ERC | CISST

LABORATORY FOR Computational Sensing + Robotics THE JOHNS HOPKINS UNIVERSITY

Visual Tracking of Surgical Tools in Retinal Surgery using Particle Filtering

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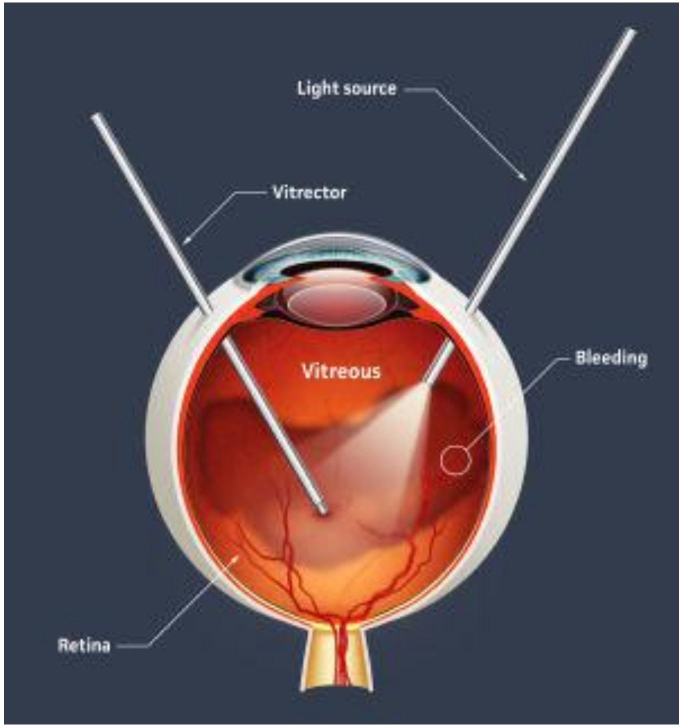
Outline

- Introduction
  - Background
  - Project Goals
- Technical Approach and Current Results
- Project Management Update
  - Deliverables & Milestones, Timeline
  - Assigned Responsibilities, Dependencies

Vitreoretinal Surgery

- Used to treat the following
  - Macular degeneration
  - Retinal detachment
  - Diabetic retinopathy
- Complications
  - Retina is very fragile
  - Indirect visualization
  - Physiological tremor
  - Lack of tactile feedback



http://www.eyedoctorguide.com/eye_problems/vitreoretinal_surgery_retina.html

Indirect Visualization

- Many limitations that hinder identification and localization of surgical targets
  - Field and Clarity of view
  - Depth perception
  - Illumination
- Long operating times and risks of surgical error

Project Goals

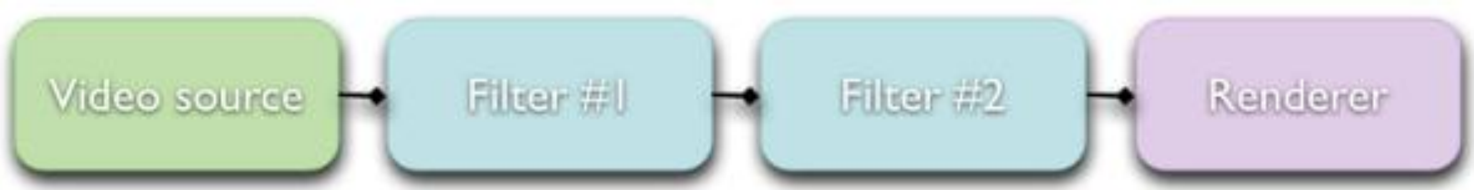
- Goal: Develop a direct visual tracking method for retinal surgical tools using particle filtering and mutual information
- Benefits of implementing a particle filter
  - Stochastic optimization method
  - Can be computed in parallel for speed
  - Computationally efficient
  - Robust

Technical Approach and Current Results

- CISST Stream Design
- Direct Visual Tracking Method
  - Mutual Information
  - Particle Filter
- Problems
  - Shadow detection
  - Tooltip detection
  - Error Analysis

