# Visual Tracking of Surgical Tools in Retinal Surgery using Particle Filtering

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## Introduction

Vitreoretinal surgery is undertaken to treat eye problems involving the retina, macula, and vitreous fluid, and is considered one of the most difficult types of surgeries to perform. Some eye problems treated by vitreoretinal surgery include macular degeneration, retinal detachment, and diabetic retinopathy. During vitreoretinal surgery, small implements are inserted into the ocular vitreous cavity through small incisions and are manipulated within through a microscope to perform the procedure. Potential complicating factors include difficult visualization of surgical targets, poor ergonomics, lack of tactile feedback, and the requirement for high precision and accuracy. Since the surgery is performed using indirect visualization, the surgeon faces limited field and clarity of view, depth perception, and illumination, which hinders identification and localization of surgical targets and leads to long operating times and risks of surgical error.[5]

While there are many tools available and in development to help surgeons with hand tremor, such as the microsurgical robot, intraoperative force transduction sensors, and intraoperative optical coherence tomography (OCT) retinal scans[1], there has not been a method of detecting and tracking the surgical tool implements from the viewpoint of the optical microscope that is robust and precise enough for practical use in a clinical scenario.[4]

## Project Goal

We aim to develop a direct visual tracking method for retinal surgical tools using mutual information and particle filtering.

## Relevance of our Approach

In determining the location of the tool during surgery, we will use template-based registration with Mutual Information (MI) as the similarity measure. We do this instead of using SSD or NCC as the similarity measure as MI is more robust in presence of changes in illumination, rotation, scale, and limited texture information.

Also known as a condensation algorithm, we will use a particle filter to track the motion of the tool. Gradient descent methods, which are traditionally used, suffer from problems with local minima which occur when there are large displacements in the tool position. In addition, a particle filter supports alternative hypothesis tracking, so that it is unlikely an incorrect hypothesis will become “sticky.”

## Technical Approach

### *Mutual Information*

A 4 degree of freedom model will be used: translation (2D), rotation, and scale. The calculation of the MI score involves calculating the joint entropy between the template (I*) and image (I), then subtracting the images' individual entropies:

$$h(I) = -\text{sum}_r[p_I(r) \log(p_I(r))]$$

$$h(I, I*) = -\text{sum}_{r,t}[p_{II*}(r, t) * \log(p_{II*}(r, t))]$$

$$MI(I, I*) = h(I)+h(I*)-h(I, I*)$$

MI is effectively a measure of the quantity of shared information between the two images being compared.

*Particle Filter*

The particle filter is essentially a two-step iterative process. With an initial constrained random sampling of particles around the last known location of the tool, the MI score is calculated for each particle. The MI score is thus the weight of the particle. The field of particles is then resampled so that each particle has equal weight, but the density of particles is proportional to the calculated MI score. The process is then iterated, and the location of the tool determined based on the most probable hypothesis currently known.

*GPU*

Ideally, the MI score calculation stage of the particle filter would be run in parallel. We propose to do this on a GPU. This would enable the particle filter to be very robust without sacrificing the performance and frame rate needed to perform a live surgery; without massively parallel computational capacity, the number and density of particles would need to be reduced in order to allow the tracker to run at an acceptable frame rate, which in turn reduces the robustness and accuracy of the tracker.

*Error Analysis*

To measure error analysis, we will use the first fully annotated and freely available image data set for tool detection in *in vivo* retinal microsurgery.[4] Error analysis will consist of two parts: tool detection using mutual information and tool tracking using particle filtering.

