Physiological Tremor Amplitude during Retinal Microsurgery

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Abstract – Using an instrumented surgical tool, high-precision recordings of hand tremor were taken during vitreoretinal microsurgery. The data obtained using a compact, custom six-degree-of-freedom inertial sensing module were filtered and analyzed to characterize the physiological hand tremor of the surgeon. Tremor during the most delicate part of the procedure was measured at a vector magnitude of 38 μm rms. Non-tremulous, lower-frequency components of instrument movement were also characterized. The data collected provide an important baseline for design specification and performance evaluation of engineered microsurgical devices.

I. INTRODUCTION

Inaccuracy in manipulation is a well-known problem in microsurgery. Physiological tremor is the most familiar component of erroneous motion, though it is not the only significant component. Several types of engineered accuracy-enhancement devices have been or are being developed in order to improve the manipulation accuracy of the microsurgeon, including telerobotic systems [1], the "steady-hand" robotic system [2], and "Micron," a fully hand-held active tremor canceling instrument [3]. To properly specify designs of such systems and preserve the normal control bandwidth of the surgeon, there is a need for high-quality measurements of the unassisted performance of microsurgeons. In addition, basic information on tremor amplitude under regular microsurgical conditions is needed in order to provide a baseline for evaluation of engineered devices. To date there has been a lack of tracking instruments that feature both three-dimensional (3-D) sensing and the requisite level of precision, and such as do exist have been laboratory instruments that are incompatible with intraoperative use [4]. Therefore, to date such data have been generally unavailable in the literature.

This paper presents and characterizes some of the first quantitative measurements of physiological hand tremor and other components of instrument motion made during vitreoretinal microsurgery. The data presented here were the first to be collected after the apparatus used in [5] was modified for further noise reduction. The sensing module used is a modified version of the one incorporated within Micron [3]. Recording instrument motion during actual microsurgery allows the quantification of tremor and other types of motion in authentic conditions, as well as a determination of the "performance envelope" utilized by the surgeon in terms of velocity, acceleration, and frequency.

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To our knowledge, the data taken in these studies represent the first recordings of physiological hand tremor ever made during real microsurgery instead of laboratory-based simulation [5].

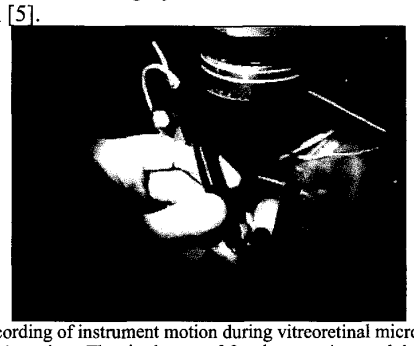

Fig. 1. Recording of instrument motion during vitreoretinal microsurgical using inertial sensing. The six-degree-of-freedom sensing module, roughly cubical in shape, can be seen at the proximal end of the instrument in the left hand of the surgeon.

II. METHODS

Collecting the data under realistic conditions required a compact sensing instrument that would have minimal effect on the dynamics of the hand motion of the surgeon. The miniature six-degree-of-freedom (6-dof) inertial sensing module originally designed for Micron was adapted for the purpose and fitted to the proximal end of a DP9603 Madlab Pic-Manipulator (Storz Ophthalmic, Inc., St. Louis, Mo.) as shown in Fig. 1. The module (38 g, 38 cm^3) incorporates a Crossbow CXL02LF3 tri-axial low-noise accelerometer (Crossbow Technology, Inc., San Jose, Ca.) and three orthogonally placed Tokin CG-16D ceramic rate gyroscopes (Tokin Corp., Tokyo, Japan). Each signal channel was filtered using a Maxim sixth order Bessel low-pass filter (Maxim Integrated Products, Inc., Sunnyvale, Ca.) with a cutoff frequency of 21 Hz. Due attention to proper circuit grounding succeeded in reducing measurement noise to 3.3 μm rms. Intraoperative motion data were digitized with 12-bit precision and recorded on a personal computer for analysis using Matlab software.

The data presented here were recorded during an epiretinal membrane removal procedure at the Wilmer Eye Institute of The Johns Hopkins Hospital. Both surgeon and patient gave written consent to the experiment under a board-approved protocol. The procedure took place under normal surgical conditions, with the surgeon viewing the procedure through a stereo operating microscope. Sensor output was sampled at 100 Hz throughout the procedure. The procedure was monitored and recorded on video through the microscope. Data analysis was limited to specific segments in which pathological epiretinal membranes were actually being engaged using the Pic-Manipulator.

