IMPLEMENTATION OF METRICS TO ASSESS SURGICAL MICROSCOPE MANOEUVRING SKILLS DURING MYRINGOTOMY

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ABSTRACT

Teaching and learning to manoeuvre a surgical microscope is one of the first steps in middle ear surgical training. In the conventional training approach, no numerical methods are used to evaluate trainee performance. The objective of this paper is to present a set of discriminatory metrics that quantify the microscope's motion path during a middle ear surgery (myringotomy with ventilation tube insertion) and numerically evaluate the trainee's performance. To collect the motion data, an experimental myringotomy was conducted on a cadaveric human ear by experienced ear surgeons and by residents. During the operation, translational and angular coordinates of the microscope's motion were captured in real-time using an optical tracker. Analyzing their data based on motion time, path length, total rotation, jitter, efficiency, and smoothness metrics, noticeable differences were observed between residents and experts. These metrics will form the basis of an automated system for providing feedback to residents during training.

INTRODUCTION

Diagnosis and surgical treatment of ear, nose and throat (ENT) diseases requires precise dexterity and fine hand-eye coordination when using a surgical microscope. To develop such skills, one must initially be able to produce and maintain a consistent optimum microscopic view of the anatomy of interest during an operation. Therefore, mastering the skill set to efficiently manoeuvre the surgical microscope is inevitably essential in the training process.

In conventional ENT surgical training, microscope manoeuvring is often overlooked as a trivial task. Following the 'see one, do one, teach one' method, residents are often required to manoeuvre a microscope without practice and/or any proper techniques to follow. By receiving qualitative feedback on their overall performance, residents do not identify the particular manoeuvring problem they need to attend to. As a result, their skill development time lengthens. Instructing surgeons agree that during surgery, residents always struggle to manoeuvre a microscope following an economic path. They repeatedly adjust the final position of the microscope and struggle to obtain the optimum microscopic view. Also, they often have unfocussed vision through the microscope optics and inadequate distance between the eyepiece and the anatomy of interest. These factors collectively limit their microscopic vision and affect their operating efficiency.

In this research study, we measured the surgical microscope's motion path by discretely tracking its motion over time. This path was numerically analysed using quantifiable metrics to evaluate one's manoeuvrability. In a laparoscopic skill training study [1], *time*, *path length* and *total rotation* were used as metrics to evaluate the traced motion paths of the laparoscope. In another study, *smoothness* served as a metric to evaluate visuomotor skills of patients with Parkinson's disease [2]. To mathematically define *smoothness*, the third derivative of the motion path $r(t)$ is utilized, which in turn allowed us to derive *velocity and acceleration* as the intermediary metrics; $r(t)$ is the distance from the laboratory coordinate system origin to a point on the path sampled at time t. Using the concept of smoothness, another metric was derived to compute the motion jitter. Lastly, motion *efficiency,* as presented by Taffinder *et al* [3], was considered to compute the efficiency of the manoeuvre. Our ultimate goal is to identify and incorporate all the discriminatory metrics into a myringotomy simulator [4]. Collectively, these metrics for evaluating the manoeuvrability of the microscope would allow a trainee to obtain automated feedback on his/her performance and track his/her improvement over time.

METHOD OF STUDY

An experimental myringotomy case was set up following a clinical scenario as depicted in Figure 1. A cadaveric head with intact ear anatomy was used as a patient and placed on a hospital bed for the participants to perform the surgery. A Leica M720 OH5 surgical microscope (Leica Microsystems Inc., Concord, ON) was used during all the trials. Its eyepiece was tagged with wireless markers and optically tracked in real-time with a NDI Polaris® Hybrid optical tracking system (Northern Digital Inc., Waterloo, ON). Two external high-definition video cameras were also set up to capture the entire surgical scene and the zoomed-in view of the operator's hands during surgery. In addition, the internal high-definition camera of the Leica microscope was used to capture the optical view of the surgical site. A group of expert ENT surgeons and a group of ENT residents from years 1 to 3 were invited to participate in the experiments. During each trial, the operator positioned him/herself, manoeuvred the microscope from a common parking position to the final position and performed the simulated myringotomy.

