Intraoperative Visualization of Anatomical Targets in Retinal Surgery

Seminar Presentation

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Project Background

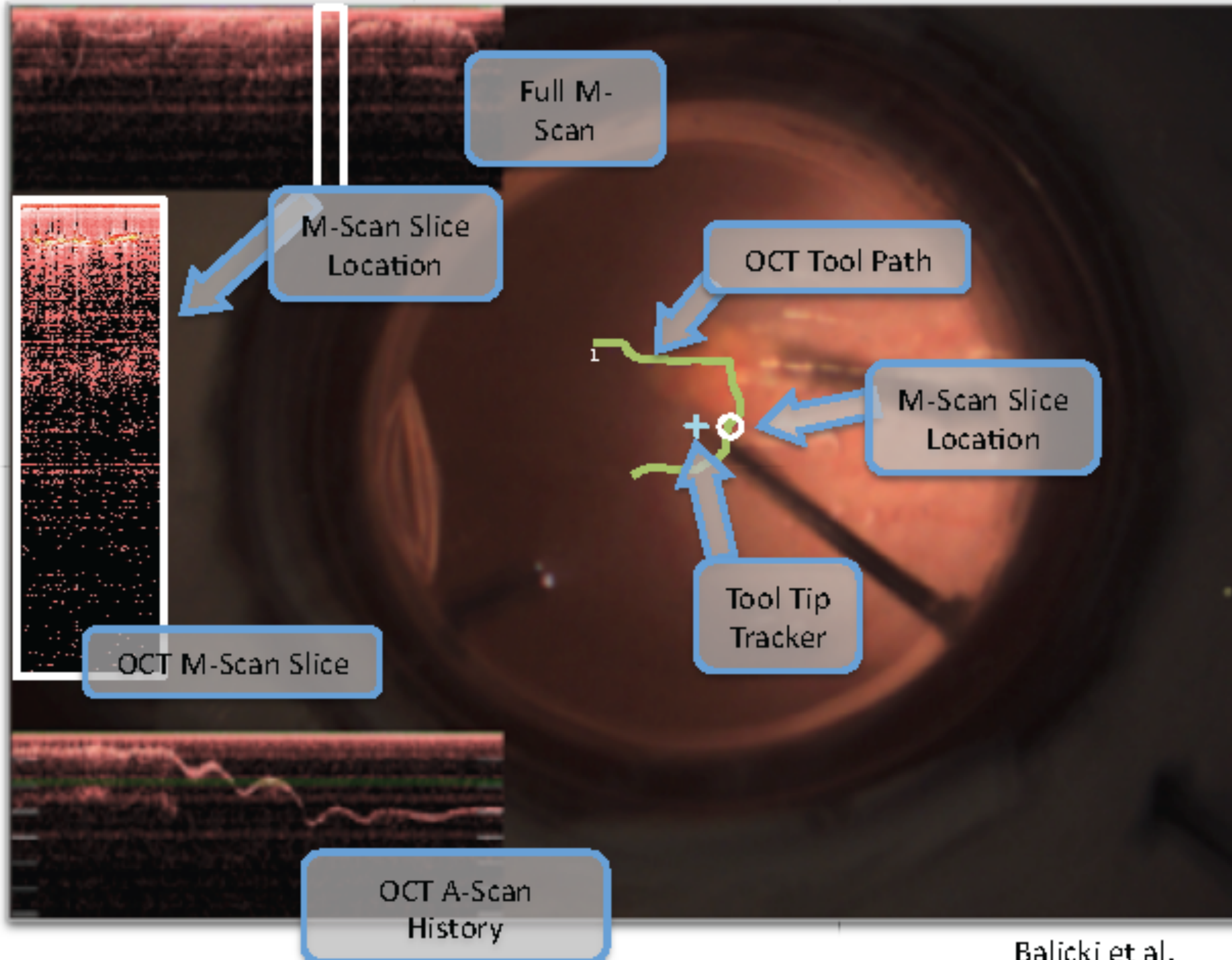
Assessment of Intraoperative OCT Imaging in a Simulated Micro-Surgical Task

Main Goals:

- Assess efficacy of intraoperative OCT for locating epiretinal membranes
- Improve the user interface/GUI
- Implement smart OCT processing & color enhancements

Important feature of system

- Visual tracking and annotation



Balicki et al.