CISST Library

- cisstStereoVision library (SVL) processing architecture: filters and streams
- Filters: input and output ports



https://trac.lcsr.jhu.edu/cisst/wiki/cisstStereoVisionTutorial

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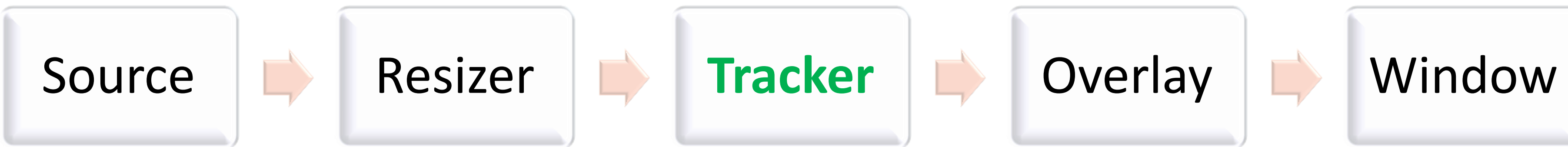
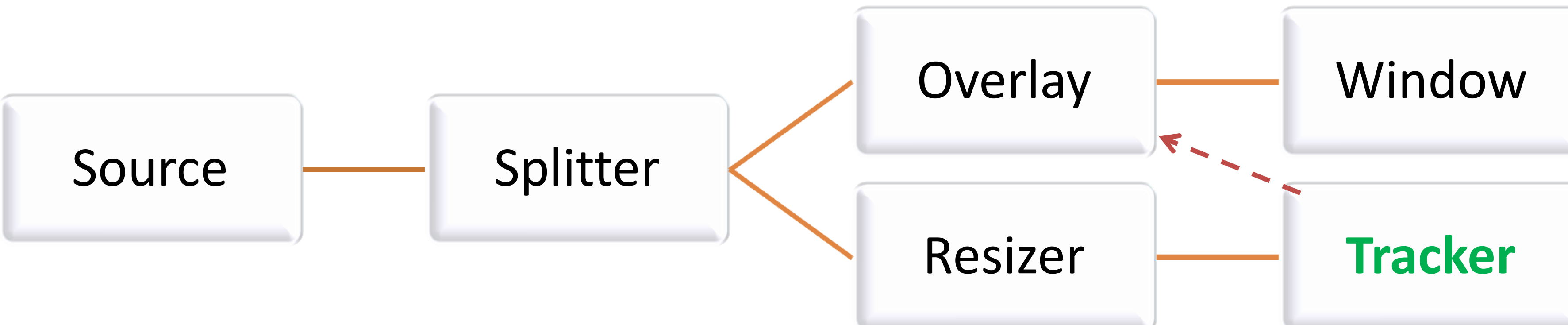
SVL Stream Design



Alternatively, an asynchronous approach…



Mutual Information

- Template registration
- Why not Sum Squared Difference (SSD) or Normalized Cross-Correlation (NCC)?
- ~~4~~ 3 DOF model

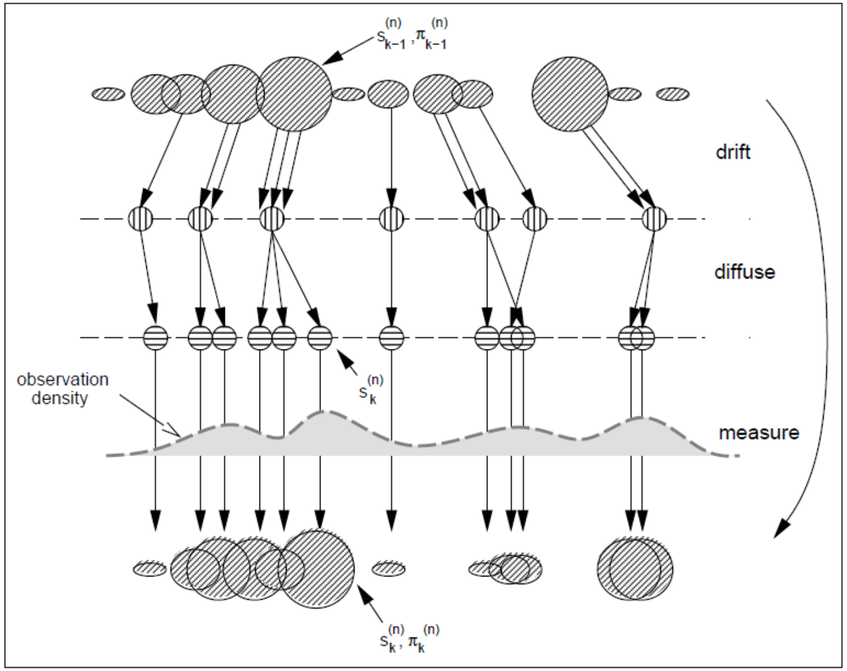
$$h(I) = -sum_r[p_I(r) \log(p_I(r))]$$

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

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

Particle Filter

- “Condensation”
- Avoid local minima in gradient descent
- Supports alternative hypotheses
- Iterative: calculate weights, resample
- Primary hypothesis chosen by weighted mean of particles

