Introducing Virtual Reality in Robot Assisted Minimally Invasive Surgery Team Training

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***Abstract*—The evolution of surgical robots is increasing and continues to do so. Training and experience with the robots is a key factor to successful operations but is a costly event, as the equipment used is expensive and has a short lifetime.**

To ease training and decrease training cost, a virtual reality simulation is created. This is done in cooperation with the Minimal Invasive Education Centre and with Jane Petersson, First Nurse Assistant and Nurse specialist in Robot surgery and Johan Poulsen, head surgeon at Aalborg University Hospital. This is done as an exploratory experiment to test if it is a viable solution to the problem at hand.

Viability checking is done by performing both a usability and utility test. The usability test is performed as a quantitative test where the utility test is an expert review with both Jane Petersson and Johan Poulsen. A contextual study has been carried out to gather the information needed to develop the system.

The results show a usability score of 67.5 proving the usability to be ??? The utility test showed an acceptance of the proof-of-concept simulation made. Therefore the product developed is a success and proves viability in further development of the simulation.

I. Introduction

Surgical robotics has evolved quickly since the 1980's and will continue to do so in the future [cite taylor medical 2008]. In some areas, it has even become an essential technology [cite sivaraman robotics 2015]. Although robot assisted minimally invasive surgery (RAMIS) is at worst as effective and at best lowers injury, complication, and death rates significantly compared to conventional surgery, errors still occur [cite razmaria does 2014, punnen how 2013, sung oncologic 2016, raza long-term 2015]. Alemzadeh et al found that around 17.4% of deaths during RAMIS occurred during the operation, and 7% were due to staff mistakes. The majority of injuries were caused by device malfunction, but a not insignificant amount were due to staff errors. The statistics are shown in Table I [cite alemzadeh adverse 2016].

Injury Reports (Total = 410)	
Example Causes	**Number of Reports (%)**
Device malfunctions	254 (62.0%)
Surgeon/staff mistake	29 (7.1%)
Improper positioning of the patient	17 (4.1%)
Inherent risks of surgery and patient history	16 (3.9%)
Burning of tissues near port incisions	9 (2.2%)
Possible passing of currents through instruments	6 (1.5%)
Surgeon felt shocking at the surgeon-side console	2 (0.5%)
N/A	77 (18.8%)

TABLE I: The most common sources of injury[cite alemzadeh adverse 2016]

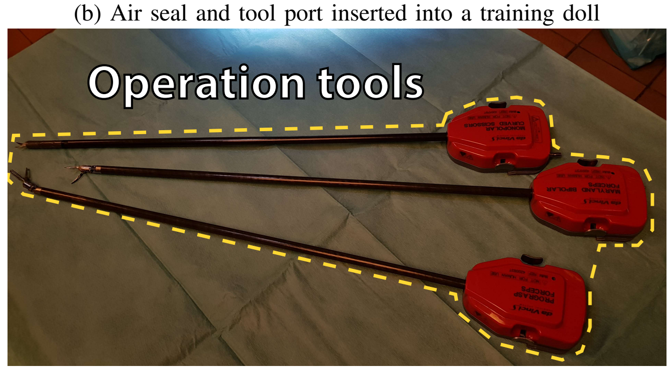
According to Alemzadeh et al, one key area of RAMIS that may be improved is the "human-machine interfaces and surgical simulators that train surgical teams for handling technical problems". Other researchers suggest a variety of methods to reduce injury numbers, such as dry lab training, simulated emergency handling (including in virtual reality (VR)), and even a complete remodelling of operating theatres [cite liberman training 2011, huser simulated 2014, ahmad ambulatory 2016, abelson virtual 2015]. These all suggest that more training is beneficial to reduce error rates.

