

Measurements of the Level of Surgical Expertise Using Flight Path Analysis from *da Vinci*TM Robotic Surgical System

Lawton Verner¹, Dmitry Oleynikov, MD¹, Stephen Holtmann¹,
Hani Haider, Ph D¹, Leonid Zhukov, Ph D²

¹ University of Nebraska Medical Center, Omaha, NE

² California Institute of Technology, Pasadena, CA

email: doleynik@unmc.edu

URL: www.unmc.edu/mis

Abstract. Laparoscopic surgical procedures require precise hand and eye coordination based on a 2-dimensional representation of 3-dimensional space. Currently, no metric exists to guide the educational process while surgeons are still on the learning curve. In this paper, we propose to identify and qualify the patterns of movements recorded from the *da Vinci*TM robotic surgical system (Intuitive Surgical, Sunnyvale CA) that are most consistent with mastery and can define levels of proficiency. We have recorded velocities and positions of complex movements made by both novice and expert surgeons using *da Vinci*TM system and performed geometric and statistical analysis of the data.

1. Background

Surgical skill is difficult to learn and ultimate competency is even more difficult to define and measure. To accurately assess a physician's technical skills, an objective analysis method must be established. Current methods of assessing surgical skill include subjective testing procedures which require an expert in the field to judge the aptitude of a lesser experienced surgeon [1,7]. The Minimally Invasive Surgical Trainer; Virtual Reality (MIST VR) represents the first attempt to quantify movements by a surgeon and therefore draw conclusions concerning the skill level. Gallagher et al. demonstrated that experts performed better and therefore could be distinguished from novice surgeons [4]. This, however, was done in a virtual reality trainer and cannot be easily adapted to clinical practice. To obtain practical assessment of surgical skill, direct procedures must be analyzed to ensure proficiency when immersed in a real surgical environment.

Rosen et al. have developed instrumented graspers which allow for the measurement of forces and torques during actual clinical procedure. By using Hidden Markov Modeling, analysis these signatures can be stratified into expert or novice performances [5, 9-12]. We have applied these principles to the human telerobotic interface to determine if entire movements could be classified into expert or beginner patterns. The *da Vinci*TM robotic surgical system allows the surgeons to perform

surgical procedures without mechanical link. We have measured the output of these signals of this system to objectively determine what characteristics are associated with surgical expertise. The procedure tested was adapted from standard surgical assessment methods [2,3].

2. Methods

With coordination from *Intuitive Surgical*TM, makers of the *da Vinci*TM robotic surgical system, a commercial, telemanipulating, computer assisted, FDA approved, surgical device (**Figure 1**), an interface was developed between the *da Vinci*TM system and an external computer. With this interface, real-time telemanipulator data can be extracted from the surgical system. This data includes elapsed time, position, orientation, grip (7 total degrees of freedom) and corresponding linear and angular velocity information of the surgical tools and hand manipulations. The tool and surgeon manipulator data are logged at 11 samples per second (for each signal) by the external computer.



Figure 1. *da Vinci*TM robotic surgical system

Novice and expert surgical operators were logged performing the task of lifting a bead, placing it on a peg, and then returning the surgical tool to its origin using only one hand (**Figure 2**). The procedure was repeated five times using the operator's dominate hand. Two right-handed expert and four right-handed novice operator data logs were obtained. The procedure was then repeated using the non-dominate hand. The data was statistically analyzed with Student t-test and analysis of variance (ANOVA) tests. Significant differences in handedness of individual surgeons and differences in the elapsed time it took to perform the task between experts and novices were determined.

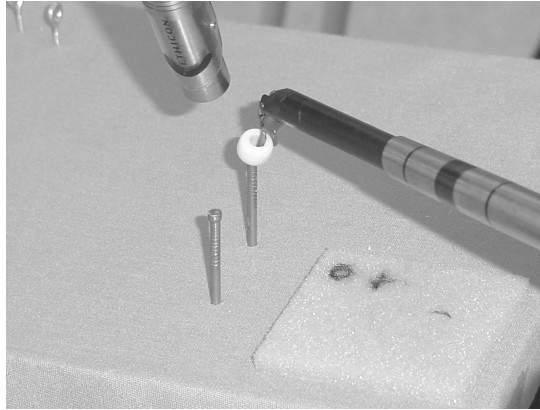


Figure 2. The task performed

3. Results

Comparison of the 3 dimensional trajectories demonstrates a visual disparity between expert and novice operators. Analysis of grip position over time (**Figure 3**) illustrates the difference between the novice (dashed line) and expert (solid line) grip patterns. Not only is it apparent that the novice required more total time, but spent much longer in transition states (constant grip values). **Figure 4** illustrates the difference in the 3 dimensional positioning of the tool. The novice (darker line, square data points) trajectory shows excess movement, a more erratic flight path, and slower movements when compared to the expert (lighter line, X data points). The slower movements are evident by the data points (stars), which are sampled at a constant 11 hertz, being closer together during the major movement portions of the test.

