Vision-Aided Active Handheld Instrument for Microsurgery

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PROJECT DESCRIPTION:

Introduction & Objectives

Humans have intrinsic limitations in manual positioning accuracy due to small involuntary movements inherent in normal hand motion. The most studied involuntary hand movement is physiological tremor, which is found to be about 78 µm rms under surgical conditions and in the frequency band of 8 to 12 Hz. The high level of manual accuracy demanded by microsurgery restricts the number of qualified surgeons. The fact that human hand stability deteriorates with age further aggravates the situation. Even for microsurgeons in their prime years, fatigue, alcohol and caffeine consumption, and other factors affect the manual stability. Some surgeons also take beta blockers to attenuate their tremors. It is inevitable that, over time, fatigue will set in and degrades the hand stability of the surgeon when operations last several hours, which is very common especially in reconstructive microsurgeries. This manual imprecision complicates many delicate procedures, and hampers the viability of certain treatments and researches.

Our proposed technique will extend the micromanipulation accuracy and steadiness of the surgeon beyond human limitation. Successful implementation will raise the quality of the current practice in microsurgery and make possible many new interventions that require higher precision.

The main objective is to develop a computer vision-aided intelligent handheld instrument to enhance human manual positioning accuracy in microsurgery.

We have developed an active handheld instrument that would detect its own motion, distinguish between undesired and intended motion, and deflects its tip for active compensation of physiological tremor under the research project - "Intelligent Handheld Instrument for Active Error Compensation in Medical and Biotech Micromanipulation Applications". This project will extend the capability of this tremor compensating instrument with image-processing and computer vision techniques to create a handheld vision-aided microsurgical interventional device.

The specific aims are to:

- Develop a microscope based high precision, high speed vision system to track the microsurgical tool and the targets for interventions.
- Develop vision-aided tooltip stabilizing algorithm with "snap-to-target" capability to enhance the performance of the existing intelligent handheld microsurgical instrument.
- Evaluate the performance of the system by trained microsurgeons with cell micromanipulation experiments and animal microsurgery trials;
- Study the human-machine interface of the proposed system and device a training program for experienced and novice microsurgeons.

While this technology is applicable to most manual micromanipulation tasks under a microscope equipped with camera(s), the targeted applications in this proposed project are microsurgery procedures that require high positioning accuracy but relatively less demanding in the dexterity of the tool movement. While this technology may still be in its infancy with regards to direct clinical application, it represents a step towards a new horizon of developing instruments for more complex clinical tasks such as microsurgical manipulation and suturing of vessels in reconstructive microsurgery.

Methodology

a) System Overview

We have developed an active tremor compensating handheld microsurgical instrument capable of:

· Sensing its own motion with three dual-axis miniature MEMS accelerometers;

· Distinguishing between tremulous and intended movement of the hand in real-time with an adaptive zero-phase filter;

· Compensating the erroneous hand movement by deflecting the tooltip in an equal but opposite motion with a 3 degrees-of-freedom parallel robotic micromanipulator.

The proposed microsurgical concept (Fig. 1) consists of the following components:

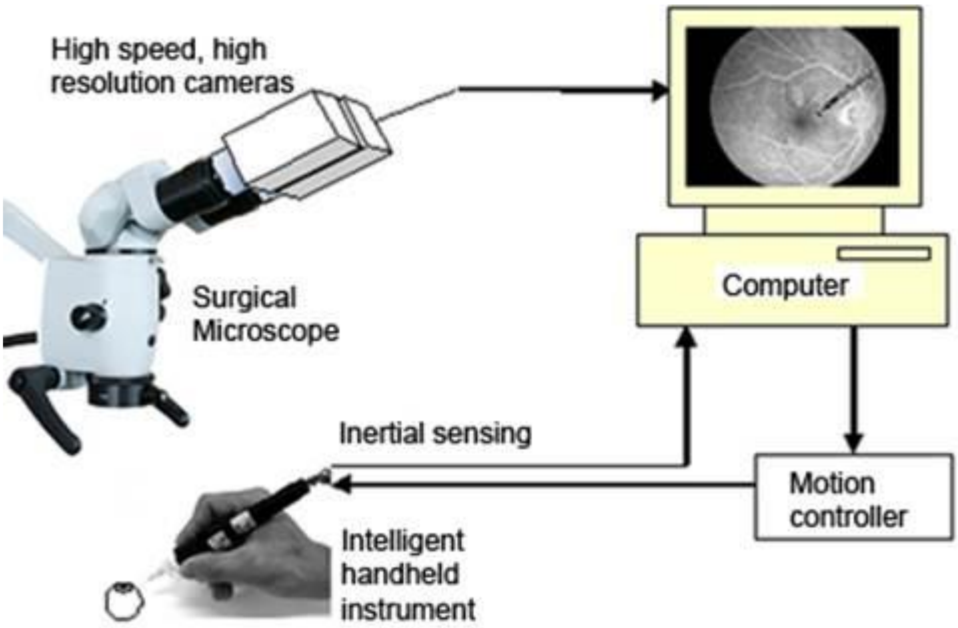

Fig 1 Vision Aided Intelligent Handheld Instrument for Microsurgery

· A surgeon performing microsurgery with the active tremor compensating handheld instrument;