Paper selection and relevance

Intraoperative Visualization of Anatomical Targets in Retinal Surgery

Ioana N. Fleming, Sandrine Voros, Balazs Vagvolgyi, Zach Pezzementi, Dr. Jim Handa, Russell Taylor, Gregory D. Hager

- Example of highlighting/annotation of features on video for intraoperative use
- Conducted subject experiment to test variation in accuracy & targeting time

Summary

Paper presents a framework for improving retinal microsurgery outcomes by

- registering preoperative diagnostic images (OCT) with the intraoperative video data
- tracking anatomical features localized thanks to the registration phase

The enhanced information is displayed during the intervention using a 3D visualization system.

Background

Typical set up for surgery

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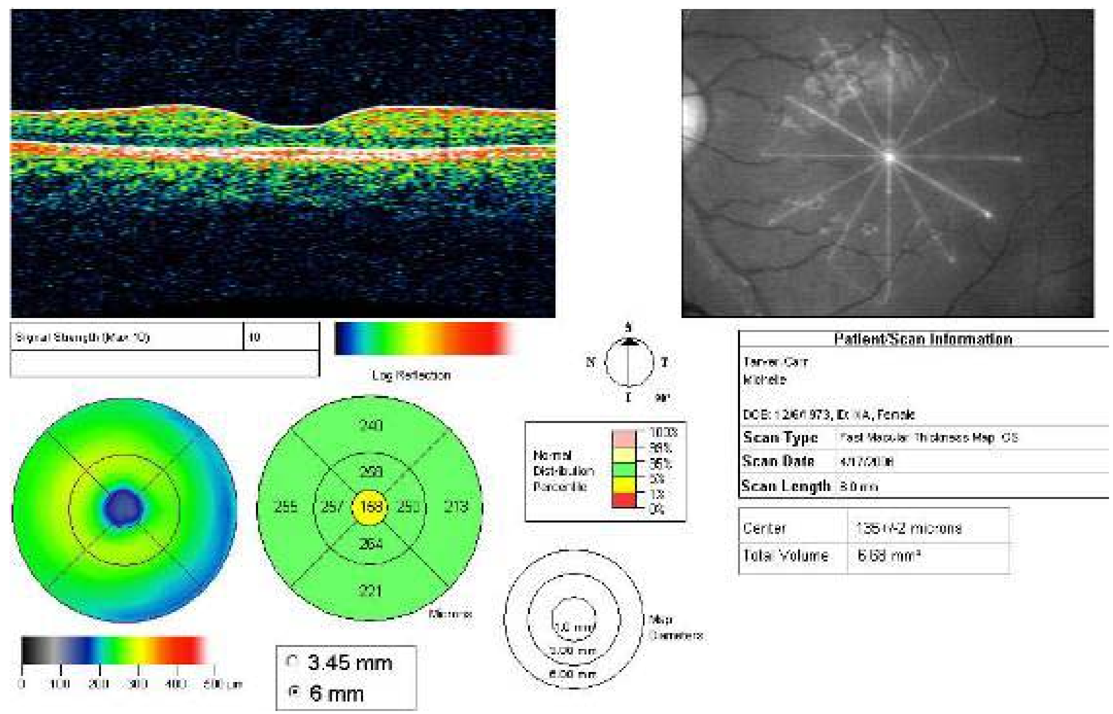
- Usually involves direct visualization
- OCT used to image pre-operatively
- Replace direct visualization with annotated video feed

Some difficulties

- Resolution & dynamic range of displays/cameras sufficient
- Registration without fiducials
- Static registration between preoperative and intraoperative imagery, of an anatomical target that is manipulated
- Retina is mobile during procedure

Methodology

- Optical Coherence Tomography (OCT) for pre-operative images
    - Provides information on depth of tissue layers
    - Paired with a low quality fundus image known as the targeting image



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Methodology cont.

