# Quantitative Endoscopy and Interventional Medicine

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# Endoscopy: The Oldest Imaging Modality

- **1804:** First endoscope by Bozzini
- **1822:** Beaumont uses in human
- **1877:** Nitze introduces fixed lens system
- **1901:** Hirschmann first use to visualize sinus
- **1953:** Fiberscope introduced by Hopkins
  - Actually patented by Baird in 1927
  - First camera coupling in 1957
  - Converted to rod-lens in 1960

Fig. 3 - Engel, R. Philipp Bozzini--The father of endoscopy
Journal of Endourology, Mary Ann Liebert, Inc., 2003, 17, 859-862

- **1980's:** First effective video scopes allowing development of minimally invasive surgery

Vision-Based Navigation in Image-Guided Interventions. Mirota Hager Ishii, Annual Review of Biomedical Engineering, 2010

# The Opportunity

- **Olympus** introduced its first HDTV surgical cameras in 2005. Millions of procedures performed.


- **Intuitive Surgical:** More the 1.6M procedures performed under high-def stereo video guidance

**None of this video is processed or archived.**

# A Steady and Growing Field

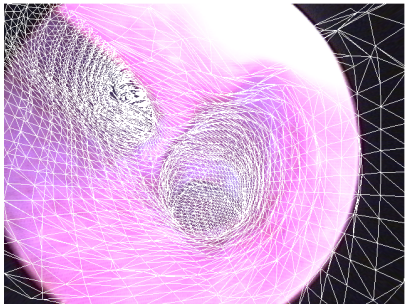

- Puerto, Gustavo A., and Gian-Luca Mariottini. "A comparative study of correspondence-search algorithms in MIS images." *Medical Image Computing and Computer-Assisted Intervention–MICCAI 2012*. Springer Berlin Heidelberg, 2012. 625-633.
- Xiongbiao Luo, Marco Feuerstein, Daisuke Deguchi, Takayuki Kitasaka, Hirotsugu Takabatake, and Kensaku Mori. Development and comparison of new hybrid mo- tion tracking for bronchoscopic navigation, ***Medical Image Analysis*** 16(3), 577-596, (2012).
- Helferty, James P., et al. "Computer-based system for the virtual-endoscopic guidance of bronchoscopy." *Computer Vision and Image Understanding* 108.1 (2007): 171-187.
- Wengert, Christian, et al. "Markerless endoscopic registration and referencing." *Medical Image Computing and Computer-Assisted Intervention–MICCAI 2006*. Springer Berlin Heidelberg, 2006. 816-823.
- Deligianni, Fani, Adrian Chung, and Guang-Zhong Yang. "pq-space based 2D/3D registration for endoscope tracking." *Medical Image Computing and Computer-Assisted Intervention-MICCAI 2003*. Springer Berlin Heidelberg, 2003. 311-318.
- Mori, Kensaku, et al. "A method for tracking the camera motion of real endoscope by epipolar geometry analysis and virtual endoscopy system." *Medical Image Computing and Computer-Assisted Intervention–MICCAI 2001*. Springer Berlin Heidelberg, 2001.

# How To Choose a Path

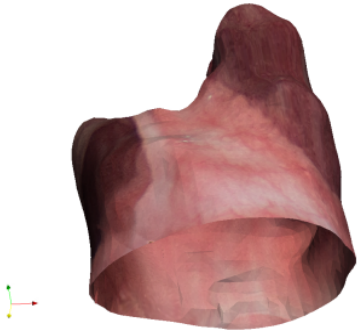

1. **Significant:** address a true need
2. **Practical:** consistent with reasonable clinical workflow
3. **Deployable**: usable in foreseeable practice for next decade
4. **Testable** in real-world settings – measurable progress!

