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CHARACTERISTICS OF HAND MOTION OF EYE SURGEONS

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ABSTRACT

Overall manual accuracy and motion frequency in simulated microsurgery have been studied. Eye surgeons were tested in two tasks: attempting to hold an instrument still, and repeatedly actuating. Rms error and overall motion range were measured. Spectral analysis was also performed. The average rms error was 49 µm and 133 µm, respectively, for the two test conditions, and the average range of motion while trying to hold still was 202 µm. Substantial low frequency motion occurred under both conditions. On average, 98.9% of the total power of voluntary movements tested was found to be below 2 Hz.

1 INTRODUCTION

Human hand movement has certain inherent involuntary components, including physiological tremor [1], jerk [2], and low frequency drift [3]. Suppression of these components would improve existing microsurgical practice and possibly allow the development of new procedures. Research in this area has led to developments along two lines: teleoperated systems [2,4] and active hand-held instruments [5]. An important consideration in the specification of these systems is the overall positioning accuracy of the surgeon's hand itself. Round estimates of accuracy attainable by trained surgeons are frequently mentioned in the literature without reference to original sources. A recent study [3] provides data from unskilled subjects, but not from trained surgeons. Careful measurements from skilled subjects would provide a valuable baseline for future surgical system development.

Knowledge of the frequency range of voluntary motion during microsurgery would assist developers of tremor-canceling techniques to ensure that voluntary movement remains undistorted. While Mann et al. [6] have reported the average dominant wrist motion frequency for 24 activities of daily living to be 1 Hz, voluntary motion during writing and drawing has been measured at frequencies as high as 6 Hz [7]. The meticulous nature of microsurgical procedures has understandably led to the assumption in the research community that voluntary movement during microsurgery is restricted to a frequency band considerably lower than this latter value. However, there has been little quantitative experimentation to support the assumption. Studies of small hand motions typically focus on physiological tremor and therefore filter out non-tremor components such as voluntary movement [3]. The present study aims to quantify absolute positioning accuracy in ophthalmological surgeons, as well as to examine the frequency content of voluntary motion during realistic surgical manipulations.

2 METHODS

The subjects for the experiment were four ophthalmological surgeons at The Johns Hopkins Hospital. In each test the subject held a microsurgical instrument with the tip inserted in a sclerotomy in the eye of a mannequin face. A Hall effect sensor mounted inside the mannequin eye detected the position, in one dimension, of a 0.26 g permanent magnet mounted on the tip of the instrument. Subjects were positioned so that the dimension in which measurements were taken was roughly perpendicular to the sagittal plane. Opposite the Hall effect sensor, oriented along the axis of measurement, a small stylus was mounted within the eye to provide subjects with a visual reference for relative positioning.

Each subject executed two tasks:

- attempting to hold the tool motionless;
- actuating the end-effector four times by repeatedly pressing and releasing a button on the side of the instrument handle.

For each subject, 6 recordings were taken at 1 kHz for 16 s in each of the two test conditions. Tests were conducted in a practice surgical suite with a binocular microscope (Storz Ophthalmic, Inc.) [8].

During the second task, pressing the actuation button unavoidably caused a small deflection of the instrument tip. Subjects were instructed to keep the instrument tip as still as possible during actuation, but were not told that the frequency content of their motion was of interest.

Root-mean-square (rms) error and overall range of test data were calculated, neglecting constant (dc) components.

Spectral analysis was performed. Sensor noise was analyzed and its power subtracted from the overall power spectrum of the data. Significance of results was evaluated via *t*-tests.