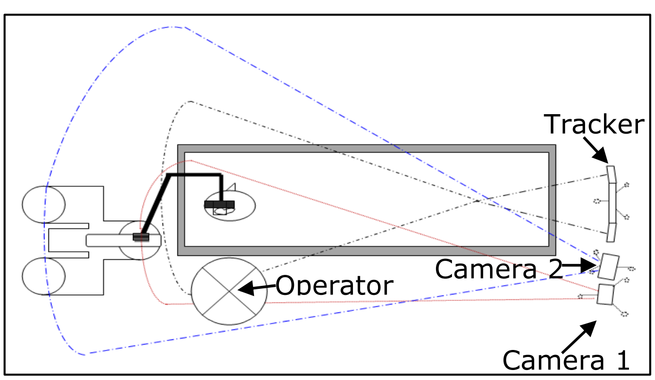

Figure 1: Clinical setup for surgical microscope tracking experiment. (Dashed lines are the Field of View of the cameras).

An application software was implemented in the Image Guided Surgery ToolKit (Kitware Inc., Clifton Park, NY) to control real-time tracking of the wireless markers. It was used to communicate with the Polaris® tracker, initiate the tracking process, import, display and record the real-time tracked position and orientation of the markers during motion. It also visually demonstrated the real-time tracking of the markers as virtual objects.

NUMERICAL METRICS

The surgical microscope's motion path during myringotomy was subdivided into gross motion and fine adjustment. Gross motion was the initial manoeuvred path from a common starting position to the surgical site. Fine adjustment was the manoeuvred path to obtain the optimal view at the surgical site. The metrics used to analyse these segmented paths are presented in the following sub-sections.

Time: For each trial, the *total completion time* was counted from the start of the microscope's motion until the surgeon removed the forceps after surgery. Then the *total operation time* was counted from the instant any tool was collected until the end of the tube insertion in the eardrum. Likewise, *tube insertion time* was counted from the instant the tube was brought into the microscope's view until it was completely inserted into the myringotomy incision. Next, *still time* was the cumulative time needed by the operator to prepare in any way to perform the surgery. Lastly, both gross motion and fine adjustment also generated individual times. These various time metrics were derived to demonstrate the variation in task duration among the operators.

Path length: Besides time, the manoeuvred path was traced in discrete form from a starting position to an end position. Its *path length* was computed using Equation 1 as shown below.

$$L_T=\sum_{i=1}^{N-1}\sqrt{(x_{i+1}-x_i)^2+(y_{i+1}-y_i)^2+(z_{i+1}-z_i)^2} \quad (1)$$

Equation (1) evaluates the total length of the path composed of N points with x_i, y_i and z_i discrete coordinates. The most economic path would be the one with the shortest path length.

Rotational length: In addition to path length, t*otal rotation* about each axis needed by an operator to obtain the desired view is computed using Equation (2):

$$R_T = \sum_{i=1}^{N-1}[\phi_{i+1} - \phi_i]. \quad (2)$$

Here, N is the number of total data points and ϕ_i is the i^{th} angle.

Translational jitter: *Jitter* computes the hand jerkiness while manoeuvring. It is derived using the motion *jerk* expression $\frac{d^3r(t)}{dt^3}$. For steady motions, this results to almost zero and non-zero for jerky motions. To extract only the non-zero components, a simple threshold filter was derived where

$$Threshold = 0.1(\max(\frac{d^3r(t)}{dt^3})). \quad (3)$$

Equation (3) allows filtering of all *jerk* values below 10% of the maximum *jerk* value computed for a particular motion path. For the remaining non-zero *jerk* values, the area underneath the curve is calculated to quantify the unit-less motion *jitter*:

$$Jitter = \frac{t^2}{L_T}\sum_{i=1}^{N}\frac{d^3r(t)}{dt^3}(t_{i+1} - t_i). \quad (4)$$

Larger values computed via Equation (4) indicate more jitter in a manoeuvred path.

