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ACCURACY IN POSITIONING OF HANDHELD INSTRUMENTS

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ABSTRACT

We quantify attainable accuracy in positioning of handheld instruments over a 1 min time span. No prefiltering of measured data is used. The average error standard deviation norm is found to be 0.34 mm with the forearm supported, and 0.19 mm with the hand supported. In both cases, a substantial amount of error is detected at frequencies lower than the range typically attributed to physiological tremor.

1 INTRODUCTION

Microsurgery with handheld instruments requires accurate positioning. The attainable degree of accuracy depends on the amplitude of the components of error, from whatever source, in hand motion. In healthy subjects, one well-known source of hand position error is physiological tremor, defined as any rhythmic and approximately sinusoidal involuntary motion [1]. Physiological tremor is inherent in all human motion [1].

Studies of small motions of the human hand often focus solely on physiological tremor, removing other motion components from consideration. This is often done by highpass filtering data before analysis [2] or by recording data over such short times that lower frequency components are effectively suppressed [3]. This facilitates specific analysis of physiological tremor itself, but makes general information about attainable manual accuracy in realistic surgical situations difficult to infer from these studies.

When pointing an instrument at a stationary target, the human hand exhibits a considerable amount of error at frequencies lower than those customarily associated with physiological tremor. These low-frequency components are often of equal or greater amplitude than the simultaneous higher-frequency involuntary motion, or tremor. They therefore clearly affect positioning accuracy, but are seldom treated in the literature. The present study aims to quantify the overall limitations on manual instrument positioning accuracy, considering all position errors, regardless of source.

2 METHODS

An OPTOTRAK (Northern Digital, Waterloo, ONT) optical position sensor with a 6-marker probe was used for data collection. The system sampled at 58 Hz. A stereo microscope with 10x magnification was used to view the workspace. Centered in the field of view was the target, indicated by the tip of a 1 cm long paintbrush bristle, mounted vertically.

Ten unskilled subjects participated in the experiments. In each experiment, the subject pointed the OPTOTRAK probe at the target. When the subject indicated he was on target, data were recorded for 1 min while he attempted to hold the tool motionless. Each subject did two tests:

(a) with the forearm braced 25 cm (measured horizontally) from the target;

(b) with the forearm braced as above, and the side of the palm resting on the microscope base, 6 cm from the target.

The test order was reversed half the time, to avoid order effects. The instrumentation noise level was determined by recording while the probe was held by a gooseneck stand and pointed at the target. This was done for 1 min before and after the series of experiments.

In each Cartesian coordinate, the measured instrumentation noise variance was subtracted from the variance of the subject tests (as the variance of the sum is equal to the sum of the variances). From the corrected test variances, the standard deviation was calculated for each coordinate of each test. For each of the two test conditions, a vector of standard deviations was constructed, averaged over the 10 subjects.

3 RESULTS

The Euclidean norm of the mean and standard deviation vectors for the two test conditions are shown in Table 1. Neglecting any steady-state position error, the mean results in Table 1 correspond to equivalent levels of rms position error.

Average power spectra of the x-coordinate (a horizontal dimension) for the two test conditions are shown in Fig. 1. Figure 2 presents an example of power spectra from an individual subject. In both cases it can be seen that the low-frequency content dominates the spectrum.

4 DISCUSSION

This study does not attempt to clarify the underlying causes of position error at low frequencies. The OPTOTRAK resolution limits detection of physiological tremor, though it is certainly present. This includes both a neurogenic component, around 8-12 Hz, and a "mechanical-reflex" component, which depends on mechanical properties of the arm and hand, and has been measured at 8-12 Hz in the wrist and 17-30 Hz in the metacarpophalangeal joint [1]. The low-frequency error detected may include other involuntary components of motion, as well as possibly voluntary compensating movements based on visual feedback of position error.

Low-frequency components of position error are present in pointing to moving targets as well as stationary ones [4]. Due to the ubiquitous nature of low-frequency error, systems to suppress involuntary motion in microsurgery ideally should take into account not only physiological tremor, but also low-frequency error. This is expected to be difficult, particularly since the frequency range of this motion is coincident to a large degree with that of voluntary motion.

5 CONCLUSION

Human motion contains not only physiological tremor, but also other error components. These components are lower in frequency than the range commonly attributed to tremor, and may be of equal or greater amplitude.

ACKNOWLEDGMENTS

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Table 1: Norm of Error Standard Deviation Vector

Type of support	*mean of test s.d.'s*	*s.d. of test s.d.'s*
arm only	0.34 mm	0.16 mm
arm & hand	0.19 mm	0.15 mm

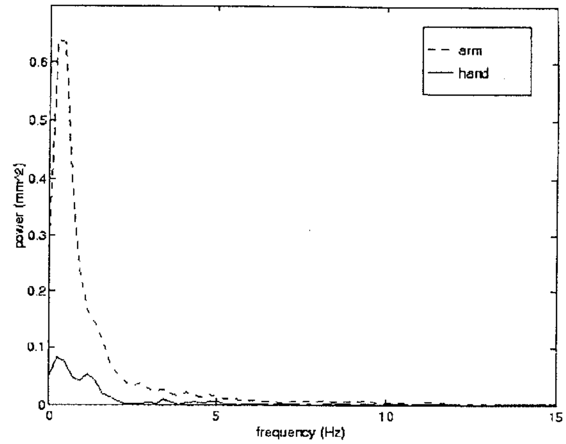

Figure 1. Averaged power spectra for all 10 subjects. Data shown are from a horizontal dimension of the motion. The dotted line indicates the supported-forearm case, the solid line the supported-hand case. Low-frequency error clearly dominates the spectrum.

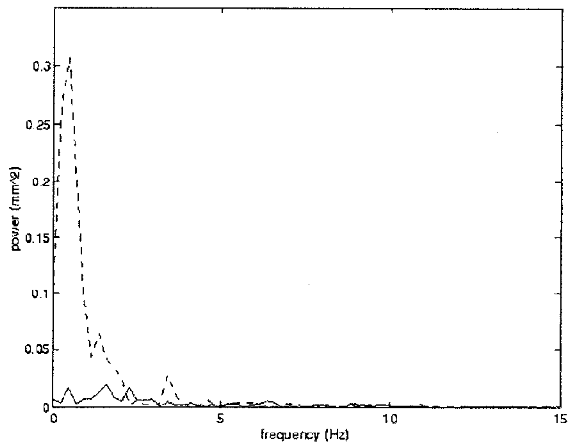

Figure 2. Typical power spectra for an individual subject. Data shown are from a horizontal dimension of the motion. The dotted line indicates the supported-forearm case, the solid line the supported-hand case. Low-frequency error clearly dominates the spectrum.