During an interview with, and observation of, Jane Petersson, First Nurse Assistant and Nurse Specialist in Robotic Surgery at Aalborg University Hospital and MinimalInvasiv UdviklingsCenter (Minimally Invasive Education Centre, MIUC), she stated that some of the most important aspects of RAMIS are routine and training, especially as part of a team. This claim is substantiated by several studies [cite moorthy qualitative 2004, chandra comparison 2010], showing clear improvements for experienced surgeons, but also a significant learning curve.

Currently, MIUC's team training consists of two full day sessions for op to five nurses and surgeons. They teach both theory and practice of the da Vinci surgical system and RAMIS. This includes setup ("docking", calibration and insertion of tools and camera), surgery, troubleshooting, and finishing ("undocking", including removal of tools from the patient). Common troubleshooting procedures include recoverable and unrecoverable situations, CO_2 leaks, and emergency undocking (converting to open surgery). Important aspects of this training is communication between all the trainees, as well as routine and error handling.

(a) Drapes used to sterilise the robot arms

(b) Air seal and tool port inserted into a training doll



(c) Operation tools used by the robot inside a patient

Fig. 1: Key objects during robot surgery. The robot arms of the da Vinci surgical system, ports used to insert the laparoscopic tools into the patient

We, together with Jane Petersson, believe this can be extended to team training in VR as shown by Abelson et al in conventional surgery [cite abelson again] and Huser et al simulating full surgery teams doing emergency fibrillation. VR training has the benefits of being cost-effective compared to regular RAMIS training (which costs 6,000-8,000 DKK per person), at the cost of reduced accuracy, as well as enabling concurrent multi-user functionality in different locations. This would allow surgeons and nurses to train certain scenarios at their work or at home instead of travelling to certified institutions.

A. Context Study

System design and minimum implementation criteria were defined after a series of observations and interviews with

Jane Petersson and Johan Poulsen. Active observations of robot surgery, surgeon training, and team training for were needed to assess the implementation requirements whereas semi-structured interviews with experts informing the design. Figure 1 shows the most important objects during RAMIS. The top image shows a nurse preparing the robot arms by covering them in drapes to sterilize the equipment. An important aspect of this preparation is to place the arms correctly to avoid collisions during surgery. The middle image shows the ports that are inserted in the patient. The placement and rotation of these are important and are therefore trained repeatedly during the sessions. The bottom image shows the operating tools that are latched on to the robot arms and through the ports on the patient. These tools perform a wide variety of tasks depending on the type of tool such as cutting and grabbing tissue. The interviews with Jane Petersson focused primarily on the important aspects of team training for surgical staff. These include communication between nurses, understanding roles in the operating room, and an introduction to the da Vinci surgical system. During training, the instructor will spend time with the trainees getting to know the robot and show important steps such as placement of the arms, insertion of ports and instruments, controls of the robot, and teach the different error messages. The trainees will then have to use their knowledge and communicate with each other when they are operating on a live pig later. This way they gain hands-on experience with the robot and its functionalities, according to Jane Petersson. She also mentioned that it is important that the instructor or someone with RAMIS experience is nearby as questions always arise. The communication is therefore not only trainee-to-trainee, but also largely trainee-to-instructor. During RAMIS there are usually two nurses present, one surgeon, one surgeon assistant, and one anaesthetic nurse or doctor. The surgeon will sit at the surgeon console, controlling the arms of the robot while looking into a stereoscopic display. The sterile nurse and the surgeon assistant (sometimes first nurse assistant) assist the surgery by providing the right tools, monitoring the patient. The second nurse, called the circulating nurse or *floor nurse* is not sterile and can therefore enter and exit the operating room as needed and perform tasks that would otherwise contaminate the other nurses. An overview of the operating room (OR) including the roles of each member of staff is visualized in Figure 2.

