

Objective Evaluation of Laparoscopic Surgical Skills

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Introduction

Minimally invasive surgery (MIS) – specifically laparoscopic (abdominal) – is a technique introduced in the mid-1980s in which a few small incisions are made to allow for insertion of surgical tools and a camera through gasketed ports. Smaller incisions aid in patient recovery times and lessen the chance of infection. They also introduce new interfaces compared to the more traditional open surgical technique. These interfaces impose motion constraints and forces on the tool(s) and hand(s). MIS surgeons must acquire additional skills beyond those used in open surgery: compensating for the inverted nature of tool movement and visualizing the procedure on a 2-D monitor that is displaced from the patient's body.

Objective analysis of surgical skill is a goal of ongoing research. Traditionally, senior surgeons observed residents performing various surgical tasks and *subjectively* scored them to evaluate their skill level. Much work has been done with regard to measuring and analyzing the forces and torques being applied by the surgeons during two common laparoscopic procedures: cholecystectomy and Nissen fundoplication [1-3]. To achieve a more objective skill analysis, a Markov statistical modeling approach was used to analyze and predict the skill level of the surgeon, based solely on the forces and torques they apply. It is assumed that tool position information would help to further discriminate skill level by allowing analysis of work and energy production by the surgeon: expert surgeons are hypothesized to produce less work than a non-expert during the course of an operation. A device has been developed that will allow the tracking of position of two tools during an actual surgical procedure.[4]

Background – Hidden Markov Models

Hidden Markov Models (HMM) were extensively developed in the area of speech recognition (for mathematical review see [5]). Based on the theory developed for speech recognition, HMMs have become useful statistical tools in the fields of robotics, teleoperation, human manipulation actions, manufacturing, and gesture recognition. HMMs have high potential to provide better models of the human operator in complex interactive tasks with machines. A convenient analogy can be drawn between human spoken language, surgery, and Markov models. Just as in speech, words can be pronounced differently and still be understood and strung together to form meaningful sentences and book chapters, surgeons can produce different tool/tissue interactions, in different sequences and with different force/torque signatures, yet still successfully complete steps in a surgical operation.

In simplified terms, the Markov model consists of three matrices (**p**, **A**, and **B**) that defines a step of an operation. The **p** vector is the probability of starting the operation in a particular state (tool/tissue interaction), **A** is the matrix of probabilities of transitioning between any of the other states (or staying within a state), and **B** defines the probabilities of observing a particular force/torque signature while in a given state. These three matrices are a compact way to describe a complex process.

Methodology

For surgery, a set of 14 “states” was defined that represent all of the possible interactions with tissue that a grasper is capable of producing. This includes an *Idle* state where the tool is not interacting with any tissues or organs (other than the abdominal wall port), *Grasping*, *Spreading*, *Pushing*, *Sweeping*, and various combinations between them. An instrumented grasper was used to record the 6 forces and torques applied by the surgeon on the tool, in addition to a grasping force. HMMs were trained on expert data from steps of actual laparoscopic surgical procedures (cholecystectomy and Nissen fundoplication) after frame-by-frame video analysis. Eight subjects (2 first-year general surgery residents – R1, 2 third-year residents – R3, 2 fifth-year residents – R5, and 2 expert attending laparoscopic surgeons – ES) each completed the experimental protocol.

Each subject watched a 45-minute video of the surgical procedure guided by a senior surgeon to standardize the technique of the procedure into 7 steps for purposes of the study. Each subject then performed a laparoscopic cholecystectomy on a pig using the force/torque sensing instrument.

Results

The data analysis demonstrated some interesting phenomena: 1) expert and novice surgeons utilized different states and transitions; 2) there was a significant difference between novice and expert groups in median completion time, due mostly to the novices spending more time in the “idle” state; and 3) simple surgical maneuvers (like positioning) may not include sufficient force/torque information to differentiate skill levels, whereas more complex skills (like dissecting) do.

HMMs were developed for each of the eight subjects. Figure 1 shows the statistical distance between novice subjects and experts (normalized to expert skill level $D_s = 1$). This objective laparoscopic surgical skill “learning curve” showed significant differences between all skill levels. The curve suggests that surgical residents acquire a major portion of their laparoscopic surgical capabilities between the first and the third years of training.

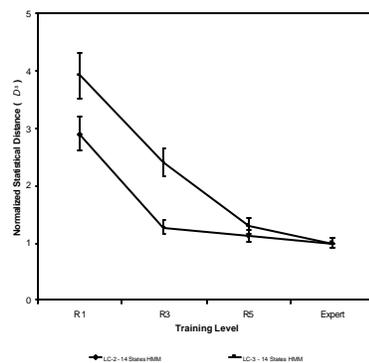


Figure 1. Learning curve of surgical residents as predicted by HMM analysis.



Figure 2. Rendered CAD drawing of the tool position measurement device.

Discussion

The power of the HMM methodology is its ability to calculate a single, objectively derived number for skill. This “skill number” represents the probability that surgical performance for the subject under study approximates that of an expert. The preliminary results expressed in this study suggest that HMMs derived from carefully standardized surgical tasks should allow objective quantification of skill. This can be extended to training modalities such as surgical simulators and robotic systems to evaluate their effectiveness.

While the bulk of this research has been done analyzing only the forces and torques applied by the surgeon on the surgical tools, a device has been developed (see Figure 2) to track the position of the tools (both hands) during an actual surgical procedure. It is assumed this will allow for a more complete analysis and better prediction of skill, since energy and work data can be obtained and evaluated. Expert surgeons do not always apply lower forces than novices, but it is hypothesized that they do less work during the course of an operation than the novices.

References

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