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
- 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 adds artificial movement to microscope videos
- Very accurate tool tracking is required to capture small, high frequency tool tremor

Solution:

- Python algorithm to track tool tremor and microscope motion

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

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

Frequency Analysis:

- Tool marker positions in each frame were matched to nearby markers in adjacent frames to form 3D trajectories in time
  \[ \bar{x}(t) = [x(t), y(t), z(t)] \]
- 1D DFTs of \( x(t), y(t), \) and \( z(t) \) are taken
  \[ X(f) = DFT\{x(t), Y(f) = DFT\{y(t), Z(f) = DFT\{z(t)\} \]
- The DFT magnitudes at each frequency were summed to compute the maximum amplitude of movement
  \[ s(f) = |X(f)| + |Y(f)| + |Z(f)| \]
- To visualize 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

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.

Support by and Acknowledgements:

- Core NSF CISST/ERC Grant

Thank you to Taylor, Dr. Reiter, and Yunus for your technical support. Thank you Paul for helping me set up the microscope and robot each time I recorded data. Thank you Abhinav for designing the background marker. Thank you Radhika for printing the background marker and for designing and printing the tray. Thank you Alexis for helping me throughout CIS 1 and CIS 2.

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 motion analysis of robot and manual tools
  - Robot Motion
  - Manual Motion

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