Multi-modal Objective Skill Assessment in Transoesophageal Echocardiography

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Abstract. This paper presents an approach to develop a more elaborate, accurate and comprehensive autonomous skill assessment system for Transoesophageal Echocardiography (TOE). In our investigation, we intend to combine data from various sensor modalities (TOE simulator, eye-tracking glasses, finger flexion sensors). By deriving combinatorial features we expect to capture the intrinsic hand-eye coordination and manipulation characteristics required for performing TOE, and facilitate the development of a novel TOE skills assessment and performance evaluation system. Initial kinematic analysis is indicative of the different probe navigation patterns exhibited by expert and novice interventionalists.

1 Background

Transoesophageal echocardiography (TOE) is an integral part of cardiovascular interventions, as a diagnostic and/or a monitoring modality. It is carried out by imaging the heart with an ultrasound (US) transducer, attached to the tip of a flexible endoscope, navigated through the oesophagus in the area just behind the heart. TOE provides comprehensive images of the four chambers and the valves, enabling detailed and accurate diagnosis/monitoring. In the previous decades, the use of TOE has increased dramatically, and today it is routinely performed for diagnosis, management of anaesthesia and surgical evaluation.

In order to facilitate the widespread use of TOE, professional and accreditation organisations have routinely published and updated guidelines and recommendations regarding training practices as well as the cognitive and technical skills required for performing TOE [2]. In summary, physicians that perform TOE at any level must demonstrate proficiency in: (a) navigating the US probe safely, without exposing adjacent tissue to danger, through the oesophagus; (b) adjusting and controlling the scanning plane in such a way so as to obtain the necessary imaging and Doppler data; (c) accurately evaluating the heart's functionality and recognizing various abnormal conditions. Clearly, (a) and (b) refer to technical manipulation skills while (c) to cognitive abilities.

Training to develop such skills is critical to patient safety and ensuring procedure efficacy. However, because of reduced working hours policies, resident trainees do not

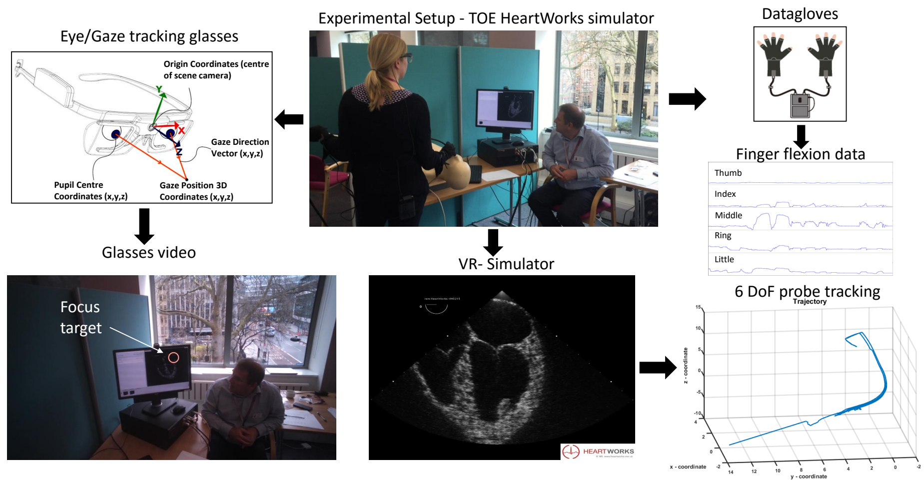


Fig. 1. The experimental setup. Left: Eye-tracking glasses (top) and obtained video with eye-focus target (bottom); Middle: A volunteer completing the test under supervision (top) and simulator's US screen (bottom); Right: Dataglove and finger flexion data (top two) and 3D trajectory of the probe's tip (bottom)

get enough exposure to clinical activities so as to develop their technical skills. In addition, the traditional method, of expert supervision, for evaluating surgical expertise is inefficient and cost-ineffective in terms of the amount of hours specialists must spend to evaluate and provide feedback to trainees. Both these issues pose impediments in the training process of new surgeons/radiologists and demand alternative directions for training and assessment to be explored. The proposed work aims at developing an autonomous objective skill assessment system for TOE.

2 Research approach

As an image-guided procedure, TOE requires complex phsychomotor skills and a high level of hand-eye coordination. Interventionalists must be able to interpret the US images, deduce the position and orientation of the scanning plane in the anatomy and make necessary adjustments using hand controlled knobs and buttons. Motivated by recent studies in skill analysis for minimally invasive procedures that show a good correlation between the level of surgical experience and the manipulation of surgical tools [1, 3], we posit that the motion analysis of the TOE probe can provide similar discriminative features that can be used for objectively assessing performance in TOE. Moreover, we believe that by employing additional sensing modalities, data representative of the hand-eye coordination exhibited during TOE can be formulated leading to more elaborate performance evaluation.

