

Critical Review

Group 14

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Project

Name - Micron Range-of-Motion Visualization

Objective – Develop an efficient visual alert assistance system for the surgeons dealing with very small anatomies.

Paper Selection

Handheld Micromanipulation with Vision-Based Virtual Fixtures

B.C. Becker, R.A. MacLachlan, G.D. Hager, and C.N. Riviere. In IEEE International Conference on Robotics and Automation (ICRA 2011), May 2011, pp 4127-4132.

Reasons for selecting paper

- Virtual fixtures are tremor suppression are some of the major advantages of microsurgical tool, micron. These papers will help me understand more about the range of motion of the micron and how it can be controlled.
- Also these features of the micron are the reasons for developing a visual alert system for the surgeons. These features are very helpful during medical procedures like vitreoretinal microsurgery, and it would be a disaster if the surgeons had no idea about how the micron tip is moving inside the retina.

Problem Statement and Goal

In microsurgery, normal physiological hand tremors causes extraneous movement during microsurgery, making some high-precision operations difficult or impossible. Many robotic systems have been developed to compensate or suppress the tremor during microsurgery. As mentioned by the authors, “Robotic control aids for micromanipulation can be grouped into three categories: tremor compensation, motion scaling, and virtual fixtures”. In this paper, authors have concentrated on virtual fixtures and its use in motion scaling and tremor compensation. They aim to derive a simple position-based virtual fixture framework for handheld micromanipulators such as Micron.

Introduction and Background

For simplicity, tremor means any involuntary hand motion that creates position error. In medical terms, tremor is defined as a quasi-periodic motion. The concern is with the position error at the tip of the micron.

Authors, very aptly, described how important it is to suppress or compensate a tremor during microsurgery. They also briefly talked about various robotic platforms that were proposed to deal with the problems in micromanipulation.

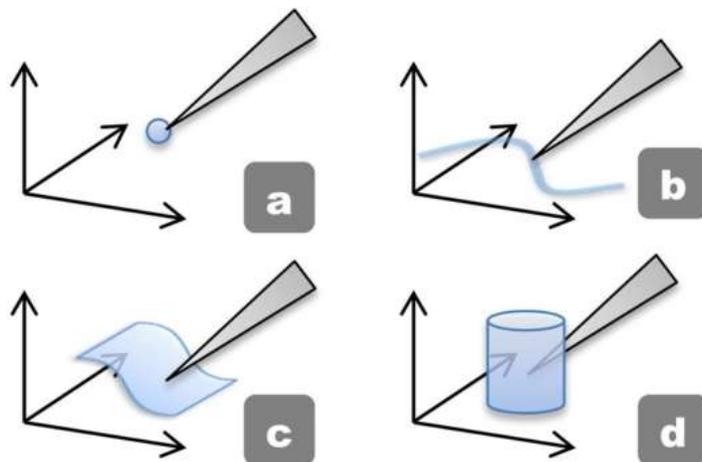
Micron was also slightly described in the introduction, which I felt was unnecessary, because they have a detailed description of micron and its setup in the background section.

Authors have clearly talked about the previous research in applying virtual fixtures to various robotic platforms and micromanipulation problems. They also mentioned why micron is different from the existing virtual fixture enabled robots and how it is more advantageous to have position instead of force as control input.

Method Overview

Author mentioned four types of virtual fixtures and their relevance in medical field,

- a) Point (0 DOF) – Steadying cannula during injection
- b) Curve (1 DOF) – Following path for laser ablation, guiding needle along a blood vessel
- c) Surface (2 DOF) – Maintaining a constant standoff distance, navigating in narrow crevices
- d) Volume (3 DOF) – Restricting the tip volumetrically to prevent tissue contact outside of 'safe' areas.



It has been asserted that Point virtual fixture is the base of all other higher-order subspace virtual fixtures.

For experimental purposes four tasks were considered,

- **Hold Still** – Held the tip of the micron 500 μm above a cross for 60s. Point fixture was used.
- **Circle Tracing** – Traced a circle with 500 μm offset from the rubber surface 3 times. A 3D curve fixture was used.
- **Move and Hold** – Moved the tip of the micron to each cross and held there for 3 s. Four plane segments oriented vertically and connecting each of the four crosses were used, forming a box fixture.
- **Volume Restriction** – Allowed the tip of the micron to move freely in a volume, without allowing the tip to leave the volume. A cylindrical volume fixture was used.

Each of these tasks were performed using a single individual familiar micron, with no surgical experience and on four different scenarios,

- **Unaided** – Micron turned off.
- **Aided with Shelving Filter** – Micron was turned on with the state-of-the-art tremor suppression and relative motion scaling algorithm.
- **Aided with soft virtual fixture** – Micron was turned on and using virtual fixtures with the motion scaling factor $\lambda = 1/5$.
- **Aided with hard virtual fixture** – Micron was turned on with virtual fixtures but no motion scaling ($\lambda = 0$).

