9-30-2018

Competence Assessment and Automated Feedback for Ultrasound-Guided Intervention Training

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Date of Report: September 30, 2018

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1. Narrative

Introduction

There is an ongoing shift in the medical education community from a time-based model of medical education to a competency-based model. In the competency-based model, trainees' performance must be continually monitored. But due to constraints on expert scheduling, this is infeasible for expert preceptors. Moreover, despite the advent of structured assessment rubrics, expert assessment remains subjective. This motivates the development of automated assessment methods. This can be complemented by methods for automatic feedback and instruction, which can be used to improve the training process and acceleration learning curves without the presence of an expert preceptor.

Ultrasound-guided interventions are particularly challenging for trainees to learn. They require simultaneous manipulation of the ultrasound in coordination with another tool. All while the operator must interpret a noisy 2D ultrasound image and mentally reconstruct it back into 3D. This means that ultrasound-guided interventions are of interest for competency-based medical education, and thus, automated assessment and feedback methods.

In consultation with clinical experts, it is imperative that assessment and feedback methods must be clinically driven, not empirically driven. That is, the methods should incorporate domain knowledge based on clinical expertise and use that as a basis for the assessment and feedback. The assessment and feedback methods should be both transparent and configurable. This allows trainees to understand their assessment, interpret the assessment into actionable feedback, and it allows the expert preceptors to adjust the assessment to their particular setup or to emphasize particular skills.

Results

Contribution #1:

We developed a framework for identifying from a set of performance metrics in an ultrasound-guided intervention, which performance metrics carried unique information about skill. This framework accounts for the group-wise differences and information gains association with each performance metrics to determine metric validity. Subsequently, exploratory factor analysis is used to eliminate redundant metrics. This leaves a unique set of metrics which each carry unique information about performance. Using domain knowledge, it is possible to understand which facet of the intervention each metric assesses. The proposed methods were validated retrospectively on three ultrasound-guided intervention datasets, and it was found that overall proficiency assessment was largely unaffected by the removal of unnecessary metrics. In all cases, it was identified that application-specific metrics have added value, but that some system complexity may be reduced by eliminating redundant metrics.

Contribution #2:

We have developed two new methods for skills assessment that are both transparent and configurable. One is based on decision trees and one is based on a set of fuzzy rules, both weighted according to feature importance identified through domain knowledge. Through retrospective validation on two ultrasound-guided needle insertion datasets, it was found that the proposed method based on decision trees, when augmented by domain knowledge, outperformed standard skill assessment approaches. Furthermore, the feedback provided by this transparent method was rated to be useful by experts. This demonstrates the utility of clinician driven approaches to skills assessment.

Contribution #3:

We developed a setup that incorporated the use of eye-gaze tracking technology into assessment for ultrasound-guided needle insertion. This allowed us to monitor, in real-time, what objects an operator is looking at during the intervention: the ultrasound probe, the needle, the tissue, the ultrasound screen, or the 3D visualization. We found that gaze patterns significantly differed between trainees and experts. This indicates that eye-gaze patterns may be an important indicator of surgical skill and could be used as a tool for monitoring performance.

Contribution #4:

We developed methods for objectively assessing technical proficiency in ultrasound-guided breast lumpectomy. This work attempted to validate whether our proposed methods could be extended to interventions other than needle insertions. We identified a set of generic and application-specific performance metrics and monitored several groups of participants. Indeed, our proposed automatic assessment methods were able to distinguish novices from intermediates from experts and correlated with scores on structured assessments performed by preceptors. This provides evidence of validity for the proposed methods in soft-tissue resection.

All the above work has been implemented into Perk Tutor (www.perktutor.org), an open-source platform for image-guided interventions training. This makes it readily available for medical educators and researchers to implement into a competency-based curriculum.

Significance and impact

All this work makes progress towards automated assessment and feedback in medical education. We have shown that our automated assessment methods can reliably discriminate operators of different skill levels. We have shown that our feedback methods are useful for improving trainee learning curves. In combination, this will be a useful tool for many medical education centers as they transition to a competency-based model. By making these tools available for free through an open-source platform, it lowers the barrier for adoption.

Where might this lead?

