Critical Paper Review
Computer Integrated Surgery II
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Paper:
Title: Review of methods for objective surgical skill evaluation
Authors: Carol E. Reiley, Henry C. Lin, David D Yuh, Gregory D. Hager

Project Background:
Title: Surgical Skill Evaluation in Endoscopic Sinus Surgery.
Goal: Mathematically model various surgical movements in an endoscopic sinus surgery from the motion of the endoscopic tool tip through the surgical procedure.

Relevance of the paper to this project:
This paper provides a great background and a very good starting point for anyone interested in evaluating surgical skills. This paper shows how motion analysis is a useful measure of surgical skill evaluation, talks about different ways to capture motion in a surgical procedure and discusses a wide variety of methods that have been used to build an evaluation model and how they compare with each other.
My project is surgical skill evaluation for endoscopic sinus surgery, which is a minimally invasive kind of surgery. This paper gives an idea of what would be a good measure for surgical skill evaluation for this surgery and what kind of tracking method would allow me to capture useful information. Finally, it gives me an idea of what kind of data modeling method should be tried in my specific case and provides a brief introduction to the method and a reference to look for in order to implement it.

Summary of the paper:
In this paper, authors discuss the history of surgical skill evaluation, how it has evolved over the years, what is the current state of art and compare the current methods in surgical skill evaluation.
In figure 1, the performance of an expert surgeon in a 4 throw suturing task is compared to the performance of an intermediate surgeon. This figure clearly shows that the plot on the left has more clearly defined actions, an efficient use of workspace and throws are very distinct.

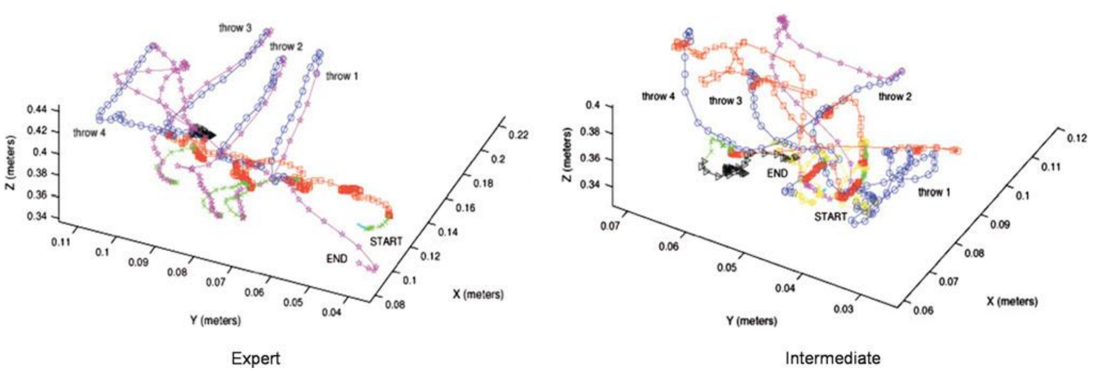


Fig. 1 Comparison - Expert Surgeon vs. Intermediate Surgeon

[C. Reiley, H. Lin, D. Yuh, and G. Hager, "Review of methods for objective surgical skill evaluation," Surgical Endoscopy, pp. 1-11, 2010.]

This also gives an idea that computationally modeling of motion analysis looks a very promising measure for surgical skill evaluation. The authors also discuss an intuition that motor skills are learned over time and improves with practice.

Data collection Methods

In order to evaluate motion, we need good data collection methods. The skills required for an open surgery are different that those required for minimally invasive surgery. Brief overview of the different kinds of surgical procedures and the corresponding data collection methods discussed in the paper are as follows:

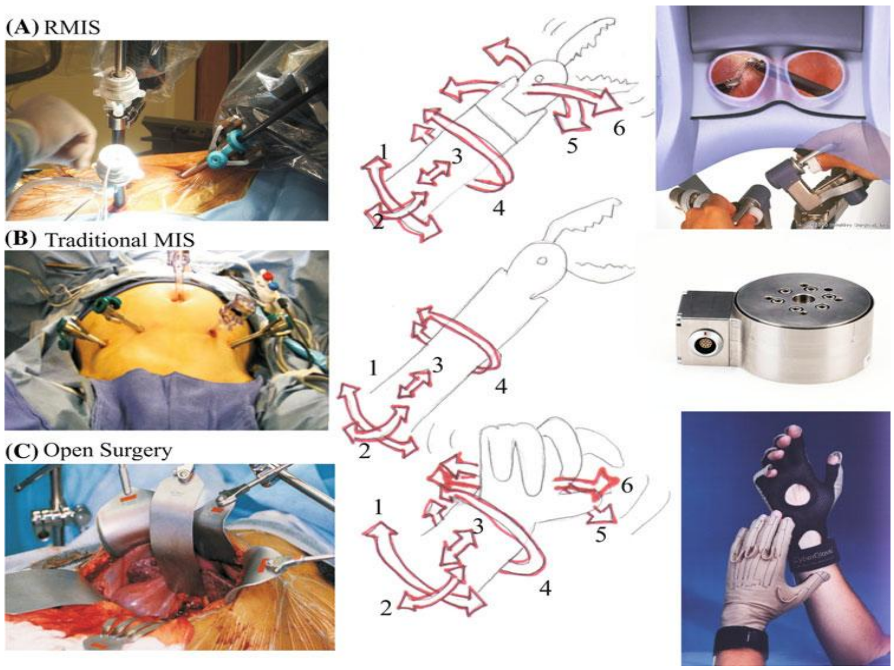


Figure 2. Different surgical procedures and the various motion information available in each of them

[C. Reiley, H. Lin, D. Yuh, and G. Hager, "Review of methods for objective surgical skill evaluation," Surgical Endoscopy, pp. 1-11, 2010.]