Following are some variables that have been extensively used in formulating equations and for experimental results:-

P_T – Position of tip of micron

P_G – Goal Position

P_N – Null position (3D tip position under the assumption that micron is off)

M_O – Orthogonal Projection

F_T^n – Tremor suppression filter

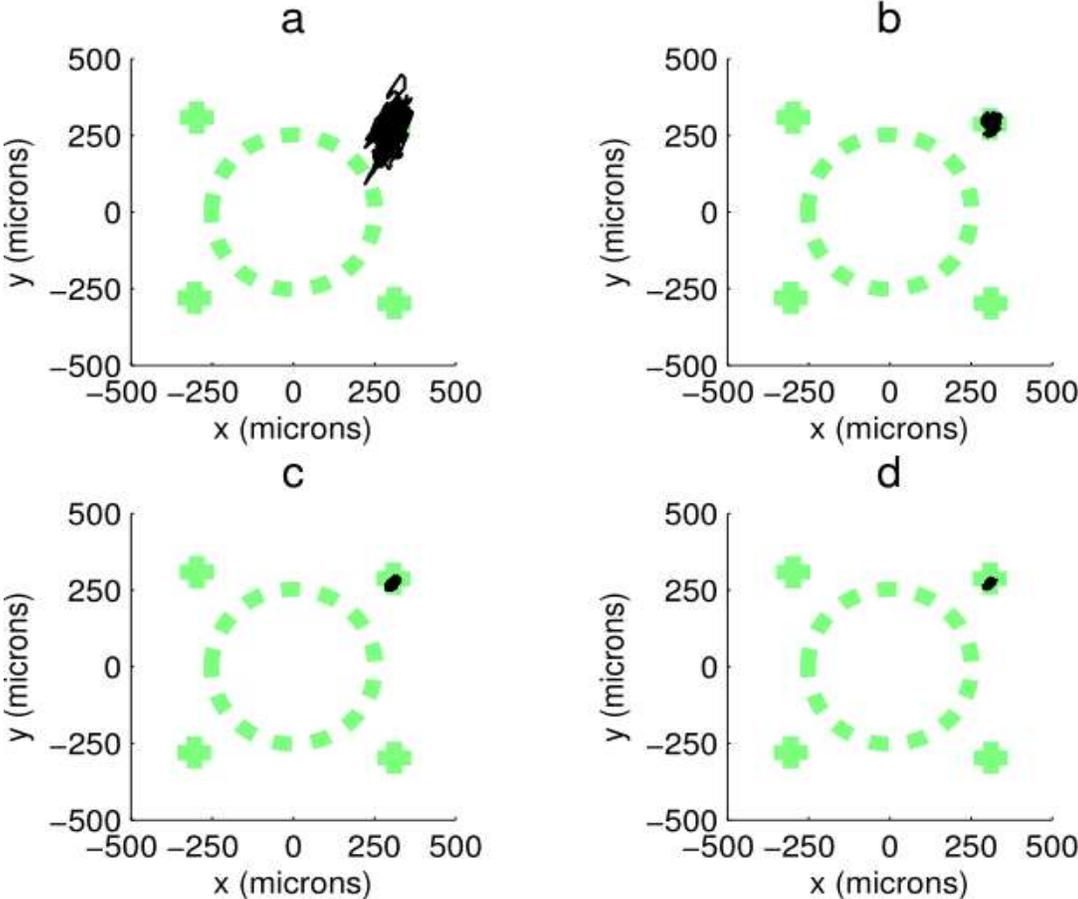
Several experiments were performed using the following two formulas to validate virtual fixture