- High-resolution fundus image
  - Photograph of the interior surface of the eye made with ophthalmoscope
  - Direct observation of microcirculation, blood vessels used as landmarks for registration

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Methodology cont.

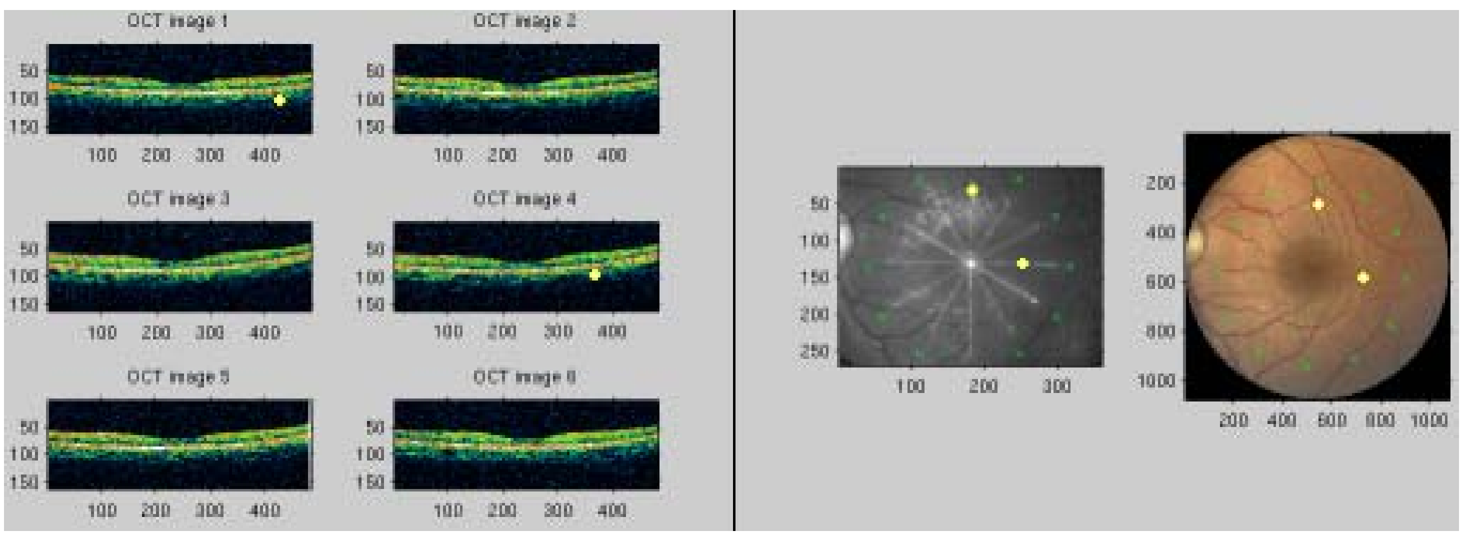
- Microscope view

Algorithm in a nutshell:

- OCT to target image alignment
- Register targeting image to pre-operative high resolution fundus image
- Register fundus image to microscope view
- Maintaining fundus microscope registration through visual target tracking

OCT to target image alignment

- Span and orientation of each OCT cross-section of retina known with respect to targeting image
- Adjust scale of OCT to fit corresponding representation in targeting image



