Towards a robotic minimally invasive surgery assessment and augmentation platform for visual-haptic acuity development

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INTRODUCTION

Up to half of the technical errors made by surgical trainees result from improper tool forces on tissue [1]. This skill inadequacy is exacerbated in robotic minimally invasive surgery (RMIS) due to the perpetual technical barriers prohibiting robust haptic (touch) sensations in clinical RMIS systems. Expert RMIS surgeons have developed a unique skill, termed visual-haptic acuity, that enables them to visually estimate the absent haptic sensations [2]. RMIS experts have developed this visual-haptic acuity through years of repeated surgical practice, on real patient tissue. For current RMIS trainees, limitations on working hours and caseloads severely constrain practice with real patient tissue [3]. Given that skill gained in virtual reality simulation does not always transfer to the real world [4], there is a critical need for a focus on visual-haptic acuity development.

Previous research has shown that supplemental haptic feedback provided during simulation-based RMIS training helps surgical trainees to reduce their applied forces when completing RMIS training tasks [5], and that this effect is sustained even when haptic feedback is removed [6]. In addition, supplemental haptic feedback has demonstrated the potential to help RMIS trainees increase accuracy (reduce applied forces) while also increasing speed (reducing task completion time) during RMIS training [7]. Unfortunately, the benefits of supplemental haptic feedback have not been demonstrated beyond basic simulated training environments. Additionally, we lack validated objective methods for specifically assessing an RMIS trainee's ability to visually estimate haptic sensations when operating on real patient tissue.

In light of this need, we are developing a modular data acquisition and multimodality haptic feedback system (as shown in Figure 1) to catalyze visual-haptic acuity development for novice RMIS trainees. The system is capable of simultaneous acquisition of multiple time-stamped data streams from sensors internal and external to the RMIS platform and simultaneous feedback of various haptic cues in different rendering modalities. In our prior work [8], we demonstrated the efficacy of this system using an Intuitive da Vinci Si clinical robot. Here, we expand on this prior work to better understand how this system may be used for objective assessment of visual-haptic acuity during RMIS training, and real-time haptic feedback based on these assessments. We recorded surgical interactions between sensorized da Vinci instruments and an ex vivo porcine bowel as an intermediate and expert surgeon completed a simulated bowel running and knot tying task. Preliminary results highlight the difference in various kinetic metrics between intermediate and expert performance. When coupled to our haptic feedback devices, these measures can be used to both assess and augment tissue handling skill during training, which we envision will catalyze visual-haptic acuity development.

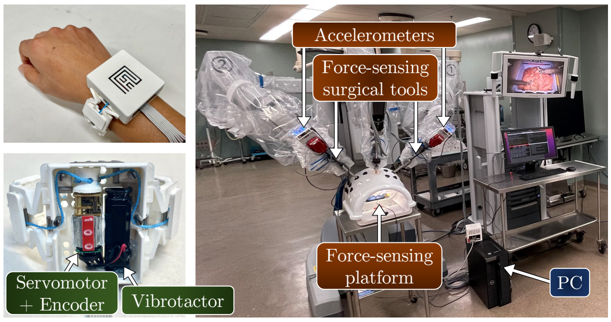

Fig. 1 Experimental setup featuring tactile actuators, da Vinci Si, external sensors, and PC.

MATERIALS AND METHODS

One experienced robotic surgeon (>50 robotic cases on human patients) and one certified surgical educator (intermediate skill level) were recruited for the experiment. Participants performed one trial each of two RMIS training tasks on an ex-vivo porcine bowel with a da Vinci Si robot: 1) bowel running task and 2) three extracorporeal single throws of a square knot. Both participants provided informed consent according to a protocol (IRB00205668) approved by the Johns Hopkins University Institutional Review Board. The experiment lasted approximately 15 minutes and participants were compensated $10 for their participation.