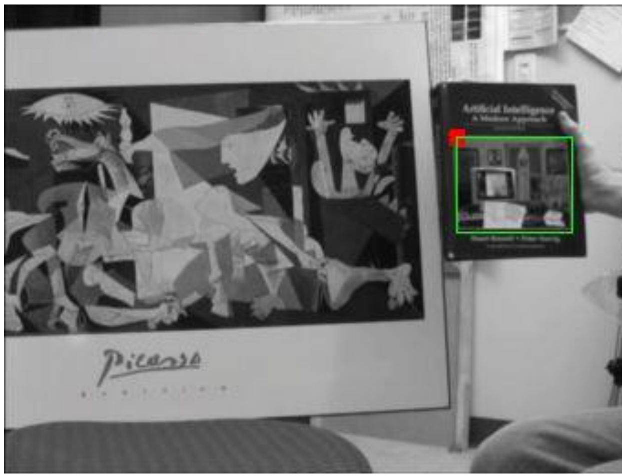


Comparison of Similarity Measures

	Inverse Sum of Square Differences (Inverse SSD)	Normalized Cross Correlation (NCC)	Mutual Information (MI)
PF Weight	$\frac{1}{\sum_{(i,j)\in W}\left(I_1(i,j) - I_2(x+i,y+j)\right)^2}$	$\frac{\sum_{(i,j)\in W} I_1(i,j).I_2(x+i,y+j)}{\sqrt[2]{\sum_{(i,j)\in W} I_1^2(i,j).\sum_{(i,j)\in W} I_2^2(x+i,y+j)}}$	Joint Probability Histogram Entropies for individual images Entropy for joint image distribution MI = Individual Entropies – Joint Entropies

- Two sample offline videos
  - Video of textbook translating in 2D, then rotating
  - Video of vitreoretinal tool tip moving in the eye

Comparison of Similarity Measures Textbook (2 DOF)



Inverse SSD

NCC

MI

20 fps video, ~5 fps runtime

Implementation of Rotation

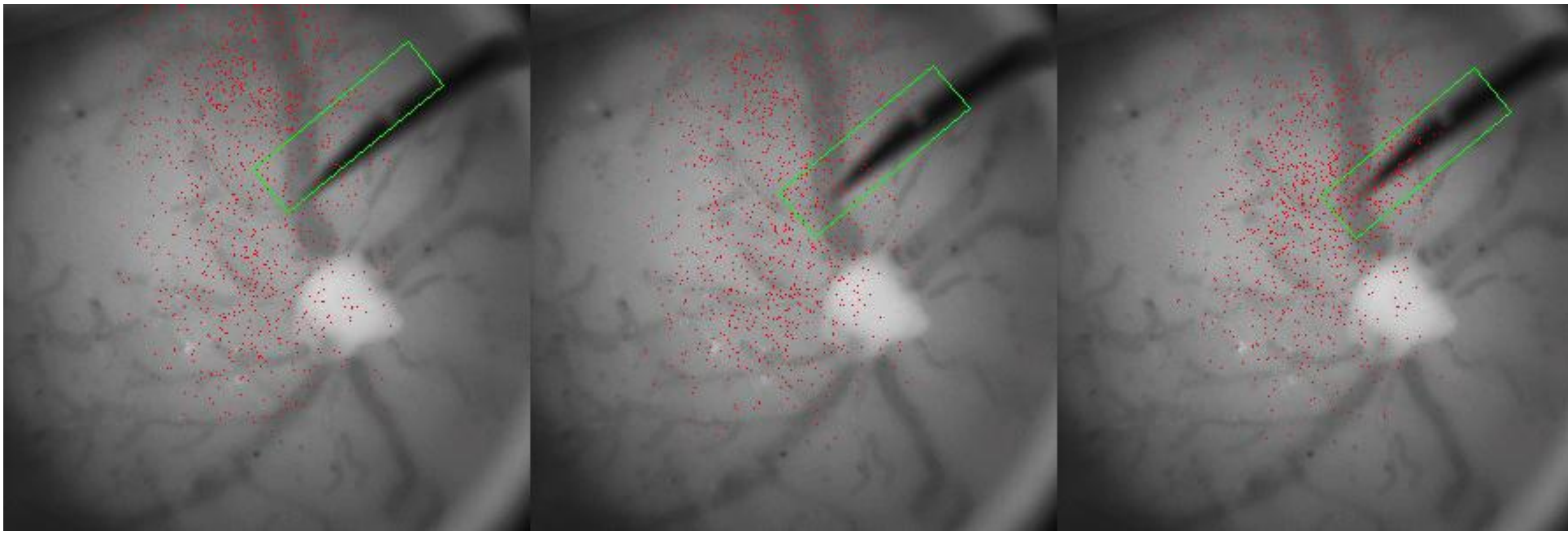
- Two degrees of freedom
  - Two independent variables (X and Y coordinates)
  - One dependent variable (Similarity measure)
  - No rotation
- Three degrees of freedom
  - Three independent variables (X and Y coordinates, rotation)
  - One dependent variable (Similarity measure)