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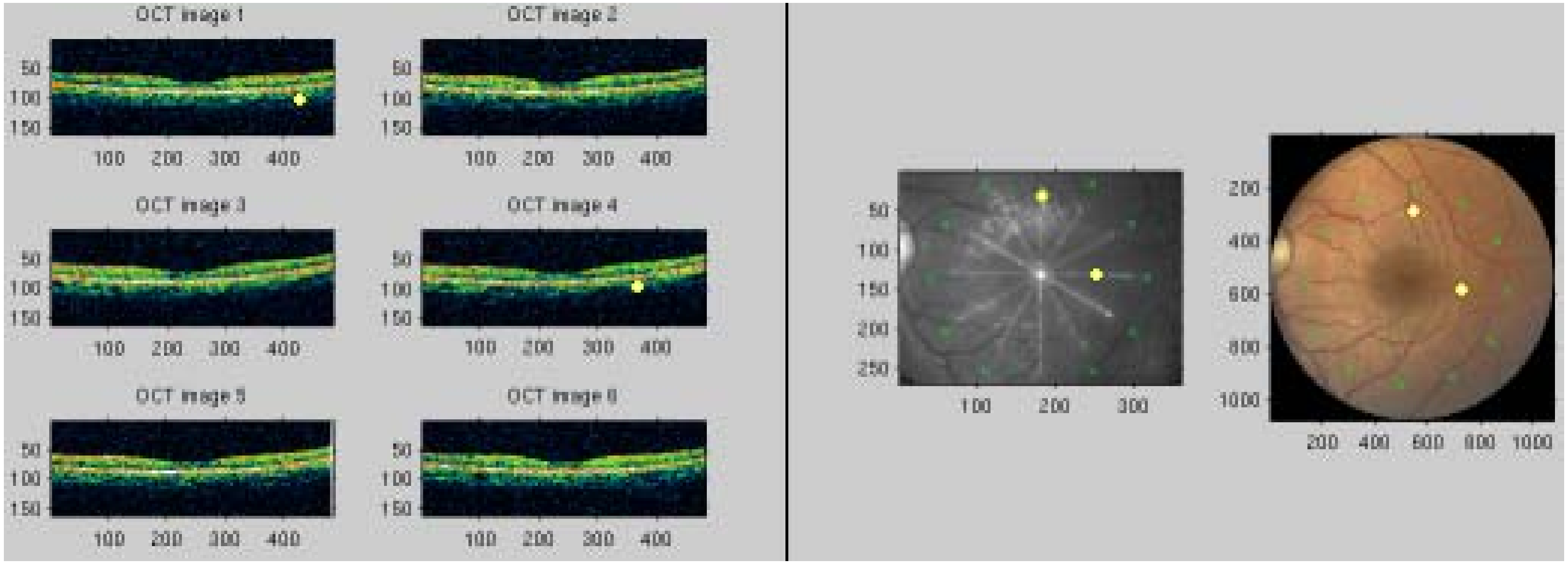
Targeting image to fundus image registration

- Targeting image low resolution
  - low overlap
  - orientation and scale differences
  - illumination variation
  - physical changes in the scene

- Stewart's Dual Bootstrap ICP algorithm used

Stewart's Dual Bootstrap ICP algorithm

- Feature based approach: uses blood vessel branching and cross-over points
- Extracts and matches keypoints to generate initial similarity transform estimates, accurate over bootstrap region
- In each region, iteratively:
  - Refine transform estimate using region constraints
  - Expand bootstrap region
  - Test to see if higher order transformation model can be used
  - Terminate when region covers overlap between images