Open Surgery:

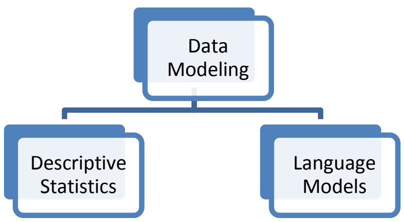
In this procedure, the surgeon can freely work with many different tools. Thus the hand motion of the surgeon is tracked in this procedure using a wireless data glove, to capture all the 23 degrees of freedom of motion.

Minimally Invasive Surgery:

In this procedure, the surgeon works with the target region using specialized laproscopic instruments. This limits the freedom of motion of the tool being operated by the surgeon and the view of surgeon is restricted to monocular view. Different kinds of Trackers are used to track the motion of the tool by attaching a rigid body to the endoscope or by using other methods.

Robotic Minimally Invasive Surgery:
In this procedure, surgical robots like Intuitive Surgical's da Vinci surgical system are used.
Using these systems allows the surgeon to regain more degrees of freedom than Minimally invasive surgery. These systems are capable of providing velocity and position of information for all the joints, stereoscopic video, etc. The motion is captured using the information from the system.

Data Modeling:



Descriptive Statistics: In this method of data modeling, descriptive statistics on velocity, position and in some cases, torque and force is provided in real time to the user. The authors discuss that studies have shown that this method is good for an individual to improve his surgical skills but not good enough to differentiate an expert from a novice.

Language Models: This method is analogous to forming a dictionary of different words in particular language and the efficiency of a speaker is analyzed in how well his pronunciation of these words are. In this case, the different words are the different surgical movements and the pronunciation corresponds to the skill or the efficiency of the surgeon is conducting these movements.
The Language models can be formed at three different levels:

1. Procedure Level: This includes the complete surgical intervention. This model would be able to provide effectiveness of the surgical procedure but will not be able to comment on the surgeon's skill level.
2. Task Level: This includes different tasks in a surgical procedure like Suturing or Dissection.
3. Surgeme Level: This includes subtasks like needle insertion, position needle, reach for the needle, etc.

In the next section the authors discuss the different methods that have been implemented to model the surgical skills at both the task and subtask (surgeme) levels. Different segmentation techniques have been used by different groups.

Segmentation methods:
Manual Segmentation: In this type of segmentation, experts annotate the data from the surgical procedure manually into different tasks. Each of these annotations now form a feature vector of the complete position/velocity, etc. during the procedure. In order to reduce the dimension of this feature vector, most of the groups used vector quantization.

Automatic Segmentation: Here the tasks are automatically segmented based on supervised learning from available training data, and then using LDA to perform discriminative dimensional reduction and then Bayes classifier is used for classification.

Different type of modeling techniques used by various groups:

Hidden Markov models: In this technique, each of the surgeme/subtask is regarded as a state in the model, the emission would be the feature vector emitted for that particular subtask and the hidden markov models are trained for each of the expertise in the surgeons. After this, when a new series of surgemes is presented, each of 3 models are tested against it and the model with maximum log likelihood wins.

Accuracy Results reported in

[C. S. Hundtofte, G. D. Hager, and A. M. Okamura,"Building a Task Language for Segmentation andRecognition of User Input to Cooperative ManipulationSystems," 10th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2002, pp. 225-230.]

- 84 % in a simulated needle task.
- 90% in a simulated retinal peeling task
- 97% for classification accuracy

Sequence matching: In this technique, the complete motion for a skilled surgeon is learnt and modeled as a sequence of characters, similar to a genetic sequence. After this, when a new series of sequence comes in, skill level of the surgeon is determined by scoring against the sequence for an expert surgeon.
No experimental results have been provided by the author.

Critique on the paper:
Overall this paper is a very nice read for anyone planning to evaluate surgical skills as it gives a required background and an overview of abundance of approaches that can be used.

Good:

- This paper gives a very nice intuition about how analyzing motion helps analyze surgical skills using the experiment done on da Vinci.
- The flow in the paper goes from how motion analysis is useful to how motion would be captured in different kinds of surgeries and what are the different techniques to model the motion to get surgical skill. Thus this provides an outline of a procedure one would be expected to follow if interested in surgical skill analysis and does a very good job of providing a very concrete outline.
- Coming to the discussion of various methods in surgical skill analysis, the paper does a good job in reviewing all the major technical approaches that are used to model the surgical motion, the results from using these approaches in different conditions and what directions have people gone or are currently working in to improve these approaches.
- Thus it gives reader an idea of what direction he should be thinking if he is planning to analyze motion effectively to analyze surgical motion.

Bad:

- This paper does not give a good idea on how the motion is segmented into different tasks or into different surgemes. Thus it becomes hard to appreciate the complete modeling process since a very intricate detail has not been well explained in this paper.
- This paper reviews many major modeling methods but does not provide enough detail that help develop an intuition of the method being used. Instead I felt that it became confusing at times to understand what actually the approach was and I had to refer to the original paper to understand the review and the experimental results the authors discuss.