Comparison of Similarity Measures Textbook (3 DOF)

Inverse SSD | NCC | MI

20 fps video, ~5 fps runtime

Comparison of Similarity Measures
Retinal Surgery (3 DOF)



Inverse SSD | NCC | MI

20 fps video, ~5 fps runtime

Shadow Recognition

- Very hard to distinguish between tool and tool shadow
- Stems from a bimodal distribution
- Attempt to take advantage of surgical technique to determine tool
  - Surgeon approaches tissue from far away; tool is seen before tool shadow
  - Detect first significant mode, weight appropriately

Tool Tip Detection

- Difficult to detect the tip of the tool
  - Template has small segment that defines tip
- Attempt to decouple tool detection with two templates/PFs
  - First detect tool shaft (2D) by varying Y-dimension and rotation with randomized X-dimension
  - Next detect tool tip (1D) by varying path length down shaft

Error Analysis

- Usage of first fully annotated and freely available image data set for tool detection in *in vivo* retinal microsurgery
- Tool Detection using Mutual Information
  - Evaluation on entire test set after validating on validation set
  - Correct predictions are within 10 pixels of true location for both (A) and (B)
- Tool Tracking using Particle Filtering
  - Evaluation on video sequences
  - Failed whenever true position of (B) is greater than some threshold σ, re-initialized using ground truth to continue analysis

Deliverables

Minimum

- OpenCV demo of tool tracking using mutual information and particle filtering (offline video)

Expected

(including Minimum)

- CISST code running on surgical platform (online)
- Documentation of code
- Poster and paper

Maximum

(including Expected)

- Parallelized implementation

Milestones

Minimum

- Milestone 1: Particle filter with SSD
- Milestone 2: Mutual information similarity measure

Expected

- Milestone 3: Port algorithm to CISST library

Maximum

- Milestone 4: Refinements to tracking algorithm
- Milestone 5: GPU or other parallel implementation added

Timeline

	2/8	2/15	2/22	2/29	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9
Milestone 1: Basic Particle Filter														
Milestone 2: Implement Mutual Information							+	+	+					
Initial mutual information (MI) implementation							+							
Add rotation to tracked state								+	+					
Switch from "book" to "surgical tool" sequence									+					
Prepare demo using offline video									-->					
Milestone 3: Port To CISST										+				
Set up CISST development environment														
Port to CISST (offline)										+				
Validate on microsurgery workstation										+				
Prepare demo using online video (no GPU)										-->				
Milestone 4: Refinements to Algorithm										+	+			
Resolve shadow false positive										+				
Decouple tool shaft and tip localization											+			
Error analysis										+	+			
Milestone 5: Parallel Implementation												-->	-->	
Review literature on use of GPU/CUDA												-->		
Implement parallel processing of particles												+		
Extend to GPU												-->	-->	
Presentation														
Prepare functional demo, draft paper and poster														
Poster complete and printed														
Document and clean up existing code														

Assigned Responsibilities

- Tentative division
  - Primary coder codes main implementation while partner checks code for errors and suggests improvements
- ~~David Li~~ William Yang
  - Particle filter implementation
  - Porting OpenCV implementation into CISST
- ~~William Yang~~ David Li
  - Mutual information
  - GPU/Parallel processing implementation
- Universal responsibilities
  - Documentation
  - Demo, Draft paper, and 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): Resolved
- Dataset for error analysis
  - Working with Rogerio to obtain
- Access to CUDA-enabled GPU for Milestone 5
  - Resolved for offline development; will work with Rogerio for online
- J-Card access to robotorium
  - Resolved
- Use of microretinal surgery workstation
  - Will need to schedule when ready
  - If not accessible, will work on pre-recorded data

Reading List

- 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
- 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.
- Isard, M. and Blake, A. (1998). Condensation – conditional density propagation for visual tracking. *Int. Journal of Computer Vision*, 29, 5-28.
- Richa, R. et al. (2012). An Evaluation Framework for in vivo Microretinal Tool Detection and Tracking. *MICCAI*
- Richa, R. et al. (2012). Hybrid SLAM for Intra-operative Information Augmentation in Retinal Surgery. *MICCAI*

Questions?