# An Opportunity for Computational Vision: **Quantitative Interventional Tools**

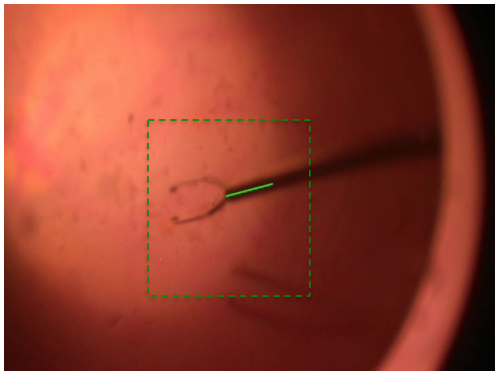
- Video-volume registration
  - Visualization/Augmentation
  - Evaluation of surgical progress



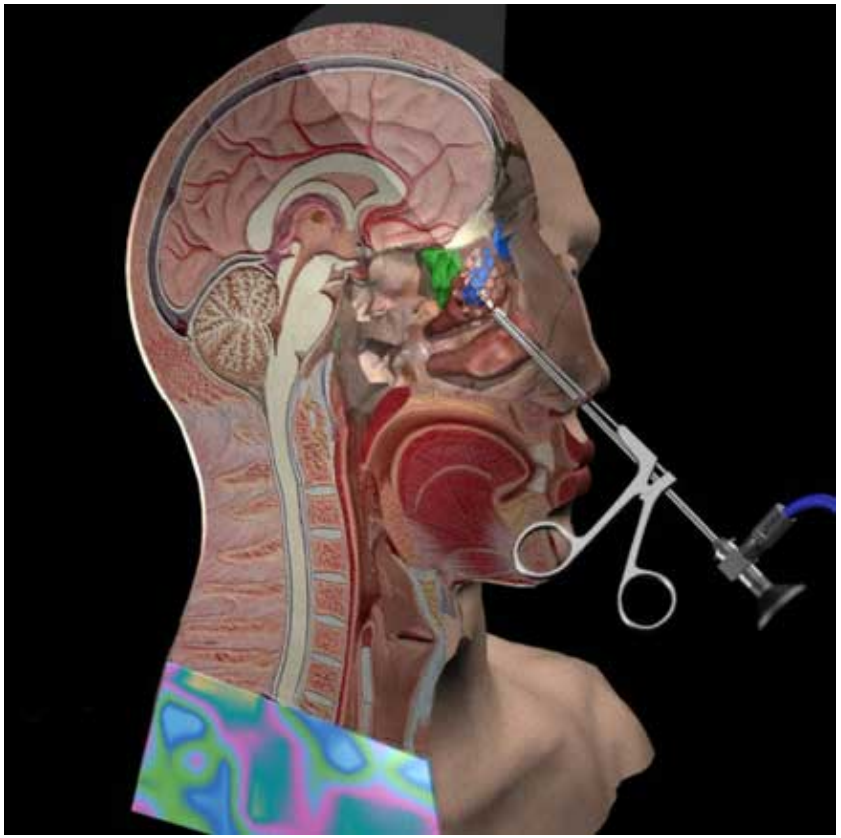
- Video reconstruction
  - Staging/evaluation
  - Monitoring
  - Registration



- Tool tracking/surface estimation
  - Enhanced tool motion
  - Automation
  - Safety zones