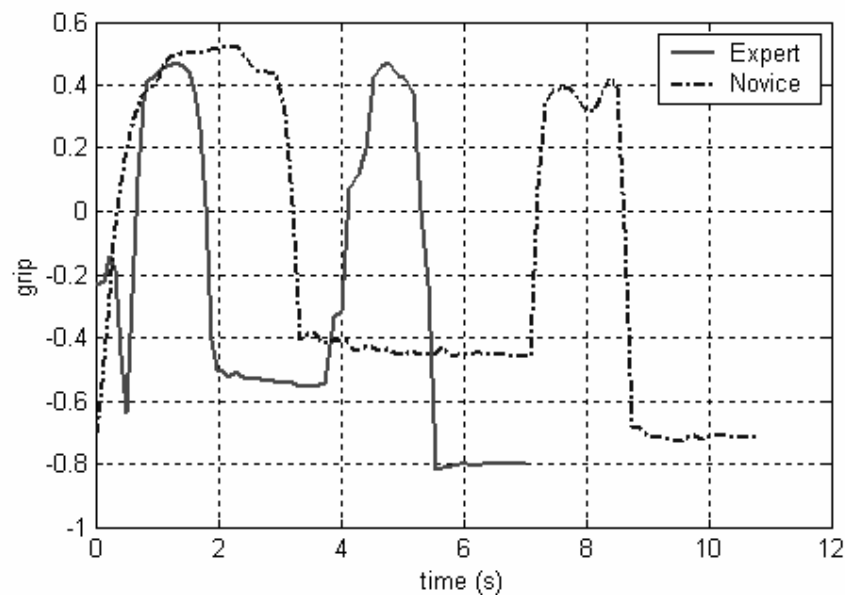


Figure 3. Grip position

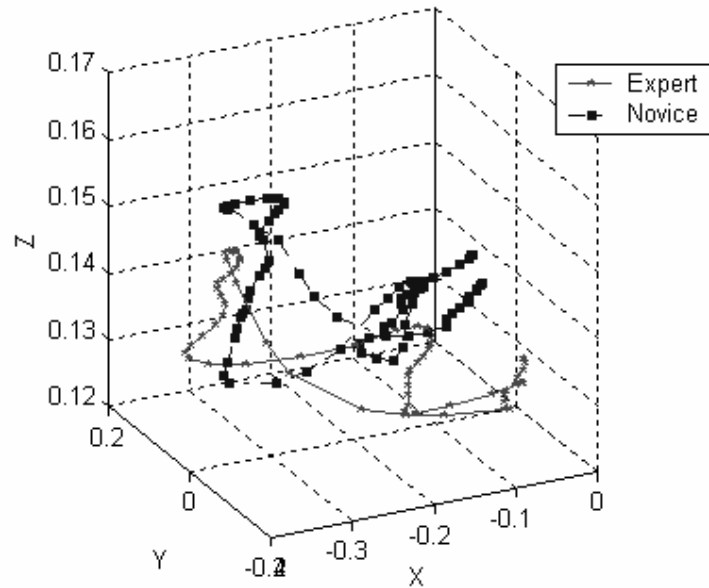


Figure 4. 3-D movements

Analysis of elapsed time illustrates an increase in procedural time for novices as expected ($p < 0.05$). Novices, but not experts, had a statistically significant difference in time between their right and left hands (Table 1). Experts were on average 15% faster with the right hand, and over 50% faster with the left compared to novices (Table 1).

Velocity analysis showed statistically significant difference in novice but not expert flight path ($p < 0.05$ in 5/7 velocity variables). Statistical analysis of variance in flight path data showed significant difference between novices and experts (Table 1). Although the difference in data could be seen in both right and left hand flight path the left hand difference was more dramatic (4/7 right vs 6/7 left velocity variables differed significantly).

