Feasibility of a Low-Cost Instrumented Trocar for Universal Surgical Procedure Analyses[1]

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1 Background

The current path to become a surgeon follows the Halstedjan model of apprentice-style training, in which a resident remains under the shadow of a senior surgeon [1,2]. The resident starts by observing the surgeon and then gradually moves on to assist him. Though the process provides immediate mentor feedback through one-on-one interaction, it fails to carry out a systematic and consistent evaluation. All of the assessment is based on a senior surgeon's subjective appraisal. Moreover, the requirement of performing a real procedure under the supervision of an experienced surgeon puts extra financial pressure on the medical school curriculum [2]. The advent and advancement of minimally invasive surgery (MIS) have made mastering such skills even more difficult, particularly psychomotor. Due to the increased complexity in required surgical skills and due to a need for a more consistent and systematic evaluation, there has been an increasing demand for an objective assessment of surgical skill.

Studies in the past have examined motion analyses of surgeon's hands and tool with a structured checklist to conclude that the motion analyses can serve as one of the measures for objectively assessing surgical skill [3]. A considerable amount of work has been done in the past to develop systems for tracking minimally invasive surgical tools. However, there does not exist a system that can be easily deployed to all three environments, i.e., virtual reality, physical benchtop, and operating room (OR). Most of these systems are only applicable to either virtual reality or physical benchtop training environment. There is only one system, Waseda bioinstrumentation 3, that can be applied in the OR. However, even that system is not validated yet and has an intrusive setup. Moreover, these systems can be very expensive with the average price ranging from $20,000 to $30,000. Hence, there is a strong need for a low-cost, noninvasive means to quantitatively discriminate surgical skill in a manner universally applicable to all environments and various surgical modalities like robotic, laparoscopic and endoscopic surgeries. This work presents the feasibility of such a system. Notably, we evaluate the feasibility of jerk cost as a low-cost alternative to skill evaluation. We hypothesize it can discriminate skill without expensive position tracking.

[1]Accepted and presented at the Design of Medical Devices Conference (DMD2014), Minneapolis, MN, April 7–10, 2014.
DOI: 10.1115/1.4027081
Manuscript received February 21, 2014; final manuscript received March 3, 2014; published online July 21, 2014. Editor: Arthur G. Erdman.

2 Methods

Psychomotor skill is one of the most fundamental of all minimally invasive surgical skills. While it presents only a portion of the necessary, broad skill set a surgeon must master, it remains indispensable since no trainee can safely and proficiently perform a surgery if he lacks this critical skill. Therefore, methods were developed to track and assess psychomotor surgical skill. Tool motion analysis was chosen as the method for skill evaluation metric based on its usage in existing systems and the evidence of its relation to the surgical skill in the literature [3].

For the purpose of tracking position, two nine-axis inertial measurement units (IMUs) were selected. One was the Invensense 9150 (Cost: $199; InvenSense, San Jose, CA), while the second was the Phidgets 1056 (Cost: $125; Phidgets, Inc., Alberta, Canada). A trocar clip and a tool clip, as shown in Fig. 1, were designed, 3D printed, and assembled to attach these sensors to the tool. The trocar was selected for this purpose based on its mandatory presence in every MIS surgery and because if the sensor is placed on the trocar instead of the tool, it witnesses less unwanted linear acceleration during position tracking. The position tracking capability of the sensor was divided into 2D and 3D tracking accuracy. The trocar clip and the custom made tabletop calibration jig were used to determine the 2D accuracy of each sensor. The Invensense IMU turned out to be not only more accurate but also capable of tracking tool roll based on its ability to stream data in quaternions: four-element vectors that robustly indicate orientation in 3D space. The tool roll in this case is defined as the tool's rotation along the axis that runs through the center of the tool along its length.

For 3D tracking accuracy, as shown in Fig. 2, IMU sensors were mounted onto the electronic data generation for evaluation (EDGE) simulator. The EDGE simulator was chosen because it comes with a calibration block, which was used as the reference trajectory for analyzing sensor's 3D accuracy.

The fundamental of laparoscopic surgery (FLS) modules were employed via EDGE in this study. FLS is an evidence-based laparoscopic surgical skill program designed for training and evaluation of surgical trainees. For this experiment, two IMU sensors were mounted on the EDGE system, as shown in Fig. 2, to measure the jerk during the peg transfer FLS task. Three subjects, including the lead author, with different levels of MIS skills were

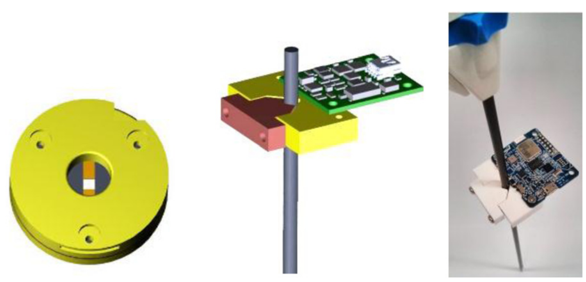

Fig. 1 Trocar clip (left) and tool clip (middle and right)

