics devices to provide force and/or tactile feedback within a simulator is a prime example of this and there are a growing number of simulators from a wide scope of medical specialties that use some sort of haptics device. A detailed survey of the current state-of-the-art can be found in [3].

A complete evaluation of transfer of skills to patients, comparing training of a control group (not using simulation) against two study groups (one using simulation with, and one without haptics feedback) has yet to be published. This has partially been addressed by Morris et al [4], who demonstrated that recall following visuohaptic training is significantly more accurate than recall following visual or haptic training alone, although haptic training alone is inferior to visual training alone. A recent review of haptic feedback in conventional and robot-assisted laparoscopic minimally invasive surgery (MIS) [5] concluded that there is no firm consensus on the importance of haptic feedback in performing MIS interventions. Whilst a majority of the studies resulted in a positive assessment of the inclusion of force feedback, results are uncertain and inconsistent. This ambivalence could well be due to the nature of laparoscopic MIS procedures that are carried out using thin elongated instruments inserted through ports that may create frictional forces in excess of 3 Newtons [6] capable of interfering with more subtle haptic cues.

In addition to open surgery where the surgeon largely relies on the sense of touch to conduct the procedure, there are several medical specialties where reacting to haptics cues is a vital part of a successful procedure. Examples of these include interventional radiology, arthroscopy and internal examinations (rectal and vaginal). Whether the above findings are true for any of these specialties has not yet been investigated. In this paper we discuss further if there is a true need for haptics devices within a medical simulator and use our work in developing simulations for interventional radiology as a case study [7][8].

2 INTERVENTIONAL RADIOLOGY

The practice of interventional radiology (IR) uses imaging (fluoroscopic, computed tomography, and ultrasound) to guide catheters (tubes) and wires through organ systems using a small portal of entry (such as a needle) into the body [7]. As a result, IR techniques generally have less risk, less post-operative pain and shorter recovery time compared to open surgery. IR extends to a vast range of imaging guided procedures that are minimally invasive. Reacting correctly to both the tactile and force feedback elements that comprise the practitioner's 'feel' during a procedure is essential to avoid complications. We describe below three stages where such cues are important and have been implemented in our simulators using haptics devices.

2.1 Palpation

Palpation is the use of a clinician's sense of touch to probe deeply beneath the patient's skin, seeking evidence of any pathology in the underlying anatomical structures. Palpation and general haptic response commonly requires multi finger, multi contact tactile manipulations. Such an effect is difficult to achieve within a medical virtual environment and when included, the manipulation is usually greatly simplified.

It is necessary to simulate both force feedback to convey the resistive force of the skin, organs and bones and, tactile feedback to convey the finer information such as the pulse and small abnormalities felt at the surface of the fingertips. Although over the last 15 years there has been a lot of activity in the development of force feedback devices, a lack of understanding of the large number of different tactile receptors in our hands has meant a much lower rate of development of tactile devices with no significant product available commercially. Possible technologies include use of piezoelectric materials (as in Fig. 1), the vibrations from a small audio speaker, pin arrays, and pneumatic solutions. Practically, stimulating each of the fingertips' receptors as stimulated in a real palpation is infeasible, however, and an approximation using a force feedback device combined with a mannequin like end effector appears to currently provide the best tradeoff between cost and fidelity.

Figure 1. Palpation device combining force feedback from a NovINT Falcon and tactile feedback at the fingertips from piezoelectric materials.

2.2 Needle Insertion

A needle insertion is a widely performed procedure which, in the context of IR, is needed for a biopsy or to introduce a guide wire into the femoral artery, liver, kidney, etc. The task requires 6 DOF but force feedback can be realistically simulated with only 5 degrees of force feedback by neglecting the forces involved in rotating the needle shaft along which it is inserted. Many needle insertion simulations, both commercial and academic opt to simulate only 3 degrees of force feedback to reduce simulation cost for example Mediseus Epidural from Medic Vision (Kensington, Australia) and our own simulator [7].

Ultrasound images are commonly used in IR to guide needles. Prior to the needle insertion, an anaesthetic solution is injected near the puncture site. It is followed by the incision of the patient's skin so that no resistance from the skin can be felt during the needle insertion. Then the ultrasound probe is placed on the patient's skin at the incision site to locate the needle target. Finally the needle can be inserted. Figure 2 shows a simulation of this stage using commercially available force feedback devices. It should be visible on the ultrasound screen as much as possible. Looking at the ultrasound monitor, radiologists often jiggle the needle to identify its tip location within the patient. Once the needle is visible on the image, it is slowly advanced s the target. Although the needle should be identified on the ultrasound images used for guidance, this is not always the case. When the visual feedback does not provide any information about the location of the needle tip, the resistance on the needle during the insertion will provide invaluable information. For example, at the interface between two kinds of tissue, the resistance will increase until the surface of the deeper tissue is punctured, then it will decrease. Also, the force required on the needle is greater for the kidney than fat, and it is greater for the diseased, cirrhotic liver than the normal kidney. Therefore, such features are also required when teaching image guided needle puncture using a VR training simulator. The response of real tissues during an actual needle insertion can be recorded and modeled analytically to integrate realistic haptics models [10].

