3D Tool Tracking in the Presence of Microscope Motion

Computer Integrated Surgery II

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Introduction:

Key Progress:

- Tracked color markers on surgical tools and in background in stereo video
- Triangulated 3D marker points from calibrated microscope
- Used bundle adjustment to track camera motion from background markers
- Stabilized tool points by applying the inverse of camera motion
- Performed frequency analysis of manual and robot tool motion

Problem:

- Hand tremor poses a risk to patients in microsurgery

Goal:

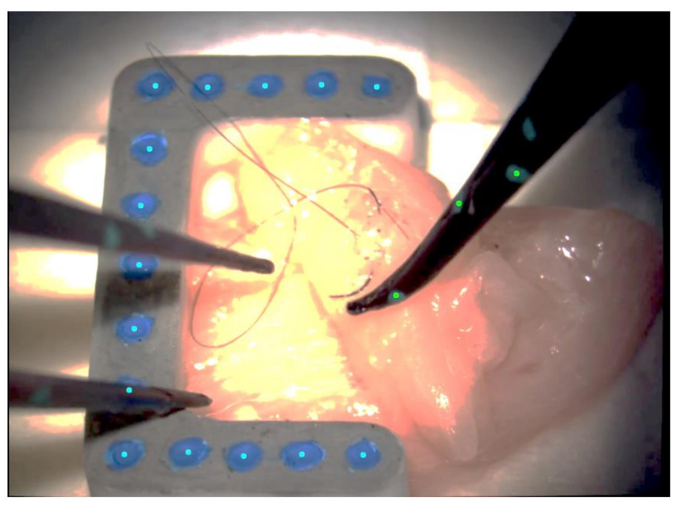
- Understand quantitatively how the Galen surgical robot reduces hand tremor

Solution:

- Python algorithm to track tool tremor and microscope motion

Stereo Microscope Video → Color Marker Tracking → Camera Motion Compensation → Frequency Analysis

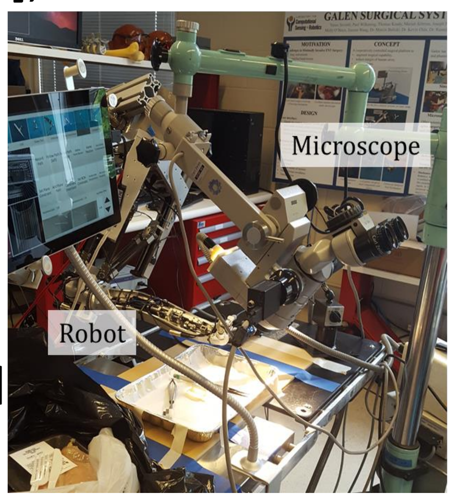
Color Marker Tracking:



- Blue markers were painted on a 3D printed background marker, green markers were painted on the surgical tools
- Color histograms were created of marker colors
- A Gaussian Mixture Model computed the probability each pixel was a marker
- Template of background markers was matched to the marker probability image created for each frame to compute the background marker positions
- Tool markers were detected with MSER blob detector

The Problem:

Experimental Setup



- Physiological hand tremor, on the order of 40µm[1], poses a risk to patients in microsurgery
- Surgical robots can reduce hand tremor, but the quantitative reduction in tremor is not known
- Hand tremor can be seen through stereo microscopes. But,
  - microscopes are not rigid and their motion add artificial movement to microscope videos
  - Very accurate tool tracking is required to capture small, high frequency tool tremor

Camera Motion Compensation:

- In the experiments the background points are stationary, any observed background motion is camera motion
- Background points in each frame were triangulated
- Procrustes algorithm was used to get initial guess of transform between the first frame of points and the current frame
- Bundle adjustment used to get optimal transform from each frame to the first frame, removing any camera motion

Frequency Analysis:

- Tool marker positions in each frame were matched to nearby markers in adjacent frames to form 3D trajectories in time

$$\vec{x}(t) = [x(t), y(t), z(t)]$$

- 1D DFTs of $x(t), y(t)$, and $z(t)$ are taken

$$X(f) = DFT(x(t), Y(f) = DFT\big(y(t)\big), Z(f) = DFT(z(t))$$

- The DFT magnitudes at each frequency were summed to compute the maximum amplitude of movement

$$s(f) = |X(f)| + |Y(f)| + |Z(f)|$$

- To visual intentional and actual trajectories, a low pass filter from [0,5] Hz was applied to X(f), Y(f), and Z(f) and then the inverse DFT was taken