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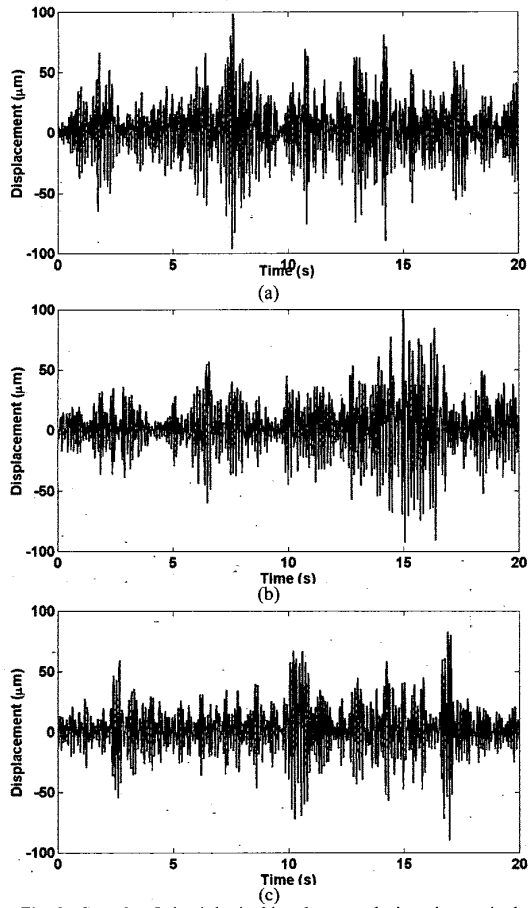

Fig. 2. Sample of physiological hand tremor during vitreoretinal microsurgery. (a) *X* axis. (b) *Y* axis. (c) *Z* axis (nominally vertical).

A *Z-Y-X* Euler angle formulation was used to compute the 3-D velocity of the instrument tip based on the 6-dof sensor readings from the proximal end of the instrument. Displacement and acceleration were estimated by integration and differentiation, respectively, of the velocity data. The tremor was then estimated using a bandpass filter to limit the displacement signal to the 7-17 Hz band.. Tremor analysis was performed on a particular 20-second segment in which the surgeon was executing the most delicate portion of the membrane removal procedure.

In a separate analysis, the displacement, velocity, and acceleration data sets (without bandpass filtering) were lowpass filtered with a cutoff frequency of 8 Hz to remove the physiological tremor and preserve the voluntary components of the motion. Velocity and acceleration results were analyzed to determine the values below which the motion of the surgeon remained 90% of the time. The lowpass-filtered displacement data were analyzed to identify the frequency below which was found 90% of the signal power. This analysis was performed on a data segment 5 minutes in duration.

III. RESULTS

The results of the tremor estimation are displayed in Fig. 2 (The *z* axis is nominally the vertical, but this designation has little true significance since the inertial sensor results are subject to integration drift.) Fig. 3 illustrates the trajectory of the instrument tip in 3-D due to the tremor during the 20-second period analyzed. Tremor rms amplitude was found to be 24 μm, 22 μm, and 20 μm, along the *x*, *y*, and *z* axes, respectively. The vector magnitude of these rms amplitudes is 38 μm. If the tremor signals along each axis were perfect sinusoids, this would be equivalent to a peak-to-peak vector magnitude of 108 μm.

In the data from which the tremor had been removed by lowpass filtering, it was found that 90% of the time the velocity was less than 0.34 m/s, and the acceleration was less than 0.44 m/s^2. Ninety percent of the power of this signal was below 0.74 Hz.

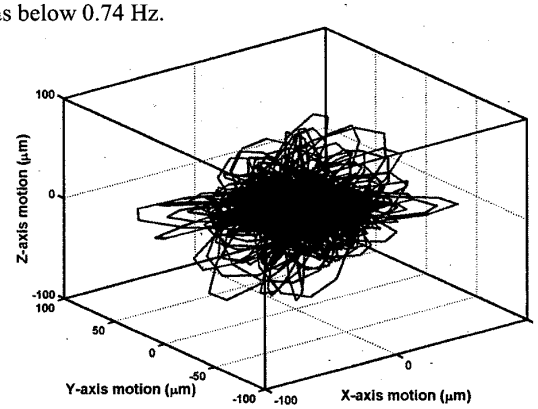

Fig. 3. Three-dimensional motion of the microsurgical instrument tip due to tremor during the 20 s depicted in Fig. 2.

IV. DISCUSSION AND CONCLUSIONS

These first data obtained during clinical microsurgery confirm the feasibility of inertial sensing in this environment, for study purposes and eventually for use in tremor-canceling devices [3], and will greatly aid the development of future microsurgical accuracy-enhancement systems by providing baseline data on performance of surgeons for use in design specification and device evaluation.

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