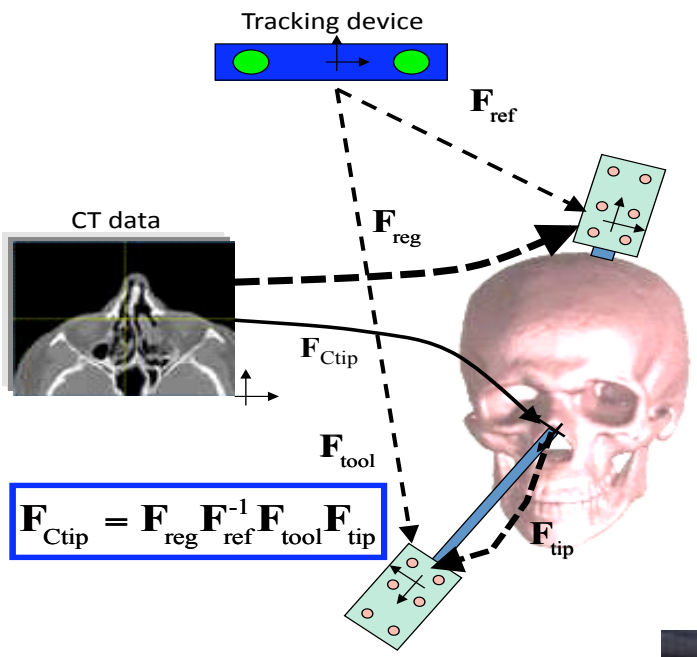


# Surgery Near the Skull Base




NIH- R21EB005201, Hager, Ishii, Taylor
NIH - R01EB015530, Hager, Ishii, Taylor, Siewerdsen