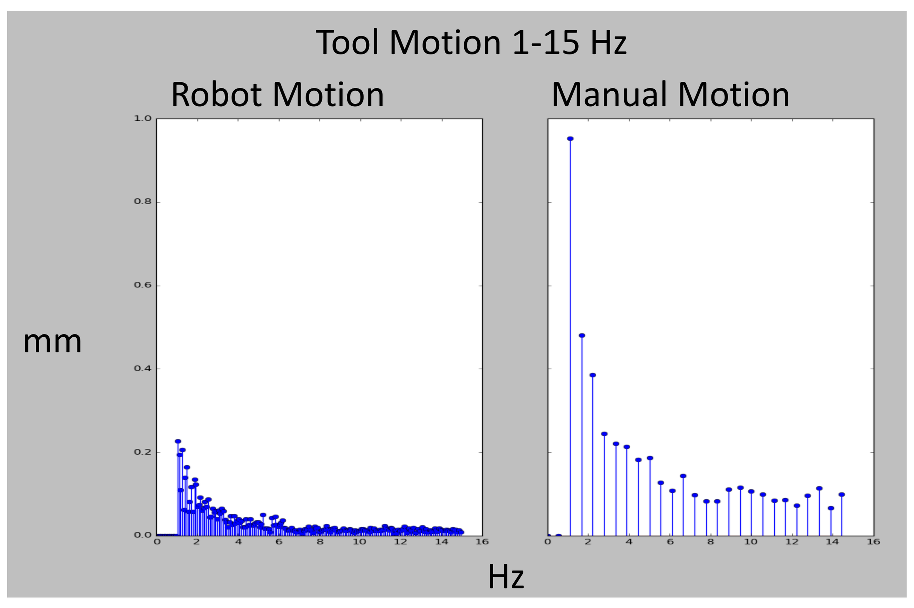
Results:

Camera Motion Compensation

- The background marker was moved a known distance
- Camera motion compensation stabilized the marker. Distance between original points and stabilized points was computed as movement

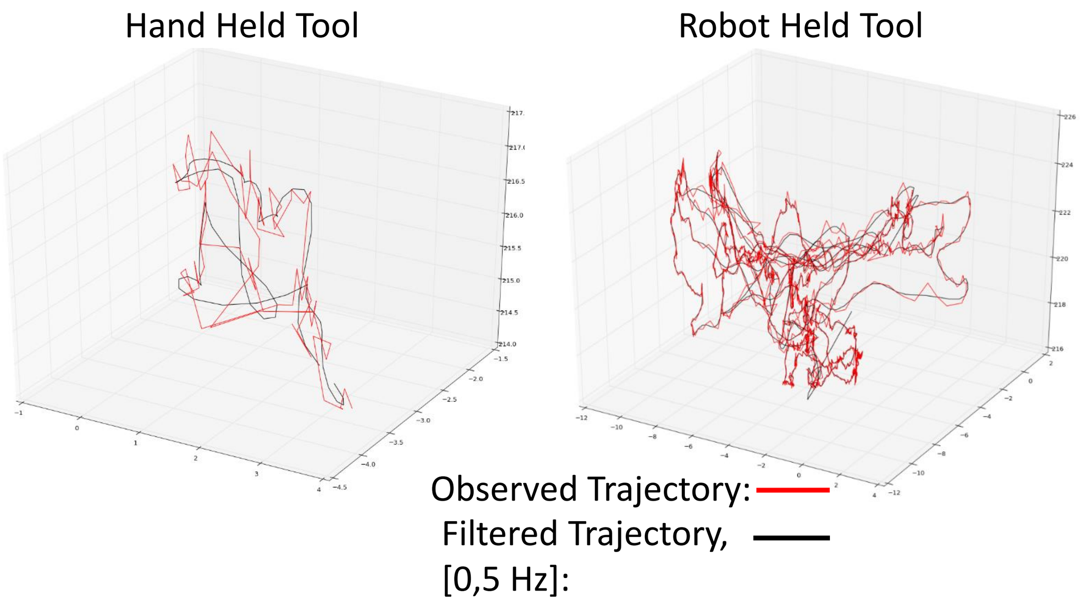
True Movement	Tracked Movement	Error
6.3 mm	6.804 mm	0.504 mm
12.6 mm	13.03 mm	0.430 mm
18.9 mm	20.33 mm	1.43 mm
25.2 mm	25.8247 mm	0.625 mm

Frequency Analysis



Tremor Results	Robot	Manual
Max Amplitude	0.050 mm	0.14mm
Frequency	5.22 Hz	6.67 Hz

Tool Trajectories



- Camera motion compensation implemented, not used in frequency results because background marker was not stable in this experiment. A marker holder was built so it will be stable in future experiments.

Experiments:

- Stereo microscope video of a novice performing suturing manually and with the Galen robot was recorded.

Future Work:

I will continue this work in the summer supporting micro anastomosis studies done by surgeons to compare hand tremor in manual suturing and robot-assisted suturing. The logical next step for this work would be tracking the tools and background without color markers. Tool tracking without is an active area of research.

Lessons Learned:

- Plan on performing experiments multiple times, you will learn about how to improve the experiment each time you record data.
- Keep the big picture in mind, understand which deliverables are essential and which are flexible.

Conclusions:

The contribution of this study is to show that with the Galen robot, motion above 5 Hz is limited to 50 microns. High frequency motion in hand-held tools is below 140 microns. The magnitude of robot motion steadily decreases as frequency increases. For the hand-held tool there are spikes in motion at 6.67 Hz, 10 Hz and 14 Hz.

Publications:

[1] S. P. N. Singhy and C. N. Riviere, "Physiological tremor amplitude during retinal microsurgery," in Bioengineering Conference, Philadelphia, 2002.

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