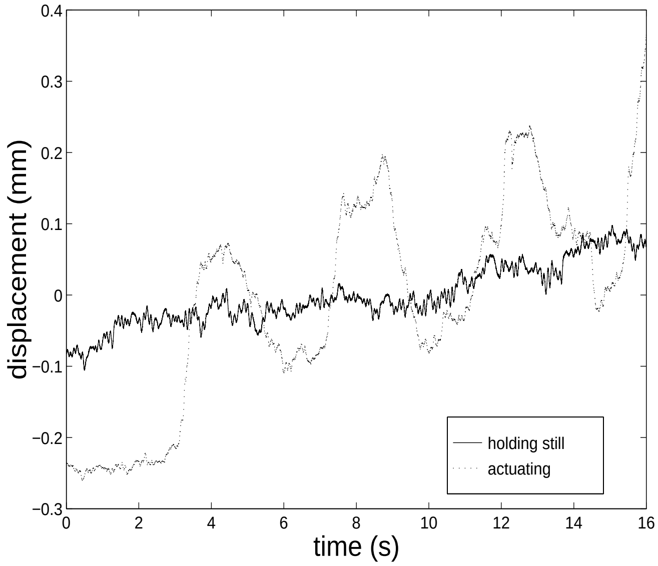

Figure 1. Sample recordings from an individual subject. The solid line represents the subject attempting to hold the instrument motionless, and the dotted line represents the motion during the actuation task. The large actuation artifact is clearly visible in the latter curve.

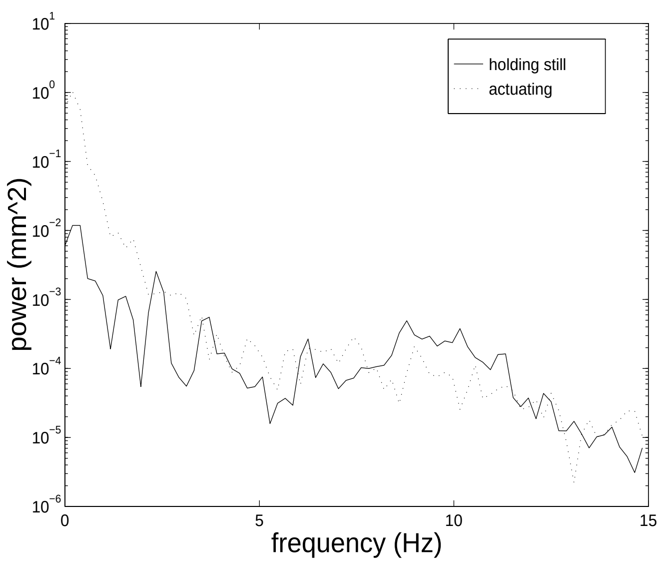

Figure 2. Power spectral densities of the sample individual data in Fig. 1. The solid line represents the motion while the subject attempted to hold the instrument motionless, and the dotted line represents the motion during the actuation task. Note the substantial low frequency component in both tasks.

3 RESULTS

Figure 1 presents one sample recording from an individual subject for each of the two tasks. With standard microsurgical tools such as the one used in this experiment, pressing the actuation button mounted aside the handle unavoidably deflects the instrument tip somewhat. This can be clearly seen in Figure 1. This actuation artifact is undesirable in surgery, and is considered a type of position error. However, since the actuation is voluntary, this artifact is also useful for quantification of voluntary motion frequency. Figure 2 presents power spectral densities for the sample data of Figure 1. The low frequency of the voluntary component is clearly visible in the spectrum for the actuation task. The spectrum from the first task, holding still, shows a broad peak in the 8-12 Hz tremor band. It also shows substantial power at low frequency.

Table 1: RMS amplitude of recorded motion from the two test conditions for all subjects

Test condition	*mean (μm)*	*s. d. (μm)*	*min. (μm)*	*max. (μm)*
holding still	49	39	14	142
actuating	133	77	59	341

Table 2: Overall range of recorded motion from the two test conditions for all subjects

Test condition	*mean (μm)*	*s. d. (μm)*	*min. (μm)*	*max. (μm)*
holding still	202	143	69	497
actuating	538	302	63	1326

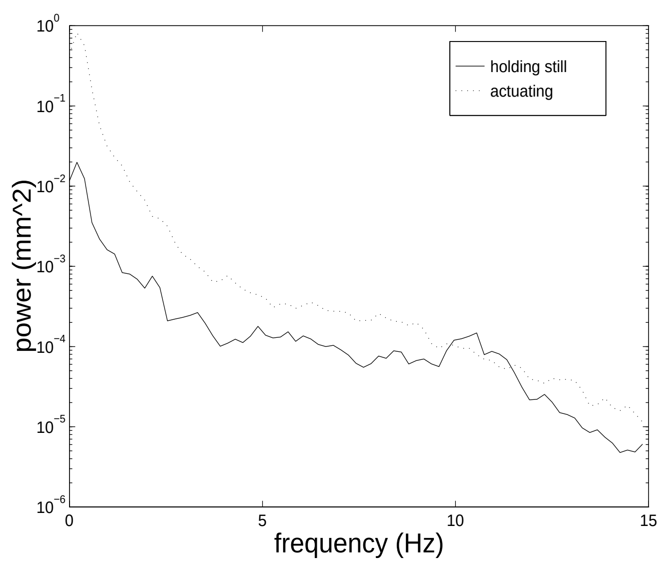

Figure 3. Average power spectral density of all 24 recordings for each test condition. The solid line represents the subjects' motion while attempting to hold the instrument still, and the dotted line represents their motion while actuating. The low frequency component is noticeable in both cases.