Fig. 2 EDGE laparoscopic tracking system (left) and peg transfer task close-up (right)

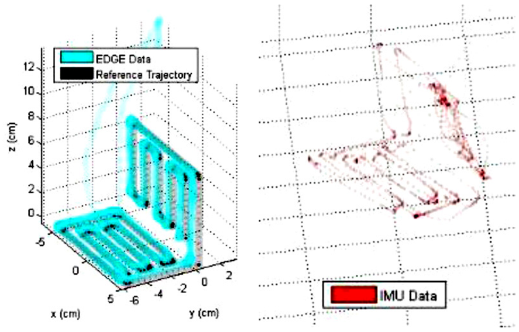

Fig. 3 3D path of a single reference block trace given by EDGE (left) and the IMU (right)

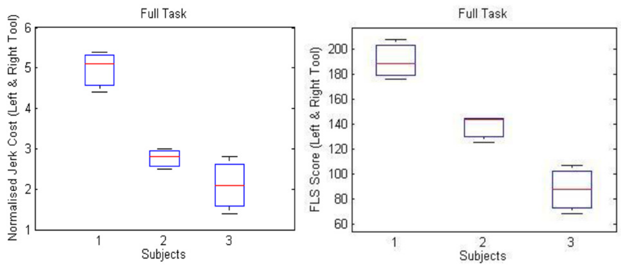

Fig. 4 Jerk and FLS score from both hands for full task

chosen to perform the peg transfer task. Subject 1 being the third year MIS surgery fellow was the most skilled among all, while subject 3 executing an MIS procedure for the first time was the least skilled among all. Each subject repeated the task three times. Total jerk for each subject was compared against the FLS score. Jerk cost, as shown in Eq. (1), was used to estimate the total jerk that according to Hogan directly relates to the smoothness in the human reaching motion [4]. Equation (2) was used to calculate the FLS score, where *time* refers to the total time for the task and *total drops* represents the number of times a peg was dropped

$$\text{Jerk cost}: \int_{t_0}^{t_f} \dddot{x}(t)^2 dt \tag{1}$$

$$\text{FLS score} = 300 - \text{time} - 17(\text{number of drops}) \tag{2}$$

3 Results

As shown in Fig. 3, the IMU provides poor 3D tracking of position compared with EDGE. This demonstrates that IMU is not suitable for measuring high-precision, position-derived skill metrics as expected.

The results of jerk cost and FLS score from both hands of each subject for all three tasks were averaged and shown in Figs. 4 and 5. Figure 4 takes into account the whole task, while Fig. 5 only accounts for the first 45 s of the task.

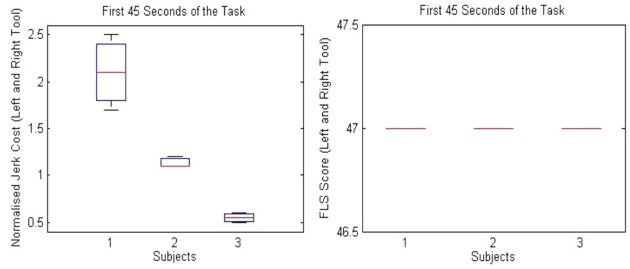

Fig. 5 Jerk and FLS score from both hands for first 45 s of the task

It is observed in the jerk plots that the average jerk cost for each subject is different from one another. Hence, the jerk cost can potentially be used as a metric for discriminating MIS psychomotor skill.

4 Interpretation

This research presented and specified the design of an inexpensive MIS skill evaluation system comprising an instrumented trocar and a method of safely collecting data during a live MIS surgery to be used for assessing surgical skill. Jerk cost as a skill-relevant metric was explored. The results demonstrate, contrary to the expectations, that the most skilled person had the highest jerk cost while the least skilled had the lowest. According to Hogan, a minimal jerk trajectory in many ways is optimal, providing the smoothest movement while also agreeing with the experimental analyses of a typical skilled human reaching motion [4]. As shown in Fig. 5, when the data were analyzed only for the first 45 s of the task, the FLS score came out to be equal for all three subjects while the jerk cost still remained different. Regardless of the method of data collection, this capability gave jerk cost additional advantage over the traditional FLS scoring method.

In conclusion, this study motivates further research and shows that the jerk cost should not be ruled out as a skill-relevant metric. More experiments are required before a statistically conclusive verdict can be reached on the generalizability of the jerk cost as the relevant skill-relevant metric for skill evaluation. This data collection is currently under way with subjects having a wide range of skill level.

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