To analyze the efficacy of mutual information as a tool detection algorithm for vitreoretinal surgery, the parameters will be determined by maximizing accuracy on a validation subset of the complete image data set and the mutual information detector will be evaluated on the entire image data set. Correct predictions will be defined as those that are within 10 pixels of true location for both endpoints of the shaft of the tool. An ROC curve will be plotted as false positive rate vs. true positive rate, and this will be compared against those generated by that of other image detectors based on SSD or NCC. Ideally, our detection algorithm should be on the order of 90% accuracy with a false positive rate on the order of 10^-8, which is what state-of-the-art face detection algorithms have.[4]

To analyze the efficacy of particle filtering as a tool tracking algorithm for vitreoretinal surgery, the complete particle filtering with mutual information algorithm will be evaluated on video sequences. At any frame, the tracking is said to have failed whenever the true position of the terminating end of the shaft of the tool is greater than some threshold σ. Whenever that happens, a note is made and the tracking algorithm is reinitialized using ground truth to continue analysis. After the sequence is complete, the number of frames successfully tracked continuously is plotted against the number of events as a histogram and is fitted to a geometric distribution. The lower the fitted probability, the better the robustness; current gradient descent tracking algorithms using SSD or MI have a p-value of around 0.1.[4]

**Deliverables**

Minimum: OpenCV demo of tool tracking using mutual information and particle filtering (offline video), well-documented and optimized code.

Expected: CISST code running on surgical platform (online), poster and paper.

Maximum: GPU/parallel implementation of particle filter.

**Milestones and Timeline (estimated dates of completion)**

- Milestone 1: Particle filter with SSD by 3/7
  - 2/15: Literature review
  - 2/22: Set up OpenCV development environment
- Milestone 2: Particle filter with Mutual Information by 3/14
  - 3/14: Implementation
  - 3/14: Prepare demo with offline video
- Milestone 3: Port algorithm to CISST library by 4/4
  - 3/21: Set up CISST development environment
  - 4/4: Port code to CISST environment
  - 4/4: Prepare demo with online video source
- Milestone 4: GPU or other parallel implementation added by 4/18
  - 4/11: Review literature on use of GPU/CUDA
  - 4/18: Implement GPU/parallel processing of particles
- Presentation and Paper by 5/9

**Assigned Responsibilities**

The division of responsibilities will be very flexible in practice. In all cases, however, the primary coder codes the initial implementation while the partner checks the code for errors and suggests improvements and optimizations. The following general assignments are proposed:

- David Li
  - Particle filter implementation
  - Porting OpenCV implementation into CISST
- William Yang
  - Mutual information
  - GPU/Parallel processing implementation

Both group members will be responsible for on-going documentation, preparing demos, drafting the paper, and the poster presentation.

**Dependencies**

- Development environment for Milestones 1 and 2
  - Resolved (Visual Studio/OpenCV)
- Development environment for Milestones 3 and 4
  - Will work with Rogerio (CISST libraries)
- Access to CUDA-enabled GPU for Milestone 5
  - Resolved for offline development; will work with Rogerio for online testing
- J-Card access to robotorium
  - Resolved
- Use of microretinal surgery workstation
  - We will need to schedule time on the system when we are ready.
  - If the workstation is not accessible, we will work with pre-recorded data.

**Management Plan**

We will hold weekly meetings with Dr. Richa every Wednesday. The project status and timeline will also be reassessed every week. Programming and peer code review will proceed on a continuous basis and is subject to source code revision control. In-person or electronic meetings will be held as needed in order to discuss approaches and test code. Documentation of code will be on-going.

**Reading List**


1. Balicki, M., Han, J., Iordachita, I., Gehlbach, P., Handa, J., Taylor, R., and Kang, J. (2009). Single Fiber Optical Coherence Tomography Microsurgical Instruments for Computer and Robot-Assisted Retinal Surgery. *MICCAI 2009*, 108-115
2. Dame, A. and Marchand, E. (2010). Accurate real-time tracking using mutual information. *IEEE Int. Symp. on Mixed and Augmented Reality*, *ISMAR'10*, 47-56.
3. Isard, M. and Blake, A. (1998). Condensation – conditional density propagation for visual tracking. *Int. Journal of Computer Vision*, 29, 5-28.
4. Richa, R. et al. (2012). An Evaluation Framework for in vivo Microretinal Tool Detection and Tracking. *MICCAI*
5. Richa, R. et al. (2012). Hybrid SLAM for Intra-operative Information Augmentation in Retinal Surgery. *MICCAI*