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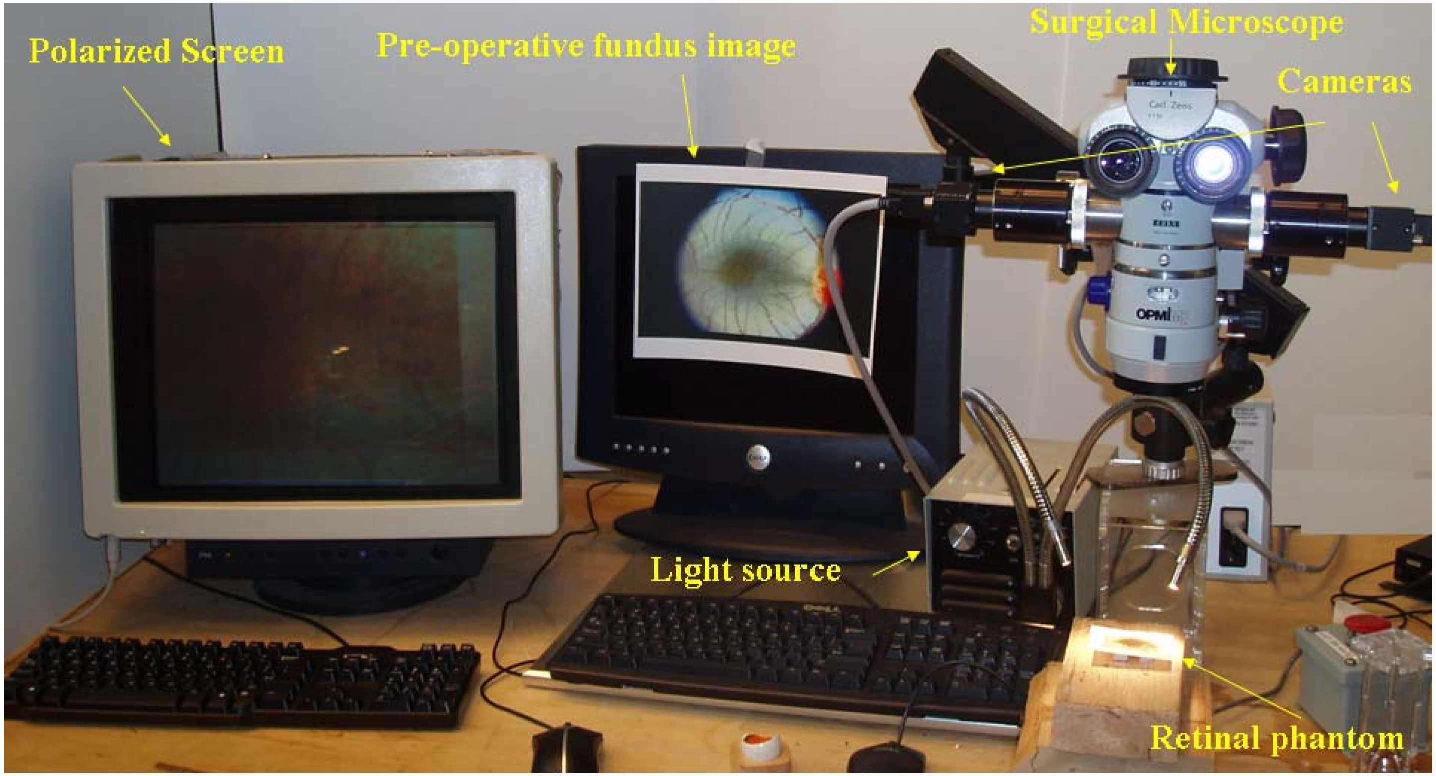
Fundus image to microcospe registration

- Register small patch of retina visible through microscope with complete fundus image
- Also uses Stewart's dual bootstrap ICP algorithm
- Anatomical targets registered tracked in stereo
    - Uses region-based tracking algorithm
        - Based on direct image matching of selected regions
        - Minimizes sum of squares differences between ground truth region and a candidate region

- Final microscopic view with target overlay is displayed in 3D using polarizing screen

System set up



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- Retinal phantom
  - Small region of high-resolution fundus image printed on glossy photo paper
  - Placed under surgical microscope as intra-operative reference image
  - Restricted target motion to planar rigid body motion
  - Single target was tracked
- Experimental design
  - Anatomical target defined on initial microscopic view, considered ground truth
  - Multiple attempts to reach target with microsurgery tool
  - Goals
    - Asses accuracy of tracker during series of motions
    - Compare target reach time with and without overlay
    - Compare accuracy with and without overlay

- To assess precision tracked one target and recorded 9 images at different positions & orientations of the reference image

- Ground truth and tracked target were projected onto same image, their distances were computed to obtain error of tracking algorithm

