Intraoperative Visualization of Anatomical Targets in Retinal Surgery
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
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

- 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

Flemming et al.
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

Flemming et al.
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

Flemming et al.
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
Flemming et al.
- 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

Fundus image to microscope registration
Final microscopic view with target overlay is displayed in 3D using polarizing screen

System set up

Flemming et al.
● 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

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

- Tracker error of $3.86 \pm 2.25$ pixels
  - Assuming diameter of eye between 23.5 - 25 mm estimate error between 0.04 - 0.044 mm
- The targeting time $8.59 \pm 4.8$ s without overlay & $8.26 \pm 2.13$ s with the overlay
- Precision in identifying target
  - Without overlay: $50.83 \pm 54.57$ pixels, $0.527 \pm 0.583$ mm
  - With overlay: $0.087 \pm 0.096$ 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?