TABLE 1: Analytical Results

Flight Path Mean Velocities:	Novice	Expert	P value
X-axis (m/s)	0.100	0.121	0.000
Y-axis (m/s)	0.079	0.109	0.000
Z-axis (m/s)	0.008	0.008	NS
Rotational (rad/s)	0.256	0.288	0.026
Pivot (major) (rad/s)	0.205	0.231	0.036
Pivot (minor) (rad/s)	0.244	0.288	0.000
Jaw position (rad/s)	0.654	0.776	0.013
Time:			
Average Time Left	13.536	8.649	0.044
Average Time Right	9.743	8.536	0.028
Inter-group P value	0.045	NS	

4. Conclusions

Complex tasks in three-dimensional space could be analyzed with flight path calculations and level of expertise determined by objective measures. Level of expertise was demonstrated by shorter times to complete the task as well as in the pattern of positions and velocities of the operator. The effect of handedness diminished with the level of expertise. It can be hypothesized that if performing a simple task such as placement of a bead illustrates a statistic disparity between expert and novice operators, it can easily delineate skill level if a more difficult task were completed. Similar findings were shown by Rosen et al. when forces and torques were studied at the tissue tool interaction [5, 9-12].

Although the raw data was voluminous, offline analysis allowed specification of patterns of movement that could be applied to the entire data set. We were able to compare the entire data set using statistical manipulation with expert performance as the benchmark. The limitation of this approach lies in the need to compare against an individual's performance rather than an ideal path analysis. That is to say that the novice could only hope to be as good as the expert rather than seek perfection due to the lack of a "perfection" benchmark. The goal of any metric of surgical skill must seek objective gold standards that are not biased by human operators. Such a benchmark would be far more enduring.

The ability to analyze telemetry from a robotic surgery system such as the *da Vinci*TM provides detailed procedural reconstruction which can lead to benchmarking expert and novice kinematics of surgical procedures. Future work will need to be performed to better define objective analysis of surgical skill.

5. References

- [1] Darzi A, Smith S, Taffinder N (1999) Assessing operative skill. *Br Med J* 318:887
- [2] Rosser JC, Rosser LE, Savalgi RS (1998) Objective evaluation of laparoscopic surgical skill program for residents and senior surgeons. *Arch Surg* 133:657-661
- [3] Rosser JC, Rosser LE, Savalgi RS (1997) Skill Acquisition and Assessment for Laparoscopic Surgery. *Arch Surg* 132: 200-204
- [4] Gallagher AG, Ritchie K, McClure N, McGuigan J (2001) Objective psychomotor assessment of senior, junior and novice laparoscopists with virtual reality. *World J Surg* 25:1478-1483
- [5] Rosen J, Solazzo M, Brown JD, Oleynikov D, Hannaford B, Sinanan MN (2001) Objective laparoscopic skills assessments of surgical residence using Hidden Markov Models based on haptic information and tool/tissue interactions. *Medicine Meets Virtual Reality Abstract*.
- [6] Hannaford B, Trujillo J, Sinanan M, et al. (1998) Computerized endoscopic surgical grasper. *Stud Health Technol Inform* 50:265-271
- [7] Darzi A, Smith S, Taffinder N (1999) Assessing operative skill. *Br Med J* 318:887
- [8] V. Falk, D. Mintz, J. Grunenfelder, J. I. Fann, T. A. Burdon (2001) Influence of three-dimensional vision on surgical telemanipulator performance. *Surg Endosc* 15: 1282-1288.
- [9] Rosen J, Hannaford B, Richards CG, Sinanan MN (2001) Markov modeling of minimally invasive surgery based on tool/tissue interaction and force/torque signatures for evaluating surgical skills. *IEEE Trans Biomed Eng* 48:579-591

- [10] Rosen J, Richards C, Hannaford B, Sinanan MN (2000) Hidden Markov models of minimally invasive surgery. *Stud Health Technol Inform* 70:279-285
- [11] Rosen J, Hannaford B, MacFarlane MP, Sinanan MN (1999) Force controlled and teleoperated endoscopic grasper for minimally invasive surgery – experimental performance evaluation. *IEEE Trans Biomed Eng* 46: 1212-1221
- [12] Rosen J, MacFarlane M, Richards C, et al. (1999) Surgeon-tool force/torque signatures—evaluation of surgical skills in minimally invasive surgery. *Stud Health Inform* 62 290-296