- To compare gesture accuracy and targeting time authors performed 6 targeting trials with overlay and 6 without it
  - Collected one microscope view at beginning and end of each trial

Registration of phantom image with fundus image

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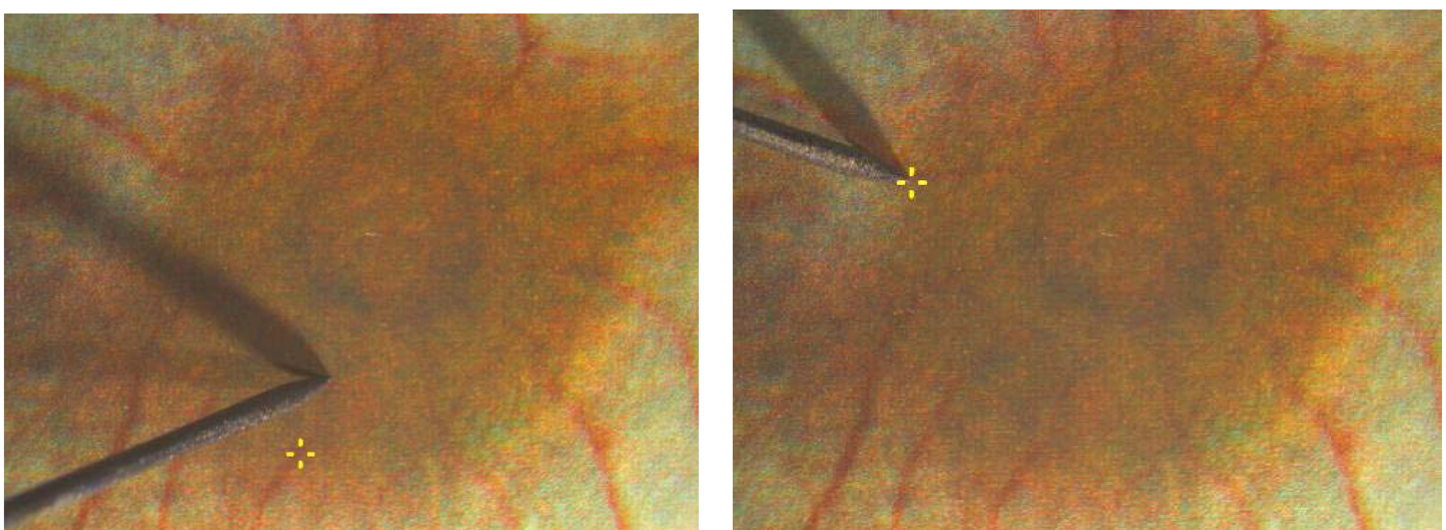

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Target reaching without overlay (left) and with overlay (right)

Result

- Tracker error of 3.86 ± 2.25 pixels
  - Assuming diameter of eye between 23.5 - 25 mm estimate error between 0.04 - 0.044 mm
- The targeting time 8.59 ± 4.8 s without overlay & 8.26 ± 2.13 s with the overlay
- Precision in identifying target
  - Without overlay: 50.83 ± 54.57 pixels, 0.527 ± 0.583 mm
  - With overlay: 0.087 ± 0.096 mm
- Tracking processing speed of 31-33 FPS using chorioallantoic membrane (CAM) of 12 days old chicken embryo

Assessment

Positive points:

- Significant increase in targeting accuracy
- Good example of video annotation for retinal surgery

Shortcomings:

- Small sample size composed exclusively of authors
- Print-out phantom not deformable unlike real retina
- Tracking algorithm supports only single target tracking, occlusion of which affects its performance
- Could use better explanation of Stewart's algorithm and tracking algorithm
- What if retina manipulation/ membrane peeling changes location of targets?

Future Work

- More extensive usability study
- Adapt tracking algorithm to detect occlusions and support multiple targets
- Replace polarized screen with head-mounted display
- Incorporate to hand-guided robot like Steady Hand Robot

Thank you!

Questions?