My future vision is that this work leads to more independent and self-guided practice for medical trainees. Trainees can come into the simulation lab on their own time, practice their skills on a simulator, track their own performance over time, receiving instruction as they perform the interventions, and receiving targeted feedback automatically at the end of each attempt. Subsequently, once the trainee and the training system believe the trainee is ready, the trainee may then have their performance truly assessed by an expert preceptor in combination with the simulator. By having self-guided training, scheduling burdens are reduced for expert preceptors, and objectivity in assessment is increased.

In the shorter term, we hope to implement self-guided training stations at several locations within Queen's University at its associated teaching hospitals through collaboration with clinicians. We hope to deploy a self-guided spinal anesthesia training station and a self-guided central venous catheterization training station just outside the operating rooms, so that trainees may engage in "just in time" practice. Furthermore, we hope for continued collaboration with the organizers of the Surgical Skills Technical Education Program, to deploy our system for training medical students in the basics of ultrasound-guided interventions.

2. How did the fellowship make a difference?

The Link Foundation Fellowship really allowed me to fully devote my time to my research vision and it permitted me the freedom to pursue the research questions that I was interested in. It allowed me to pursue more fundamental research in building a framework for skills assessment and feedback for ultrasound-guided interventions. Furthermore, it has allowed me to foster collaboration with several leading researchers in surgical performance modelling throughout the world.

3. Future Plans

At present, I am finishing my doctoral dissertation entitled "Computer-Assisted Assessment and Feedback for Image-Guided Interventions Training". I aim to defend my doctoral dissertation in Fall 2018. I am starting a postdoctoral fellow position at Johns Hopkins University in the Malone Center for Engineering in Healthcare. This work will continue my research in assessment and training for image-guided interventions for new clinical applications. As a postdoctoral fellow, I will continue to develop my analytical skills in simulation-based training and assessment for interventions.

4. Publications, Presentations, and Other Outputs.

The following journal articles or conference presentations were published or presented:

Caitlin T. Yeo, Justine Ring, **Matthew S. Holden**, Tamas Ungi, Gabor Fichtinger, Boris Zevin, "Validation of Surgery Tutor for Assessment of Technical Proficiency in Soft-Tissue Tumour Resection," Canadian Surgery Forum (Sep 2018

David Garcia-Mato, **Matthew S. Holden**, Andras Lasso, Adam Szulewski, Javier Pascau, Gabor Fichtinger, "3D Gaze tracking for skill assessment in ultrasound-guided needle insertions," 32nd International Congress and Exhibition of Computer Assisted Radiology and Surgery, Supplement 1, S52-S53 (Jun 2018).

Matthew S. Holden, Hillary Lia, Sean Xia, Zsuzsanna Keri, Tamas Ungi, Gabor Fichtinger, "Configurable Overall Skill Assessment in Ultrasound-Guided Needle Insertion," 16th Symposium Imaging Network Ontario (Mar 2018).

Matthew S. Holden, Zsuzsanna Keri, Tamas Ungi, Gabor Fichtinger, "Objective Proficiency Assessment in Point-of-Care Ultrasound Interventions: The Stopwatch is not enough," MICCAI Workshop on Point-Of-Care Ultrasound (Sep 2017).

The following journal articles or conference presentations are in preparation, in submission, or to appear:

Matthew S. Holden, Sean Xia, Hillary Lia, Zsuzsanna Keri, Colin Bell, Lindsey Patterson, Tamas Ungi, Gabor Fichtinger, "Transparent and Configuable Machine Learning for Automated Technical Skills Assessment in Ultrasound-Guided Interventions," Manuscript in Preparation.

Matthew S. Holden, Zsuzsanna Keri, Tamas Ungi, Gabor Fichtinger, "Computerized Skills Assessment in Freehand Interventions: A Review," Manuscript in Preparation.

Caitlin Yeo, Justine Ring, **Matthew S. Holden**, Tamas Ungi, Ayca Toprak, Gabor Fichtinger, Boris Zevin, "Surgery Tutor for Computational Assessment of Technical Proficiency in Soft-Tissue Tumor Resection in a Simulated Setting," Journal of Surgical Education (submitted).

Justine Ring, Caitlin T. Yeo, **Matthew S. Holden**, Tamas Ungi, Gabor Fichtinger, Boris Zevin, “Surgery Tutor for Assessment of Technical Proficiency in Open Soft-Tissue Tumour Resection: A Validation Study,” International Conference on Residency Education (Oct 2018).