Path Smoothness: It is computed as:

$$NJ_P = \sqrt{\frac{t_P^5}{2L_T^2}\sum_{i=1}^{N-1}\left(\frac{j_{x_{i+1}}^2+j_{x_i}^2+j_{y_{i+1}}^2+j_{y_i}^2+j_{z_{i+1}}^2+j_{z_i}^2}{2}\right)[t_{i+1}-t_i]}. \quad (5)$$

Here, t_P is the time to trace the path and $j^2=\left[\frac{d^3r(t)}{dt^3}\right]^2$. Smaller values of NJ_p indicate smoother motion paths.

Efficiency: The most efficient path from one point to another is a straight line. *Efficiency* reduces as the path length increases with added deviation and/or jaggedness and termed as *path increment*. The smaller the *path increment*, the more efficient is the motion.

$$Path\ increment = \left(\frac{L_{experimental}}{L_{ideal}} - 1\right) \times 100\% \quad (7)$$

Here, $L_{experimental}$ is the traced path length, while L_{ideal} is the straight line length from the same start to finish points. Based on the result of Equation (7), efficiency of the manoeuvre is ranked.

RESULTS & DISCUSSION

For the same surgery performed under the same protocols, the computed results of the numerical metrics are graphed to make visual comparison between an expert and a resident. In Figure 2, the computed time metrics are plotted. It shows that for all the 'overall time' metrics, a resident always needed more time to complete a certain task than an expert.

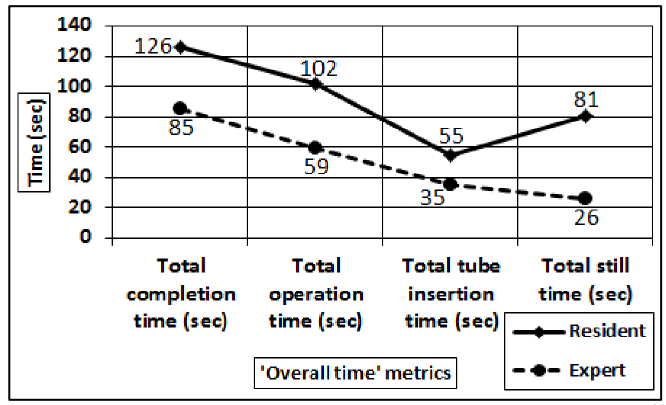

Figure 2: Time metrics of an expert and a 3rd year resident.

As for the segmented paths of gross motion and fine adjustment, all other numerical metrics are computed separately. As shown in Figure 3, an expert needed shorter motion time than a resident during both segmented motion paths. Likewise, the expert always needed much less cumulative rotations in all three axes than a resident in the segmented motion paths.

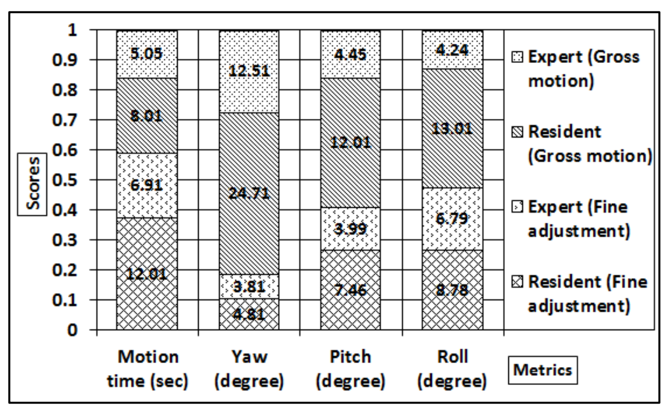

Figure 3: Metrics for time and rotation.