2.1 System

Breakthroughs in computing enabled the developed of virtual reality (VR) systems that simulate the operational environment and provide a platform for trainees to develop primarily their technical dexterous skills. In this work we will use the HeartWorks TOE simulator (Inventive Medical, Ltd, London, UK) as our experimentation platform. This system offers a realistic environment that also involves an upper-body mannequin with a mouth opening to emulate probe insertion. The HeartWorks probe has similar shape, dimensions and controls (flexion, rotation, angulation) as standard TOE probes. Dedicated software simulates the operation of the heart (either normal or abnormal) and visualises the US image according to the position/orientation of the scanning plane. This software also provides kinematic information of the probe's tip (position, depth and orientation). To evaluate hand-eye coordination, we will compliment the simulator tracking data with eye-tracking and gaze focus information, obtained from the Tobii Pro Glasses 2 (Tobii AB, Stockholm, Sweden) eye-tracking system and with finger flexion data, from the 5DT Data Gloves (5DT Technologies, Pretoria, South Africa). Such heterogeneous sensing modalities are unexplored thus far in surgical skill analysis and present the potential to expand the area of TOE technical skills assessment.

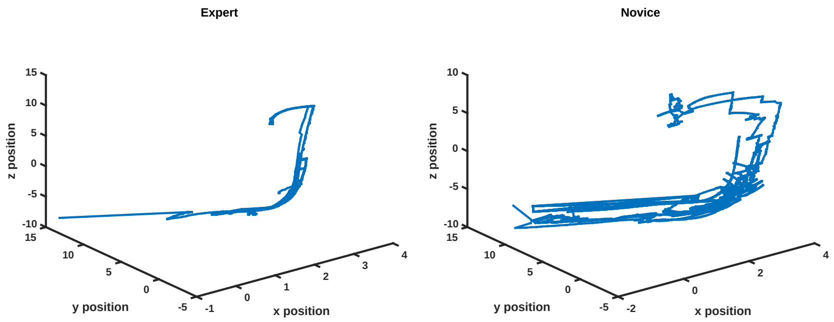
A series of experiments with both expert and novice anaesthetists/ radiologists took place recently. Each participant was asked to complete a predefined examination/ test comprising the acquisition of 10 standard US image planes, used thoroughly in TOE training and visualising different parts of the cardiac anatomy. Participants wore the eye-tracking glasses and data-gloves sensors while operating and expert anaesthetists manually assessed the performance of each participant using an OSATS-based grading scale for TOE. An illustration of the experimental setup is given Fig.1.

3 Preliminary data analysis and results

To visualise the differences in the probe handling between the users of the two experience groups, Fig.2 illustrates the 3D trajectory of the US tip, during a test performed by an expert and a novice. It is evident that the expert navigates the probe in a smoother more economical way than the novice. To quantify these differences, standard kinematic features like speed, acceleration, and total path length were extracted from recordings of 7 expert and 12 novice volunteers. In the Heartworks simulator the user controls the insertion depth and orientation (twist) of the probe and this information was used in our preliminary kinematic analysis. The nonparametric Mann-Whitney U test was used to test statistical significance. Median values and p-values are listed in Table 1, from where we observe that significant differences ($p<0.05$) are exhibited for every parameter apart from the total path length travelled.

4 Discussion

Preliminary investigation shows statistically significant differences appear in the kinematics of the TOE probe between the two groups. Our analysis will be augmented by the eye-tracker data that localise the gaze focus in the field of view of the operator



(a) (b)

Fig. 2. Example probe tip trajectories of an expert (a) and a novice (b) during experimentation.

Table 1. Median Values and p-values of the calculated features

Parameter	Novices	Experts	p-value (MW)
Total time (sec)	439.9	226.2	0.0007
Depth path length (m)	2.838	2.509	0.482
Average depth velocity (m/s)	0.007	0.009	0.0004
Average depth acceleration (m/s^2)	0.240	0.304	0.009
Average twist (deg)	18.8	11.9	0.0004

and the finger flexion information. Additional metrics, such as the amount of time (or percentage of time) that operators have their focus fixed on the imaging screen will be derived. At the second stage of the analysis, combinatorial features from all datastreams will be formulated. Such an approach of combining heterogeneous information from multiple sensors has yet to be reported for surgical skills assessment and presents an interesting challenge. Ultimately, the most representative features will be employed to formulate an autonomous scoring system for performance evaluation. Validation will be completed through comparison against manual evaluation scores.

References

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