As shown in Figure 1, the da Vinci Si was augmented with our ROS-based haptic feedback and data acquisition framework for measuring instrument forces and vibrations, as well as the forces applied to the tissue. Two Endowrist Large Needle Drivers, sensorized

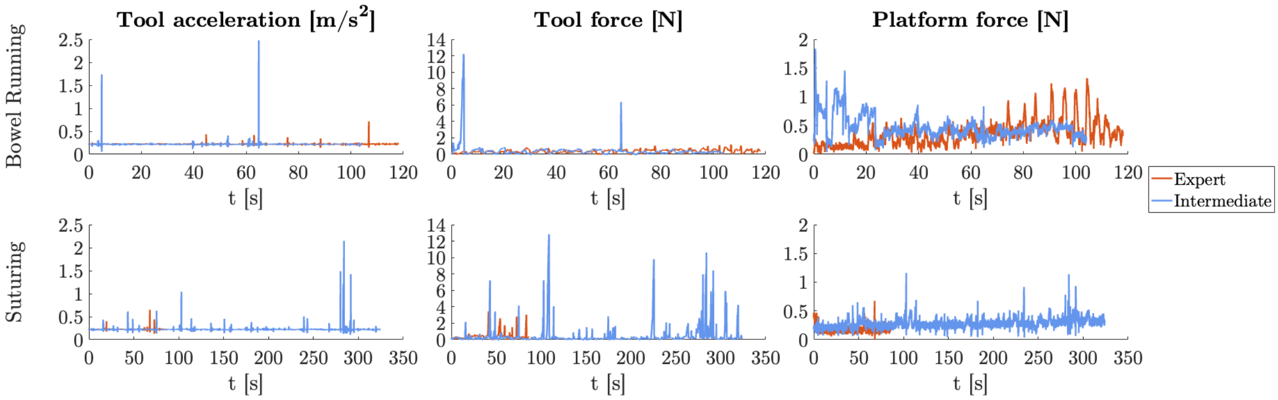

Fig. 2 Sample of kinetic signals captured by data collection system.

with transducer film (Forcen Inc., Canada), provided measurements of the mid-air forces (e.g., when pulling a suture). An instrumented platform containing an ATI Mini40 SI-40-2 F/T transducer provided measures of the forces applied to the surgical task materials by the instruments. Finally, two Arduino Nano RP2040 Connect microcontrollers mounted to the top of the left and right da Vinci tool arms measured the contact accelerations created by the instruments and the motion kinematics of the arm. All signals were published to individual ROS topics, time-stamped, and recorded to rosbags, as detailed in [8], using a PC (Dell Inc. Precision 5820) with an internal PCIe Sensoray 826 data acquisition board.

Our data collection system is also capable of measuring kinematic streams and recording stereoscopic video from the da Vinci Research API. For this manuscript, however, we will focus on the data recorded from our external sensors. Tool accelerations, tool forces, and platform forces are reported as the average measurement from both tools.

RESULTS

All average applied forces were lower for the expert surgeon than the intermediate surgeon. Tool accelerations were the same for both participants in both tasks. The task completion time was lower for the intermediate surgeon than the expert surgeon in the bowel running task, but much higher than the expert surgeon in the suturing task.

Figure 2 shows a sample of real-time kinetic signals collected during a trial, including tool forces, tool accelerations, and platform forces.

DISCUSSION

The results from this preliminary assessment clearly show differences in skill level between intermediate and expert skill level surgeons. While our expert surgeon produced less average force overall on the porcine bowel in both tasks, the intermediate surgeon completed the bowel running task faster. Here, the expert surgeon was likely more careful in performing the task at the cost of task completion time. Conversely, the intermediate surgeon completed the suturing task much slower than the expert surgeon, possibly because of the increased complexity and difficulty of suturing compared to bowel running. Finally, the average tool accelerations were likely the same across both participants and tasks because the participants both had a baseline level of surgical experience that precluded them from producing clearly different magnitudes of vibration with the tools, as might be the case when comparing against the performance of a surgical novice.

Improving the tissue handling skill of novice and intermediate surgeons to the level of expert surgeons will require a focus on developing their ability to visually estimate the haptic cues generated by their tool-tissue interactions (i.e., visual-haptic acuity). The data generated by our system will be vital for both assessing a trainee's visual haptic acuity as well as understanding the best way to augment it.

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