· A surgical stereo microscope with an assistant scope;

- A pair of high speed monochrome CCD cameras with on-board microprocessor are attached to the binocular eye-pieces of the assistant scope;

- An industrial computer equipped with a real-time multi-channel ADC/DAC card.

b) Vision Tracking System

The research and implementation of the microscopy-based stereo vision tracking system involves the following:

(i) Calibration and Registration

Our work in vision guided robotic cell micromanipulation led to the development of a template-free registration method where registration is performed on-the-fly with a sequence of tool tip images produced by known movements of the instrument. This method will be extended to perform simultaneous calibration of the vision system and registration of the instrument.

(ii) Visual identification and tracking of tooltip and surgical targets

Two strategies will be adopted in our algorithm development for visual identification and tracking of surgical targets, one for simple scenes (e.g. single cell micromanipulation) and the other for complicated scenes (e.g. bloody surgical situation). Template matching techniques may be employed to identify and track the target in simple scenes where the target's shape and appearance is known. For complicated scenes where the target may be partially occluded by blood or other tissues, or where there may be poor contrast between the target and the background, the initial target will be selected by the surgeon or one of the assistants by pointing and clicking the cursor on a computer monitor. A feature-finding algorithm will be used to locate and lock on to the target. In subsequent images, a window containing the target and surrounding image landmarks will be automatically selected from the initial image and matched to the next image. With sufficient image landmarks in the window, the vision system can infer and estimate the location of the target even if the target point is temporarily occluded partially or totally. It is possible for the proposed vision system to track multiple targets simultaneously, with slight degradation of the vision sampling rate.

(iii) Image processing for high frame rate visual servoing

Surgical targets are usually almost stationary whereas the intended hand movement of a surgeon during microsurgery is typically less than 0.5 Hz. However, physiological hand tremor is usually in the band of 8 - 12 Hz. Thus, it is desirable to have a vision sampling rate of at least 60 fps for effective visual servoing. We propose to implement both software and hardware solutions to this issue.

c) Vision-Aided Instrument Stabilization Algorithm

The vision-aided instrument stabilization algorithm will include the following components:

(i) Sensor Fusion

The absolute pose of the instrument must be known to maintain registration between the instrument body frame and the camera frame. After registration is done, the two sets of correlated information describing the kinematics of the instrument may be combined using sensor fusion techniques to enable superior sensing.

(ii) Snap-to-Target

This is a visual servoing technique to manipulate the instrument tip to point at or move toward a visual target while the instrument continues to compensate for the physiological tremor of the user. In addition to performing image-guided stabilization of the tool tip, the system can also use the visual information to determine the position of a target relative to the tooltip. When the target(s) come within the workspace of instrument robotic micromanipulator, the system may ‘snap’ the tooltip toward the target.

d) Human-Machine Interface

With any introduction of new instrument to surgical interventions, some form of retraining will be needed to help the surgeons to adapt and home their skills to perform with the new tool. Experienced microsurgeons have, over their years of practice, developed skills to compensate for their inherent manual inaccuracy. While it is impossible to stop their hand from tremulous oscillations, many microsurgeons time their own oscillations and coordinate their intended manipulations with the up- or down-swing movement in a trial-and-error manner.

It is observed in our previous work that a user of the handheld instrument performs micromanipulation differently when the tremor compensation function is turned on and off. While preliminary experiments have shown that performance of the user can be greatly enhanced by the system in simple micromanipulation tasks, the specific skill of the individual to overcome his tremor oscillation in complex maneuvering might be altered.

A formal study will be performed to determine the extent to which the new handheld instrument can be used by the surgeons to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

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PUBLICATIONS:

Refereed Journal (Published/In Press):

1. Y. N. Aye, S. Zhao, and W. T. Ang, "An enhanced intelligent handheld instrument with visual servo control for 2-dof hand motion error compensation," Intl. J. Advanced Robotic Systems, vol. 10, no. 355, 2013.
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8. Y. N. Aye, S. Zhao, C. Y. Shee, and W. T. Ang, "Fusion of inertial measurements and vision feedback for microsurgery," in Intelligent Autonomous Systems 12, ser. Advances in Intelligent Systems and Computing, S. Lee, H. Cho, K.-J. Yoon, and J. Lee, Eds. Springer Berlin Heidelberg, 2013, vol. 194, pp. 27 – 35.