TRAINING MINIMAL ACCESS SURGERY SKILLS WITHIN A VIRTUAL ENVIRONMENT

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ABSTRACT

A training system for Minimal Access Surgery (MAS) has been developed by the Centre for Human Sciences, part of the Defence and Evaluation Research Agency. The system consists of an object model database which can be interacted with via simulated MAS surgical tools. It is based on two low cost networked personal computers and linked to a pair of laparoscopic tools to provide accurate force feedback within a virtual environment. Development of an integrated training system forms a necessary part of delivering an effective training tool. A hierarchical task analysis (HTA) has been used to determine the key skills demanded of the surgeon in laparoscopic ectopic pregnancy. The experimental evaluation of system features to enable cost benefit trade offs to be made is discussed. From the HTA and a review of the literature new conclusions about the fundamental nature of the tasks to be trained in MAS are presented. The conclusion that adaptation to a continually varying control law is the fundamental task to be trained in MAS has implications for the design of MAS training systems.

A future programme of experimental trials work on the simulator design parameters of force feedback, scene detail and 3-D, and the application of Distributed Interactive Simulation (DIS) networks, being carried out in conjunction with the Surrey RCS MATTU unit and Loughborough University is discussed.

INTRODUCTION

The DERA Centre for Human Sciences has a background in developing and evaluating simulation for military sponsors and has recently developed a training system for Minimal Access Surgery (MAS). The system VISTA (Virtual Interactive Surgery Training Aid) has been described in previous papers (Kelly & Beagley, 1997) and consists of a novel hardware platform which includes a deformable database, viewable in 3-D, which can be interacted with via simulated MAS surgery tools which have simulated low force feedback (Figure 1). Over the course of the VISTA systems development a small number of similar systems have been developed by universities, medical research laboratories and industry, with many common features. However a number of issues remain to be addressed by this (and other) systems before they are fully taken up by the medical world, and these are discussed below.
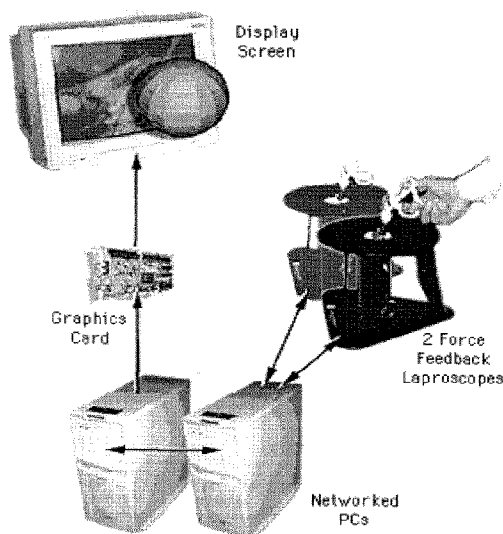

Figure 1.

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Training System Requirements

In an ideal world one should first have an application in mind and then design a system to meet the application needs, based on an analysis of the applications requirements, with the design features optimised for this, or a limited set, of applications. Systems designed to be all things to all men are rarely cost effective solutions. However technological advancement does not usually proceed like this. Most virtual surgical environments have moved from a technological concept demonstrator to retrospectively define an application. The best systems have a narrow application focus (e.g. training surgical procedures) the less satisfactory systems offer a wide range of applications (e.g. surgical planning, surgical rehearsal, skill training, and operative support). The value of developing the system design based on a thorough analysis of the application, and of selecting design features to provide maximum cost benefit for the chosen application is demonstrated by the approach taken for the design of VISTA.

Task Analysis

The application focus for the VISTA system is training MAS skills, using a cost effective training system. To identify the requirements for the training material an analysis of MAS skills was carried out (Shepherd, 1989) using Hierarchical Task Analysis (HTA). This focused on the surgical procedures relating to the condition of ectopic pregnancy. This is a relatively common condition which is potentially life threatening (Graber, Allen, Levy, & Talley, 1994). Treatment is predominantly surgical and is an area where MAS has made an important impact. The analysis was constructed through interview with surgeons. One of the resulting diagrams is presented in Figure 2.

