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Computer Integrated Surgery II
Critical Review: Intraoperative Visualization of Anatomical Targets in Retinal Surgery
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1. Introduction

This critical review will analyze a paper relevant to the problem of the overlay of preoperative images with the intraoperative microsurgical view in the operating room during retinal surgery.

1.1 Retinal disease and vitreoretinal surgery

Retinal disease is one of the leading causes of blindness world wide, and comprises condition such as macular pucker, macular holes, retinal detachment and vitreous hemorrhage.

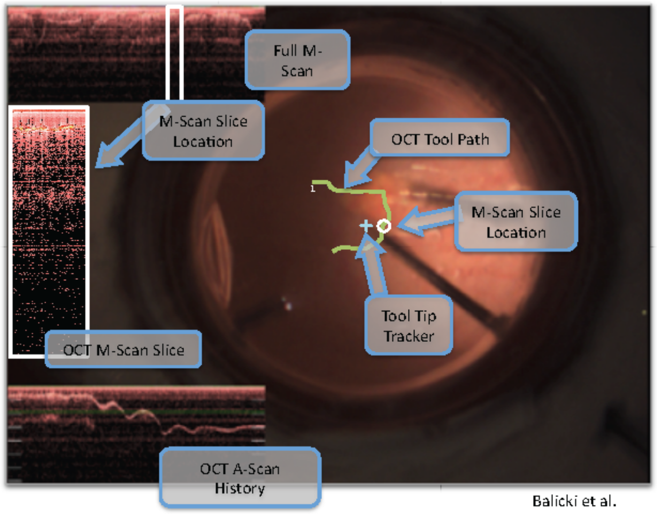
Commonly these conditions are treated through vitreoretinal surgery: a micro-surgical procedure presenting many challenges. Among these are the delicate nature of the retina, with micron scale layers of tissue on which clear and difficult-to-observe scars can be formed that need to be precisely located and peeled. This requires high levels of manual precision over a small, hard to visualize area.

In order to facilitate these tasks preoperative images acquired using OCT on which interesting anatomical landmarks (such as the edge of an epiretinal membrane) are registered to microscope view images during surgery, and overlaid on the latter to facilitate targeting.

1.2 Our project and paper selection

The goal of my group's project is to assess the efficacy of a system of intraoperative OCT imaging in a simulated micro-surgical task through the use of an IRB approved subject experiment. As well as improvements to the system's user interface/GUI, implementation of smart OCT processing, and color enhancements to the OCT image.

One of the fundamental premises of the system we wish to evaluate is that it allows for imaging intraoperatively, thus guaranteeing that the images obtained are up to date with the anatomical reality, even after manipulation of the tissue. In order to facilitate recalling which areas of the retina have been imaged already, the imaged path is overlaid on the video feed presented to the surgeon. As can be seen below.



The paper chosen is "Intraoperative Visualization of Anatomical Targets in Retinal Surgery". It was chosen because it provides an example of successful highlighting/annotation of features on video for intraoperative use, and because in order to test its effectiveness the authors conducted a subject experiment to test variation in accuracy & targeting time, as we intend to do in our project.

2. Paper 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 then displayed during the intervention using a 3D visualization system.

3. Brief methodology of framework

The framework described by the paper involves the imaging of the retina pre-operatively using Optical Coherence tomography, on which it is assumed at least one anatomical landmark of interest is found. The OCT images come paired with a low resolution fundus image called 'targeting image' which shows the location on the retina corresponding to each cross-sectional image. Then, there is an OCT to targeting image alignment which consists of adjusting the scale of the OCT cross-section to fit its corresponding representation in the targeting image.
Following that a high-resolution fundus image of the same area is taken and registered to the targeting image using Stewart's Dual bootstrap ICP algorithm, which makes use of the blood vessels as landmarks to perform the registration.
Finally, the fundus image is registered to the microscope view video feed, again using Stewart's algorithm, and the registration is tracked using a region-based tracking algorithm. The video is processed to mark the landmarks and displayed on a polarizing screen.

4. Experimental design of subject trials

A retina phantom was constructed by taking a small region of high resolution fundus image and printing it on glossy photo paper. In order to assess precision, the authors tracked one target

and recorded 9 images at different positions and orientations of the reference image.
Both ground truth and tracked target were projected onto the same image, and their distances were computed to obtain the error of tracking algorithm. To compare gesture accuracy and targeting time authors performed 6 targeting trials with overlay and 6 without it, and collected one microscope view at beginning and one at the end of each trial.

5. Error

Tracker error was found to be 3.86 ± 2.25 pixels, and assuming the diameter of eye is between 23.5 - 25 mm, the authors estimated the error to lie between 0.04 - 0.044 mm. This error represents a sum of both the tracking algorithm and the registration method employed. The targeting time was measured to be 8.59 ± 4.8 s without overlay, and 8.26 ± 2.13 s with the overlay. Therefore, not much improvement was made with respect to targeting time.
Precision in identifying target was measured to be 50.83 ± 54.57 pixels or 0.527 ± 0.583 mm without overlay , and 0.087 ± 0.096 mm with overlay.
Tracking processing speed was measured to 31-33 FPS using chorioallantoic membrane (CAM) of 12 days old chicken embryo, which was used to replace the glossy photo phatom because the latter could not provide the same level of detail that is visible on a live retina in the microscope, and which makes Stewart’s algorithm a good choice.

4. Assessment of Paper

Positive points:

- Significant increase in targeting accuracy was observed.
- The paper presents a very good example of the possible improvements of video annotation for retinal surgery/

Shortcomings:

- The small sample size used for the subject experiments, and the fact that it was composed exclusively of the authors.
- The glossy photo phantom is not a very accurate retina model because it is not deformable.
- The tracking algorithm supports only single target tracking, and occlusion of this single target would affects its performance.
- The paper does a very brief, and consequently rather unclear, explanations of both Stewart's algorithm and the tracking algorithm.
- Possibly the biggest issue with the framework presented in the paper is that it does not account for the fact that as the surgical procedure progresses the retinal is modified, peeled, etc. which can alter the location of the landmarks found, or create new edges of interest. These would likely require new OCT image to guide the next steps, but this cannot be done. And the pre-operative OCT images avilable are possibly very outdated.

5. Future Work

Possible future improvements or expansion to the work presented on the paper include

- A more extensive usability study with surgeons as participants.
- Adapting the tracking algorithm to detect occlusions and to support multiple target tracking.
- Replacing the polarized screen with a head-mounted display (HMD) for a more ergonomical system.
- Incorporating the framework to hand-guided robots like the JHU Steady Hand Robot.

References

“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