Figure 2. Using PhanToM Omni Force feedback joysticks as an ultrasound probe and virtual needle.

Although validated needle insertion simulations have been produced, none as yet lead directly on to the next stage of an IR procedure, guide wire manipulation.

2.3 Guidewire and Catheter manipulation

In laparoscopic surgery, rigid instruments provide access to the abdominal cavity. These convey limited tactile cueing from viscera, with key cues being visual, from 2D imaging. In IR, the long flexible tools (catheter, guide wire) involved may convey greater tactile feedback, which is highly relevant to avoiding complications and maintaining safe practice. For this reason, realistic IR catheterisaton simulations cannot use joystick like interfaces. Instead, frictional sensors provide essential rotational and translational haptics, such as would be needed for Endoscopy simulations.

Replication of haptics in simulations is necessarily an approximation, but can be enhanced by seeking evidence from procedures performed in the real world. This in itself is challenging work, which must use unobtrusive, novel sensors that avoid interference with correct performance of a procedure in a patient. At the same time, collection of procedural force data might indicate the basis of haptics cueing for a procedural step, distinguishing between cues that use absolute force, and those that are based on relative values during one or more actions. Such data can then be used as a basis for refining algorithms, and identifying the actual resolution needed for an interface device to meet a specific level of fidelity.

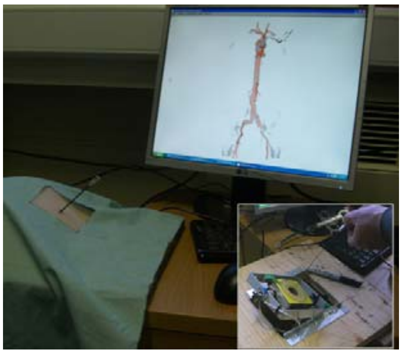

Figure 3. Simulator for the Seldinger Technique. Real guide wires and catheters can be fed through a needle portal into the virtual patient. Custom hardware has been designed to orientate the needle (inset picture) and provide force feedback.

A major goal for a successful outcome is not to penetrate a vessel wall with the guide wire. In some cases a very low force can result in penetration (particularly in complete occlusions, where the force to continue along the lumen can be very similar to that which allows wall perforation). Responding correctly to the perceived haptics cues is then vital.

3 DISCUSSION

A good overview of the issues that need to be considered when assessing a surgical simulator can be found in [11]. The need for multidisciplinary collaboration to build an effective simulator is advocated. Other important points made are the advantages for training in deconstructing tasks into simple steps, unlimited deliberate practice with this repeatability of procedures facilitating learning from mistakes, the provision of objective feedback, and the need to integrate the simulator into the education curriculum. There is often a tradeoff between the fidelity of the simulation and its cost, and it is not always necessary to achieve ultra high fidelity in order to provide a training benefit.

Basic research on cross-modal perception does indicate the likely importance of haptics in virtual medical environments. Its potential contribution is most readily apparent when vision and haptics provide qualitatively different information. This arises frequently because the two sensory systems have very different capabilities: vision provides precise information about spatial properties, whereas haptics provides information about texture, and material properties such as stiffness/compliance [12]. Recent research shows, however, that haptic perception also plays an important role even when equivalent information is available, simultaneously, from vision. In this case perception is not dominated by one sense (i.e. vision). Instead, information from vision and haptics is unconsciously and automatically integrated, with each signal weighted according to how reliable it is in a given instance [13]. The benefit of this is that object properties are estimated more precisely than is possible from either sense alone. If sensory integration occurs in real-world bimodal tasks, it should presumably occur in medical simulators too. The process of sensory integration only operates appropriately, however, if the brain can determine which visual and haptic signals 'belong together'-that is, which signals provide information about the same object and which do not [14][15]. This process appears to be dynamic and flexible: visual-haptic integration has been observed when using tools, for example, which systematically alter the normal spatial relationships between visual and haptic signals [15]. However, spatial (and temporal) congruency between movements of the hand and/or surgical instruments and the visual consequences of those movements seems to be crucial for sensory integration to occur [14][15]. This suggests that it is critical to achieve spatial and temporal co-registration of visual and haptic signals in virtual environments. Moreover, we currently know little about the importance of sensory integration for learning bimodal tasks such as surgical procedures. There is evidence that people form 'amodal' spatial representations when visual and haptic information is presented simultaneously (as is the case when carrying out a task in the real world), but not when they are temporally separated [16]. It seems plausible, then, that training in the same (bimodal) sensory conditions as the real task could lead both to better learning and better overall performance.

The current published evidence clearly demonstrates that VR simulation can improve intra-operative performance. We advocate that good use of haptics (e.g. force responses are accurately modeled, the resolution of the haptics device is appropriate, one to one registration between the haptics hardware and the virtual tool is achieved, the haptics cue appears at the correct location in the anatomy, etc.) has an important role to play in achieving this goal. This will be particularly important in many medical specialities where reacting to haptics cues is a vital part of a successful procedure, such as the IR tasks described above. We plan to use the needle puncture simulator to set up a test study to prove this hypothesis.

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