Proceedings of the 2020 Winter Simulation Conference
K.-H. Bae, B. Feng, S. Kim, S. Lazarova-Molnar, Z. Zheng, T. Roeder, and R. Thiesing, eds.

DYNAMIC DATA-DRIVEN SIMULATION-BASED DECISION SUPPORT SYSTEM FOR MEDICAL PROCEDURES

Saurabh Jain

Systems and Industrial Engineering
The University of Arizona
Tucson, AZ 85721, USA

ABSTRACT

Medical procedures require high precision and accuracy under circumstances involving time and situational uncertainties. Hence, the caregivers are to possess higher cognitive and technical skills to perform complex operations in a timely and appropriate manner. Thus, it poses a need to provide a system that can provide effective training, personalized objective assessment, and appropriate decision support to make rapid progress throughout the process of overcoming steep learning curves. This work proposes a dynamic data-driven simulation-based decision support system for medical procedures, which can address aforementioned challenges. We aim to address three key research objectives: (a) design and develop a high-fidelity physics-based simulation environment, (b) provide online proficiency assessment to generate real-time personalized feedback for trainees, and (c) formalize the taxonomy for representing behaviors of caregivers under time and situational uncertainties. The proposed work has been effectively implemented and validated using numerous experiments comprising expert and novice users.

1 INTRODUCTION

Recent advances in the Virtual reality (VR) technology are creating new opportunities for design and development of advanced healthcare systems. The advent of VR has brought a paradigm shift by providing effective methods of procedural planning and training, and subsequently showing significant improvements in patient safety and postoperative outcomes. It provides a high fidelity immersive simulation and photorealistic visualization to practice on difficult patient specific cases. Minimally invasive procedures are gaining traction and becoming the standard of treatment for healthcare procedures. However, these procedures follow different protocols in comparison to the invasive procedures (e.g. open surgeries). These minimally invasive procedures require caregivers to cope up with a variety of challenges including restricted movement, visual field-of-view, effective coordination between hand and eye, and evolution in medical equipment. This work focusses on utilization of VR-based interventions into two different applications viz. surgical procedures (Functional Endoscopic Sinus Surgery (FESS)) and Emergency procedures (Airway management) to provide real-time decision support.

2 METHODS

This section provides an overview of methodologies for three distinct objectives of the proposed work.

2.1 Design and Develop a High-fidelity Physics-based Simulation Environment

The first objective of the proposed work is to design and develop a system to provide trainees the immersive experience of the realistic operating room, handling of real surgical tools, and patient-specific anatomical structures. The system design phase is comprised of developing high-fidelity CAD models for patient-specific anatomical structures (e.g. CT-scans, MRI scans) and commercially available medical equipment (design documents). Modeled anatomical structures and medical equipment are 3D-printed to provide the realistic haptic feedback based on physical interactions between them. Subsequently, high-fidelity physics-based simulation was developed using Unity 3D, and the virtual procedural tools and anatomical structures were overlaid on their physical counterparts which were tracked using HTC Vive system (Barber et al. 2018; Jain et al. 2020)

2.2 Online Proficiency Assessment

This work utilizes the hierarchical task analysis (HTA) to decompose procedural tasks into three levels of hierarchy: procedural, task, and surgeme levels. Each level provides metrics at different abstraction levels to provide the effective performance evaluation of the trainee. The analysis of real-time continuous stream of data is performed in two phases: (a) time-series analysis using dynamic time warping, and (b) classification using decision tree C5.0. The adaptive feedback system adjusts the fidelity of simulation cues based on the proficiency level of the current trainee.

2.3 Formalization of Taxonomy

The proficiency level of caregivers (Experts vs. Novice) has high variability in many aspects such as decision-making skills, behaviors, and motor skills based on varying practical experiences, intuition, and knowledge. Therefore, a formal taxonomy to represent these varying behaviors using the principles of naturalistic decision-making has been devised. This taxonomy will provide timely decision support to different groups of caregivers under different situations during the procedure.

3 RESULTS

Preliminary experiments were conducted with the proposed approach (Figures 1 (a), (b), and (c)) to validate the classification of trainee's performance based on defined metrics. The surgical proficiency of 48 subjects (24 Experts, and 24 novices) with different styles of surgical movements and expertise were used to compare with the approximate motion trajectory of three expert surgeons. Figure 1 (d) shows classification results that identify the top 3 features that serve as the basis for classification (top), classification accuracy (middle), and confusion matrix (bottom) of the surgical proficiency.

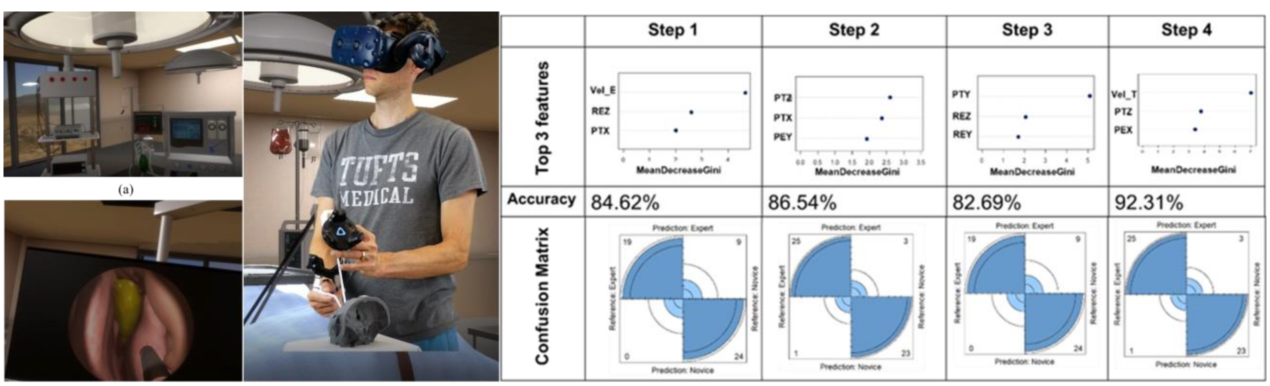

Figure 1. (a),(b), and (c) Overview of the proposed VR-based training system for FESS. (d) classification results: Top 3 features (top), Classification accuracy (middle), and Confusion matrix (bottom)

REFERENCES

Barber, S. R., S. Jain, Y. J. Son, and E. H. Chang. 2018. "Virtual Functional Endoscopic Sinus Surgery Simulation with 3D-printed Models for Mixed-reality Nasal Endoscopy". *Otolaryngology–Head and Neck Surgery* 159(5): 933-937.

Jain, S., S. Lee, S. R. Barber, E. H. Chang, and Y. J. Son. 2020. "Virtual Reality based Hybrid Simulation for Functional Endoscopic Sinus Surgery". *IISE Transactions on Healthcare Systems Engineering* 10(2):127-141.