The training tasks represented within VISTA include synthetic representations of the basic skills batteries that are employed by a number of MAS training hospitals (e.g., Rosser, 1995). However the HTA, along with observations and discussions with surgeons has enabled us to identify an additional basic skill component of MAS that is not currently part of the skills training in many hospitals and which has important design implications for any simulator that may be used to train these skills.
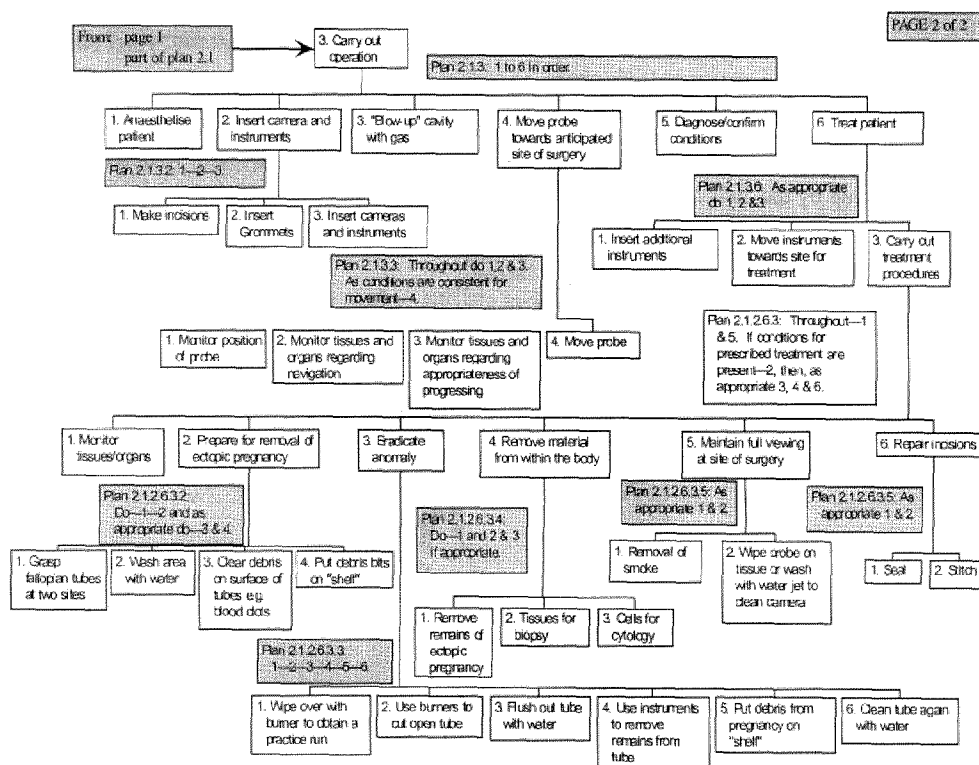

Figure 2. Part of HTA Decomposition.

Initial consideration of the unusual working environment of the minimal access surgeon suggests that they must be able to rapidly model and adapt to a variable control law. That is the relationship between their hand movements and the displayed control (Laparoscopic surgical tools) movements can continually change from moment to moment as the camera's position, orientation and FOV is changed. This may be the most fundamental skill difference from conventional open surgery techniques. The surgeon is continuously sampling the environment, modelling the CD relationship and confirming the model by test movements. An example of such a test movement can be seen in the lower level HTA task (plan 2.1.2.6.3.3; task 1) "Wipe over with burner to obtain practise run". Therefore it is a design requirement of a basic MAS skills trainer that the camera position can be controlled and varied during a training task. This feature cannot be found on some skills trainers which arguably limits their training value. Pilot studies on the rates of learning MAS skills in a virtual environment with and without variable camera position have been carried out using the VISTA system (Raynor, 1997). These confirm that the skills learnt in a variable camera position regime transfer better to a criteria task, than when learnt with a fixed camera regime, and that when MAS skills were learnt in a fixed camera regime interference was found on transferring to a criteria task.

Design Trade Offs

Developing a cost effective solution was also supported by taking a modular approach to the technology. All elements of the development system were hosted separately to enable their contribution to the overall systems training effectiveness to be assessed and optimised. The final design solution could then be packaged as a single platform solution using hardware and software solutions that would be state of the art at the time of delivery. The contribution of features to the overall training effectiveness of the system was the basis of the supporting experimental programme. Systems exist which enable force or tactile feedback to be implemented in a virtual surgical simulator (Immersion, 1997), however it is the sophistication of the underlying mathematical model of tissue deformation which makes this task easy or difficult to simulate. Accurate implementations of force feedback are a high cost driver and may offer low benefits at the basic level of MAS skill acquisition. The main areas to be evaluated for their contribution to the training systems effectiveness are given in Figure 3.

FUTURE RESEARCH ISSUES

The main research issues we are concerned with can be grouped into three areas; the hardware issues, the ergonomic issues and the training media and method issues.