# Traditional Navigation

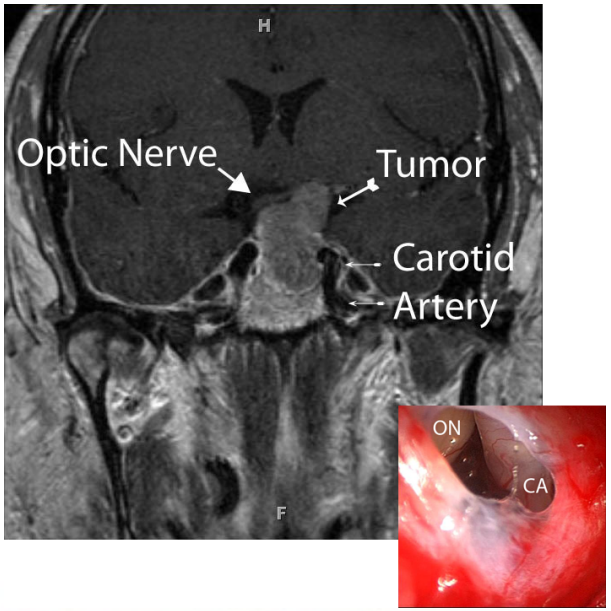


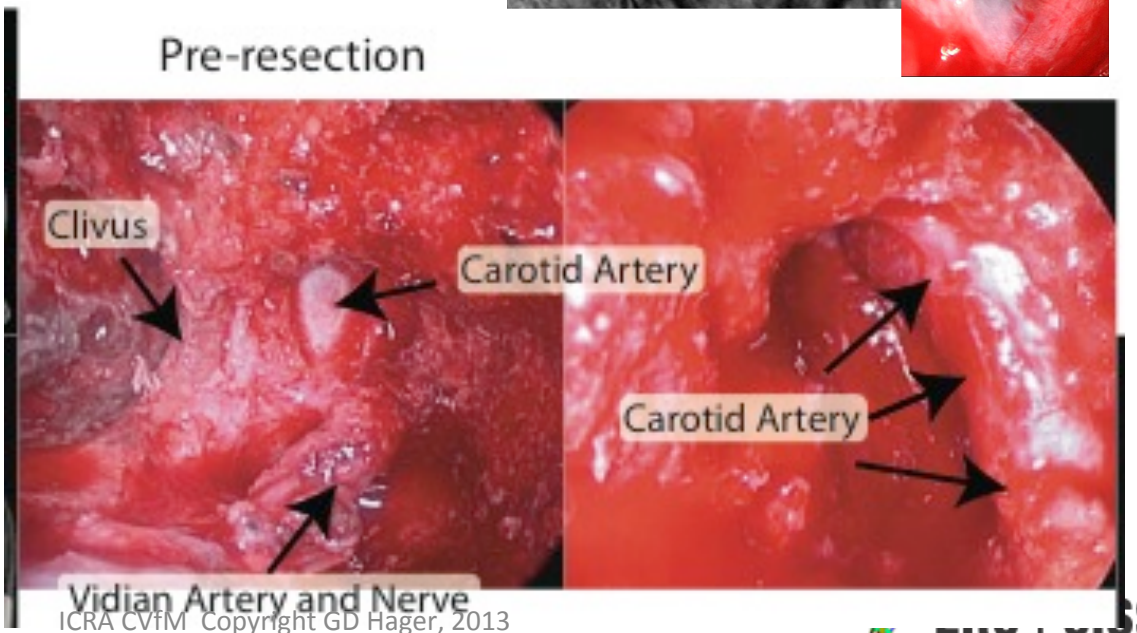

Quoted accuracy of 2mm

BrainLab Intraoperative CT Solution

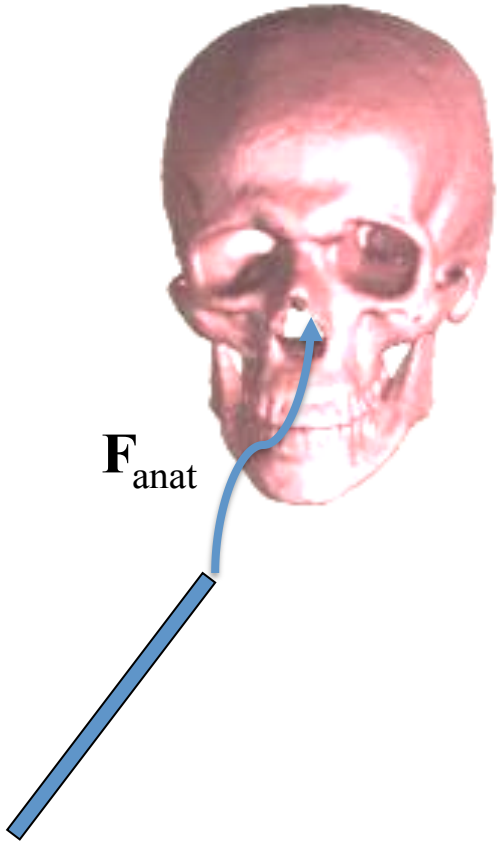
# Motivation: Surgery Near the Skull Base

- Challenge: Carotid artery mobilization
  - Large bone excision to track artery
  - Long time in OR
  - Traditional navigation methods are inadequate