$$P_G = M_O(\mathbf{V}, F_T^3(P_N))$$

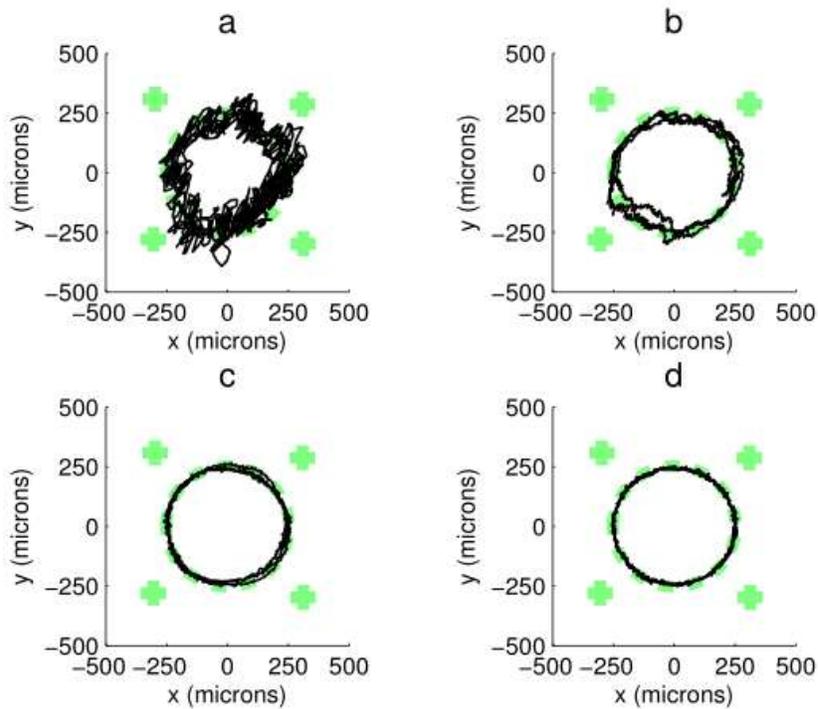
$$P_G = F_T^n(M_O^n(\mathbf{V}, P_N))$$

Results

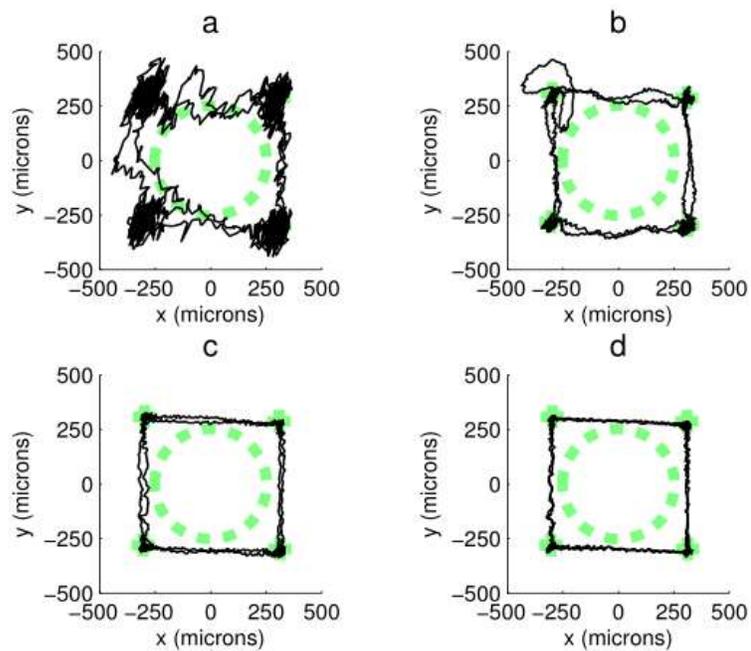
It has been observed that the move and hold experiment had much lower overall error, since the fixture was not restricting Z-movement. Also, in cylindrical volume fixture, hand motion exceeding 500 μm was successfully restricted to the volume with a max error of 25 μm . Following are some graphical results of Hold still, Circle tracing and Move and hold tasks,



Hold Still (a) Unaided (b) Aided with Shelving Filter
(c) Aided with soft fixtures (d) Aided with hard fixtures



Circle Tracing (a) Unaided (b) Aided with Shelving Filter
(c) Aided with soft fixtures (d) Aided with hard fixtures



Move and hold (a) Unaided (b) Aided with Shelving Filter
(c) Aided with soft fixtures (d) Aided with hard fixtures

Critique

The system setup for the experiment has been explained with minute details. Also having a screenshot of the hardware system, with clearly numbering each hardware, and describing their functionality, is very useful for the reader to understand the system architecture.

However, the author states that “**the 3 LEDs on the actuated shaft of the instrument allow a 6 DOF position tracking of micron’s tip**”, and he also mentions that “**the stereo cameras track both the tip of the instrument and the anatomical targets**”. My question is, if the cameras already track the micron tip, then why is there a need of 3 LEDs, or if the author actually is using those 3 LEDs for a different purpose, he should have mentioned that, even if it was a very minor dependency.

Problem definition has been explained again briefly before starting to describe the methods for solving them. I think that’s a good way of reminding the readers about the problem statement before reading the procedure.

In the rest of the paper the author has dedicated to devising virtual fixtures that modify the behavior of the tip of the micron, while using the handle position as the indicator of the operator’s intentions. He elaborately describes virtual fixtures with various degree of freedoms, like a point (0 DOF), line (1 DOF), surface (2 DOF) and volume (3 DOF). It has also been mentioned why point fixture is the base of all the fixtures.

Various formulas have been provided for the reader to understand the concepts of motion scaling and different fixtures.

The graphical representation of the different scenarios have been presented, detailing the errors as well.

Results are also displayed in the form of bar graphs, which I believe is very useful for the readers to just have a glance, rather than reading the detailed explanation.

Conclusion and Future Work

In the paper, authors have successfully demonstrated a derivation of virtual fixtures for handheld micromanipulators that takes handle or hand position as control input instead of force. Virtual fixtures have been validated with relevant tests and the results have been portrayed in an understandable manner.

In the future, authors propose to implement virtual fixtures in critical procedures like vitreoretinal microsurgery, where extremely high precision is required.