Feature	Cost	Technical difficulty	Training benefit
3-D	Medium	Low	Unknown/Low?
Force Feedback, Simple Algorithms	Medium	Medium	Low?
Force Feedback Advanced Algorithms	High	High	Medium?
Polygonal Organ Models	Medium	Low	Medium
Voxal Organ models	High	High	Low?
Performance measurement	Medium	Low	High
Skill based tasks	Low	Low	High
Variable camera Position	Medium	Low	High
Olfaction	Medium	Medium	Low?

'?' indicates areas for further research

Figure 3. Simulator Features for Design Trade Offs

Hardware Research Issues

There are two main areas in the development of the hardware on which SME's appear to differ; these are the requirement for 3-D and the requirement for force and kinaesthetic feedback. This difference of opinion may be because of some difference in the applications which the SME are concerned with, or differences in the training and execution of the surgeons skills (and the cues they are accustomed to using). Or it may be confusion or unfamiliarity with the potential of

each of these technical possibilities as opposed to their limitations. It is clear that both 3-D and Force feedback are issues requiring further research.

Force/Kinaesthetic Feedback

Many surgeons say that any MAS training system must have force and kinaesthetic feedback for the surgical tools. But it is clear that one of the problems in this environment is the low levels of force feedback present which can be exacerbated by the flexibility, damping and adsorption of the surgical tool being used.

The high cost of force feedback in the system meant that its contribution to training effectiveness was one of the first areas to be addressed. Pilot studies (Kelly & Cotter 1998) have indicated that the simple model for force feedback implemented in VISTA can have a beneficial effect on the accuracy and speed with which a training task is performed in the system.

3-D

Early MAS systems did not have colour displays and few now have 3-D. Technology is now able to offer 3-D to the MAS surgeon and it is likely that unless there is a strong reaction to it 3-D displays will form part of future MAS surgical suits. Nonetheless the benefit from its use is still unclear, and while lightweight headsets that still allow a degree of peripheral and local normal vision are now available, some surgeons still find their use uncomfortable and restricting. It is clear that many MAS tasks require depth perception but it is also clear that depth cues are present in normal displays (e.g. shading, shadows, occlusion etc.) and that not all surgeons benefit from enhanced 3-D. There is some evidence that two-handed tasks can be carried out faster using 3-D, but the conclusive research remains to be done. VISTA has a selectable 3-D output to enable the contribution of the 3-D displays to training effectiveness to be researched.

Ergonomics

The variety of designs of MAS systems available for surgeons indicate that there is still a need for some basic ergonomic studies on relative screen, body, and hand positioning, and to consider the possibility in some cases of seating or supporting the surgeon. Studies of operating theatre team interactions are being carried out (Helmreich & Schaefer, 1994) and VISTA has been sourced to provide the operational task in these studies.

Training Media

The development of Objective Performance Measures (timings, error rates, positioning and placing accuracy – see, Johnston, Bhoru, Satava, McGovern, Fletcher, Rangel, & Loftin, 1995) to support the traditional subjective assessment of performance normally found in surgical training is seen as a key area of research for MAS. Objective Performance Measures (OPM) will be developed using the analysis of MAS skills and additional information from SME interviews and the examination of current training practices. These measures support the setting of training performance standards and aid in the provision of feedback during skill development. It is also seen as important that the training material is based on the training analysis and on existing training theory. This is to ensure that training is effectively structured, with appropriate sequencing, level of exercise detail and feedback. This will lead to the development of a series of training tests that can aid in the development of an auditable training trail for MAS.

CONCLUSION

It is clear that the new surgical procedures of MAS offer many advantages for patient care and that technology offers a degree of solution to the training problem.

Computer based simulation provides an opportunity to extend the current approaches to MAS training. Simulation of the surgical environment combines complete control over the training task with the means of gathering objective performance data.

The rise in litigation in this area has led to demands by surgical training organisations for an accredited, structured and validated training programme for MAS, based on Objective Performance Measurement, that can provide a defensible audit trail for MAS competence. The degree to which technology provides a solution to the training problem and the

exact benefit of all or each of the technical possibilities in this new field is the focus for further research in this programme. This paper has presented the initial work towards the integration of an interactive virtual environment with a theory based training structure, grounded in the analysis of MAS procedures. In doing so, it has raised some fundamental issues relating the skill elements that underpin MAS.

We believe that a skills trainer that is cost effective can be built, but that a system for full surgical simulation whilst possible technically is still too costly for the basic surgical training market place. It is likely that any surgical training centre would eventually have a range of training systems each with differing amounts of technical sophistication, catering to basic training, advance skill training and full surgical simulation.

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