The last four discriminatory metrics are shown in Figure 4. It shows that for the gross motion path length, the expert recorded a shorter length (0.30 m) compared to the resident's record (0.77 m). While the difference was small, a similar trend was still observed for the fine adjustment path length as well. Also, the expert's gross motion path length was only 3.53% greater than the ideal path, while the resident's path was 69.5% greater than the ideal path. The low score of the expert indicates the path's close resemblance to a straight line, which is the most efficient manoeuvre. In fine adjustment, the expert's manoeuvred path length was still shorter than the resident's, showing still higher efficiency than the resident. Similarly, in both segmented paths, the expert had less motion jitter compared to the resident. Finally, for smoothness, the expert again scored lower than the resident showing greater path smoothness compared to the resident.

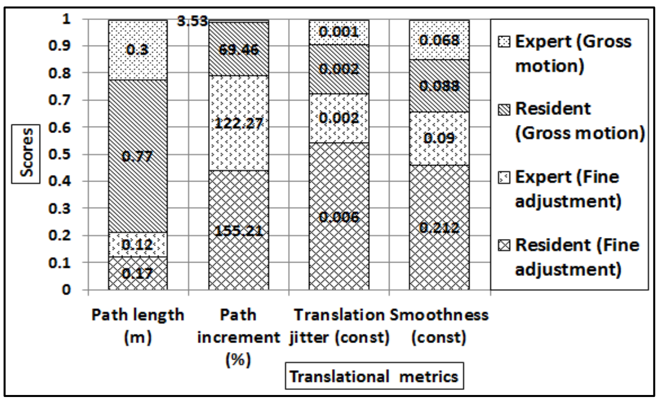

Figure 4: Metrics to evaluate translational quality of the motion path.

Finally, the manoeuvred paths are graphed in Figure 5. Here, the solid path is that of the resident while the dashed path is that of the expert. The path traced by the resident is longer and less linear as compared to the expert's shorter and smoother traced path.

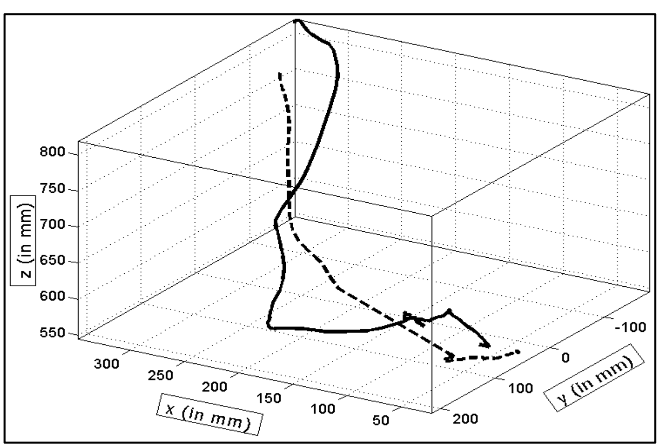

Figure 5: Manoeuvred path of a resident (solid) and an expert (dashed).

CONCLUSION

Computed metrics indicated that experts always performed better than residents in terms of shorter completion times, shorter path lengths, smaller rotations, less jitter and path smoothness. Currently, the pool of participants is being extended to form a normative database for training purposes. Furthermore, we will incorporate these metrics into our myringotomy simulator to provide automatic feedback during training.

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REFERENCES

[1] S. Cotin, N. Stylopoulos, M. Ottensmeyer, P. Neumann, "Metrics for Laparoscopic Skills Trainers: The Weakest Link!," MICCAI, vol. 2488, pp. 35–43, 2002.

[2] J. Contreras-Vidal, E. Buch, "Effects of Parkinson's disease on visuomotor adaptation," Exp. Brain Res., vol. 150, pp. 25-32, 2003.

[3] N. Taffinder, S. Smith, J. Mair, "Can a computer measure surgical precision?," Surgical Endoscopy, vol. 13 pp. 81, 1999.

[4] B. Wheeler, P. Doyle, S. Chandarana, S. Agrawal, M. Husein, H. Ladak, "Interactive computer-based simulator for training in blade navigation and targeting in myringotomy," Computer Methods and Programs in Biomedicine, vol. 98, pp. 130-139, 2010.