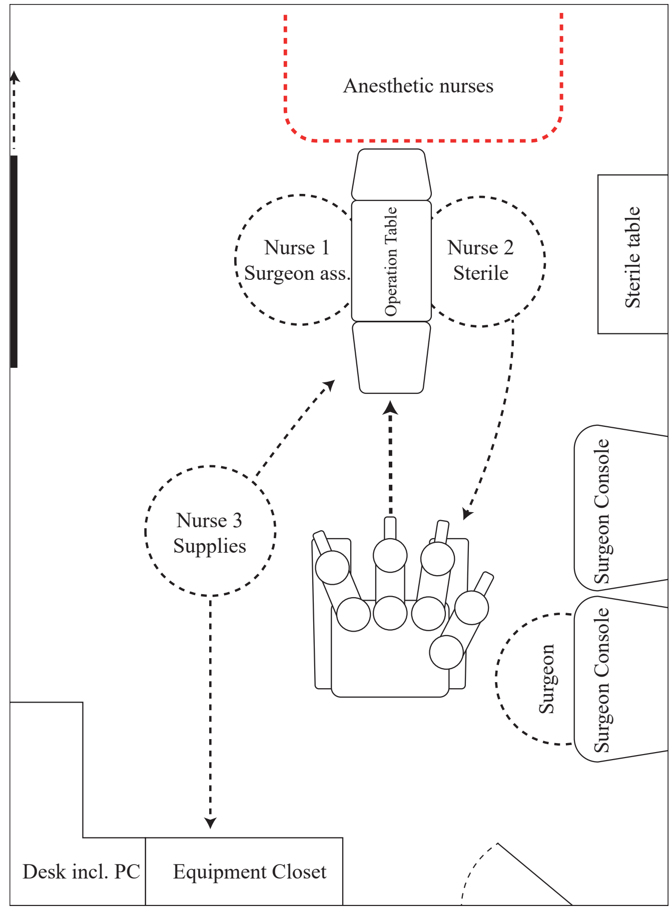


Fig. 2: An overview of the operating room from the field observations

The training room during team training is much smaller than the OR and space can be a problem in this context. Another benefit of virtualising team training would therefore be more space.

Observations of the team training emphasized the importance of precision. When dealing with surgery every variable is situation dependent. This means there is no universal way of e.g. placement and orientation of the ports and tools, tilt of operating table, or even manual control of the laporascopic tools. These procedures require concentration and are constantly evaluated and corrected by the nurse or surgeon performing them. Trainees are given visual feedback from screens placed in the room. These screens show the camera inside the patient.

A lot of questions arise during training. These questions are often directed at the instructor. The instructor then gives an in-depth answer while often also visualizing it using the tools and robot. These questions come sporadically and often unpredictably and it is therefore important that an instructor is nearby to make sure the procedure continues. Team training also prepares the nurses for emergencies, specifically emergency undocking of the robot. When an emergency undocking is issued, the two assistants at the robot has to remove the arms and the ports on the patient and prepare for an open surgery, while the circulating nurse assists by calling for assistance and preparing the surgeon for open surgery. During this procedure precision and accuracy is not important, instead the time taken to perform the procedure becomes essential.

II. Method

Two types of tests were performed, a usability test and an expert review with Jane Petersson and Johan Poulsen, head surgeon at Aalborg University Hospital (AUH). Both tests were part of a system review. The system allowed multiple concurrent users to act in an operation environment with the intent of ultimately allowing RAMIS surgeons and nurses to train specific scenarios in VR with emphasis on communication and routine. The scenario is emergency undocking because of low precision requirement and time constraints. The test procedure is listed below:

- Participants are introduced to the system and the project
- The usability participants are split up in different rooms
- The participants perform the required tasks together
- Usability test participants fill out questionnaires
- A short exit interview is held

The VR environment allowed participants to interact with a virtual robot modelled after the da Vinci Si, see Figure XX. They were able to move the arms and fit it with tools. Additionally, they were able to interact with items such as scrubs found in the room, which was modelled after the AUH robotic operating room, as shown in Figure 2.

The scenario simulated was chosen based on interviews with Jane Petersson. They were tasked with performing an emergency undocking procedure and converting to open surgery. An overview of roles and tasks during emergency undocking is shown in Figure 3.

