Robotic Microsurgery

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In modern medicine, microsurgery has become commonplace. The advantages of reduced cost, reduced impact to the human body, and reduced recovery time are undeniable. Although technology has given the surgeon unlimited resolution when viewing the target area, the steadiness of his hand has become the weakest link in assuring a safe and successful procedure. This is true especially in the areas of ophthalmological (eyes) and neurological (brain and nervous system) surgery where the slightest twitch could prove dangerous to the patient (Choi Flexure). For surgeons performing microsurgery, involuntary hand motion limits the accuracy with which he or she operates. These involuntary hand motions include physiological tremor and jerk, and are inherent in a normal human body (Riviere). This research survey presents a potential solution to this problem that is a handheld probe which actively compensates for tremor-like hand motions. Surgical probes serve many functions ranging from and endoscope which transmits images to lasers that can destroy tissue. This particular active probe was designed at the Robotics Institute at Carnegie Mellon University and is referred to as the Micron. "A full prototype of the Micron, with three motion sensors and three actuators (i.e., motors), has been completed and preliminary tests have demonstrated attenuation of tremor-like oscillations by as much as 50% (Riviere)."

Physiological tremor was traditionally thought to be nearly sinusoidal with a typical amplitude of 50 microns (um) peak to peak and frequencies in the range of 8-12 Hz (Choi Test) "However, more recent research and further studies at Carnegie-Mellon have shown that involuntary motion has lower frequency components which are below 1 Hz and need to be considered in order to achieve the desired accuracy of 10 microns (um) (Choi Test)."

The operating principle behind the Micron probe is very straight forward. The probe uses 3 sensors to sense motion in all 6 degrees of freedom (DOF), x motion, y motion, z motion, rotation about x, rotation about y, and rotation about z. From these measurements, one can estimate the resulting motion of the probe tip, x, y and z. Because the probe tip is simply a point in space, any translations or rotations in the probe can be expressed as only translations at the probe tip. Mathematical algorithms then separate motions which are determined to be characteristic of physiological tremor. These motions are then canceled out by subtracting them from the probe tip via the x, y, and z actuators (Ang).

To provide motion information on the probe tip, "Micron currently uses a 5 degree of freedom (DOF) optical sensing system called "ASAP" (Apparatus to Sense Accuracy of position) (Choi Test)." The sixth DOF is provided by a pair of accelerometers used to determine the rotation of the Micron probe about its center axis (Choi Test). "The noise for ASAP is about 0.5 μm RMS (Choi Test)."

"The mechanical mechanism in Micron is a flexure based 3-DOF manipulator that uses three piezoelectric stack actuators. Flexures are levers used to mechanically amplify forces or displacements. Piezoelectric actuators produce a force or displacement proportional to the applied voltage. These actuators can produce a motion of 15 um which is mechanically amplified with a set of lever arms (Choi Flexure)." "The range for the manipulator is about 400 μm in the transverse axes (i.e., x & y directions) of the probe and about 80 μm in the axial direction (Choi Flexure)." Due to the limited range in the axial direction, compensation was only performed in the transverse directions (Choi Flexure).

A series of tests were performed comparing the probe's performance in both compensated and uncompensated mode. The subjects, six novice users and one surgeon were asked to perform a tracing task, six times without active tremor compensation, and six times with active tremor compensation (Choi Test). This was repeated for 10 consecutive days to understand the effect of learning on the process. Results showed a significant improvement in going from uncompensated to compensated for novice users. RMS error was reduced from about 40 microns to about 20 microns (Choi Test). Also, learning was a key factor for the novice in reducing the RMS error from about 30 microns to about 20 microns after a few days. However, for the surgeon, results with and without active compensation were not statistically significant (Choi Test).

In conclusion, the active probe is a good idea and proved very effective for novice users. Based on very limited data (i.e. a single surgeon), the probe did not appear very beneficial to the surgeon, who is primarily the intended target for the device. There should be concern that this method may not be feasible based on new data that tremors exist at frequencies below 1 Hz. How can one separate an involuntary tremor from a voluntary movement at such low frequencies?

Works Cited

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