Table 3: Percentages of total power in various frequency bands for the averaged power spectral densities (Fig. 3).

Test condition	*below 0.6 Hz*	*below 1 Hz*	*below 2 Hz*
holding still	75.7	81.8	88.7
actuating	91.9	95.9	98.9

Table 1 presents the total rms amplitude of the recorded motions. These results offer a baseline for rms error, or standard deviation of motion, from a desired location during instrument manipulation. The mean rms error in these tests was 49±30 μm ($p<.05$). As expected, this value is much lower than that measured for unskilled subjects in similar experiments [3].

The overall range of motion during the two tests is presented in Table 2. These results quantify the size of the window within which surgeons are able to remain for a duration of 16 s. On average, when attempting to hold still, the surgeons tested were able to stay within a window of the width of 202±110 μm ($p<.05$).

Figure 3 displays the averaged power spectral density of all recordings for the two test conditions. As with the individual results in Figure 2, the low frequency component is noticeable in both tasks. Table 3 presents the percentage of total power present in various frequency bands for the data of Figure 3. In order to obtain the frequency content of the voluntary component alone, the average power from the first test condition was subtracted from that of the second test condition to yield the results in the bottom row of Table 3. In both tasks, the majority of the power present was at the low end of the spectrum.

4 DISCUSSION

Physiological tremor includes both a neurogenic component, around 8-12 Hz, and a "mechanical-reflex" component dependent on mechanical properties, which has been measured at 8-12 Hz in the wrist and 17-30 Hz in the metacarpophalangeal joint [9]. The existing literature on canceling of position error in surgery often gives the impression that improving manual precision in surgery is solely a question of canceling tremor and other errors of similar frequency (e.g., jerk). The spectral analysis of the test results clearly shows this is not the case, in that even when surgeons attempted to hold the instrument motionless, 75% of the power was below 0.6 Hz. Suppressing this low frequency component of error is difficult due to its overlap in frequency with voluntary components of motion. Methods to suppress low frequency error in microsurgery are currently being investigated [10] (Note: the units in [10] are inches, but are erroneously reported as mm).

There is general agreement in the literature that linear time-invariant lowpass filtering is undesirable in the human machine interface because of the sluggishness it introduces [4]. However, many other, more suitable, canceling methods are also frequency selective to some degree. An example of this is adaptive notch filtering [5]. The preservation of voluntary motion is an important issue with such systems. The results shown in Table 3 suggest that methods that do not alter signal components below 2 Hz run little risk of corrupting the voluntary portion of the signal.

For the task of holding still, a tremor peak is visible at roughly 10 Hz in the averaged spectrum in Figure 3. No such peak is clearly visible in the spectrum from the actuation task. Further study is necessary to determine whether this is due to a frequency shift in the mechanical-reflex component of tremor during voluntary motion, or merely the result of non-tremor components increasing the power in the 5-10 Hz band and thereby obscuring the tremor peak.

The results indicate that when attempting to hold an instrument motionless for a duration of up to 16 s, the surgeons tested are able to remain within an interval 312 μm wide or smaller, measured in one dimension roughly transverse to the instrument shaft. The average range is much larger during actuation, due to the undesirable actuation artifact. It has recently been demonstrated that the incorporation of remote actuation within the surgical instrument removes this artifact [8]. More comprehensive characterization of motion in surgery requires that motion be measured in three dimensions. Development of an apparatus that will allow three-dimensional measurements in simulated microsurgery, with more precise marking of target location, is presently underway.

5 CONCLUSION

The hand motion of eye surgeons has been studied. Baseline values for rms error, overall extent of position error, and frequency of voluntary motion have been presented. Considerable low frequency motion has been measured both when surgeons are actuating and when attempting to hold still.

ACKNOWLEDGMENTS

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