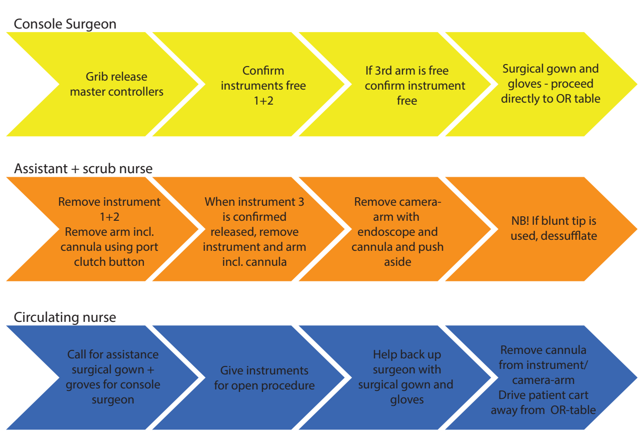


Fig. 3: Workchart showing the flow for each role regarding emergency undocking

This scenario was chosen since it enables training vital procedures that can be represented in VR with fair accuracy. According to Jane Petersson, these are the most important tasks to train since they are what trainees undergoing team training at MIUC usually struggle with the most. Additionally, it would allow trainees to practice emergency procedures in a safe environment. Each participant was randomly assigned a role matching one shown in Figure 3, and informed of their tasks.

The participants used an HTC Vive head mounted display (HMD) and motion controllers connected to a non-dedicated server hosted on computer A. Computer C was located in a separate room from computer A and B. The specifications of these computers are shown in Table II.

	Computer A	*Computer B*	*Computer C*
CPU	Intel Core i7-6700K	Intel Core i7-4770	x
GPU	Nvidia GTX 1080	Nvidia GTX 980	Nvidia GTX 980Ti
RAM	x	x	x

TABLE II: Specifications of the computers used

Prior to the test, participants were informed of the two actions they could perform, namely grabbing (using the HTC Vive controller's trigger) and teleporting (using the touchpad on the controller). Teleporting is important in VR since there is limited space to move around in the real world, and thus participants were also cautioned not to move outside the bounds shown in the world by poles. They were also informed about the possibility of VR sickness [cite XX] and that should it happen, they were to inform the observers and disengage from the system.

During the tests, participants' video feed were displayed on the computer monitors for observation. They were able to communicate in the room and through voice over IP (VoIP). In the event of system error or when participants forgot tasks, controls, or otherwise were confused, facilitators were present to assist.

After the test, participants were given a questionnaire. The questionnaire used in the usability test contained the System Usability Scale (SUS) and additional questions regarding age, gender, familiarity with VR, and XX. Following that, a short interview was held to ensure their experience matched the expectations of the test, primarily to ensure they understood the tasks. Participant performance was not observed.

An expert review was held after the usability test to assess the utility of the system qualitatively. This review is also done to determine if there are critical errors in the simulation. Jane Petersson and Johan Poulsen both participated in this interview after observing and trying the system themselves. The review followed a simple structure with a facilitator and an observer. The results from this review were used to determine the viability of the system in context.

III. Results

A system usability scale (SUS) was used to evaluate the usability of the system - gathering the subjective assessment of usability through a likert scale. The test included XX participants, with XX males and XX females. The SUS scored a general result of XX concluding that the interface was usable and understandable by the users. According to Bangor et al, if the results are higher than 7.3 the interface is concluded good whereas 8.5 and above is excellent cite[bangor empirical 2008].

An expert review was conducted with Jane Petersson and Johan Poulsen at CREATE Aalborg University. The simulation proved to be useful as the students are able to work with the robot and thus becoming familiar with it. However, the robotic movements did not exactly resemble those of the real version but proved to not be a primary factor of the simulation. As stated by Jane Petersson / Johan Poulsen "XX". "The simulation is useful for situation that otherwise would endanger human life."

A. System Usability Scale Results

The system usability scale (SUS) contains ten statements all related to the user experience that are scored from strongly disagree to strongly agree. These answers correspond to the numbers 0 to 4, and a final score is calculated using Equation 1.

$$\frac{(\sum_{n=1}^{10}\sum_{p=1}^{P} S)\cdot 2.5}{P} \tag{1}$$

where n is statement, p is participant number, P is number of participants, and S is score. It is multiplied by 2.5 to get a score between 0 and 100 to compare with as a percentile.

The first statement does not necessarily apply to most of the test participants as they can not expect to use the system again, however the authors decided the question was still relevant to gauge whether the participants enjoyed the experience.

The median score was 67.5, with the first quartile scoring 45 and the third scoring 86.25.

There were also X other questions following the standard SUS that were meant to gauge user familiarity and experience. These were concerned with age, gender, and familiarity with VR controls.

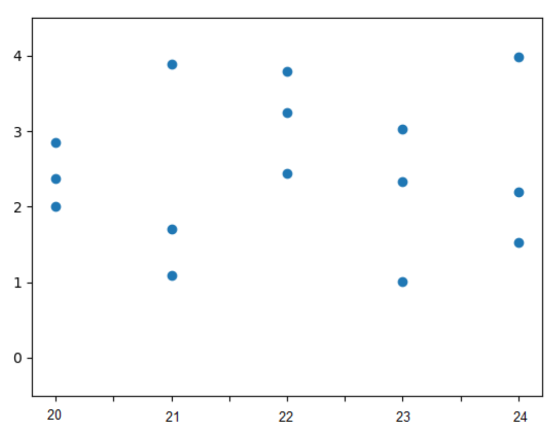


Fig. 5: Mean scores plotted as a function of participant age

Figure 5 shows the participants' scores plotted as a function of their age. Linear regression returns $y = 0.03x + 2.06$. R^2 returns value close to 1 (0.99). Mean scores from both genders were also close (3.01 and 2.99).

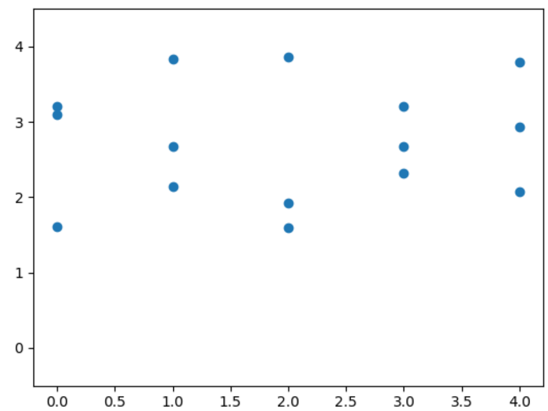


Fig. 6: Mean scores plotted as a function of participants' familiarity with VR tools

Finally, Figure 6 shows participants' mean scores plotted as a function of their self reported familiarity with VR. This question was to gauge whether participants had trouble with VR itself or the system, thus if there was an obvious learning curve for those inexperienced with VR and whether that affected their experience. Linear regression yielded $y = -0.05x + 3$, and R^2 returns close to 1 yet again ($R^2 = 0.89$).

IV. Discussion

The current system was made to test the viability of a fully implemented training simulation. The training sessions at MIUC focuses on certain key points such as communication, precision, and hands-on experience. However, implementing a system that is capable of simulating entire training scenarios where all these competencies are in focus is not possible with the available resources. As such, emergency undocking was chosen as it was deemed important for working with the da Vinci Surgical System as to not increase trauma risks for the patient.

The system was made for multiplayer use as communication and teamwork are key factors in successful surgeries. As observed in team training, it is important for trainees to know their tasks and roles of the rest of the medical personnel. Another important factor in the team training is to get familiar with the robot and increase ones time spent with it. As such, a single-player version of the simulation could be developed to allow for using the system without any other participants. Furthermore, having a single-player simulation would also allow the user to perform all the tasks required for surgery and thus learn the tasks of every member of the surgical team.

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References

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