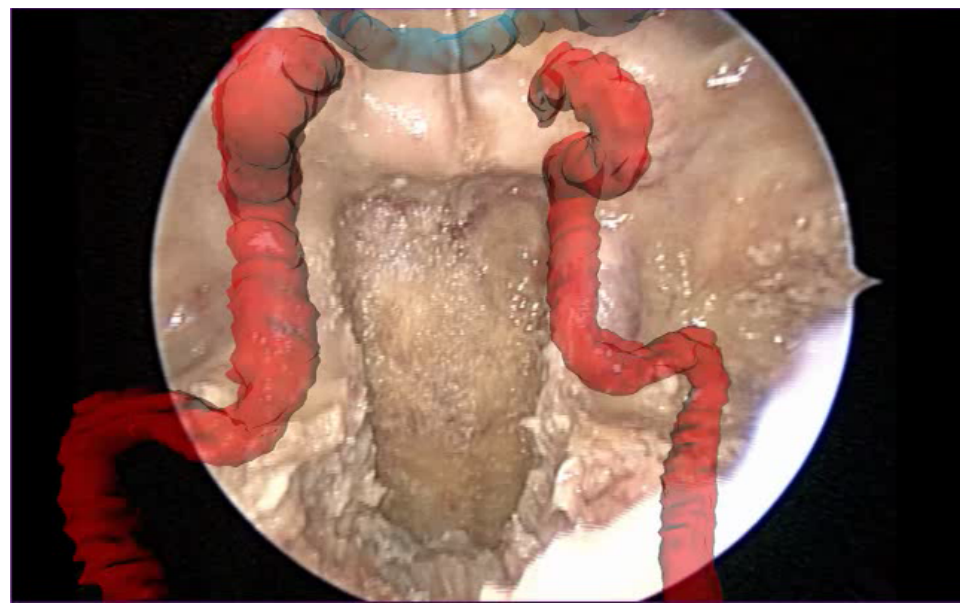


# Goal: Direct Video-CT Registration

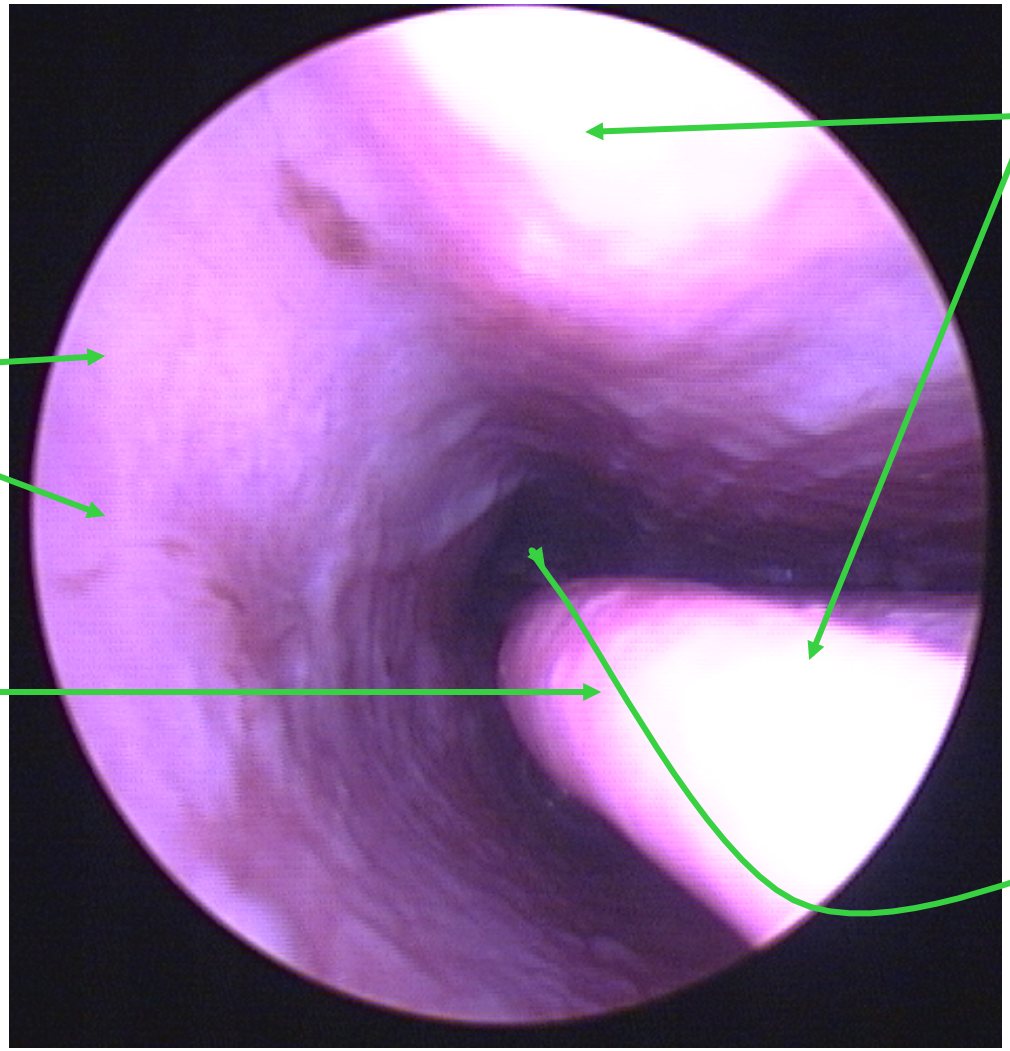



From a sequence of **monocular** endoscope images, compute high-accuracy **local** registration to CT

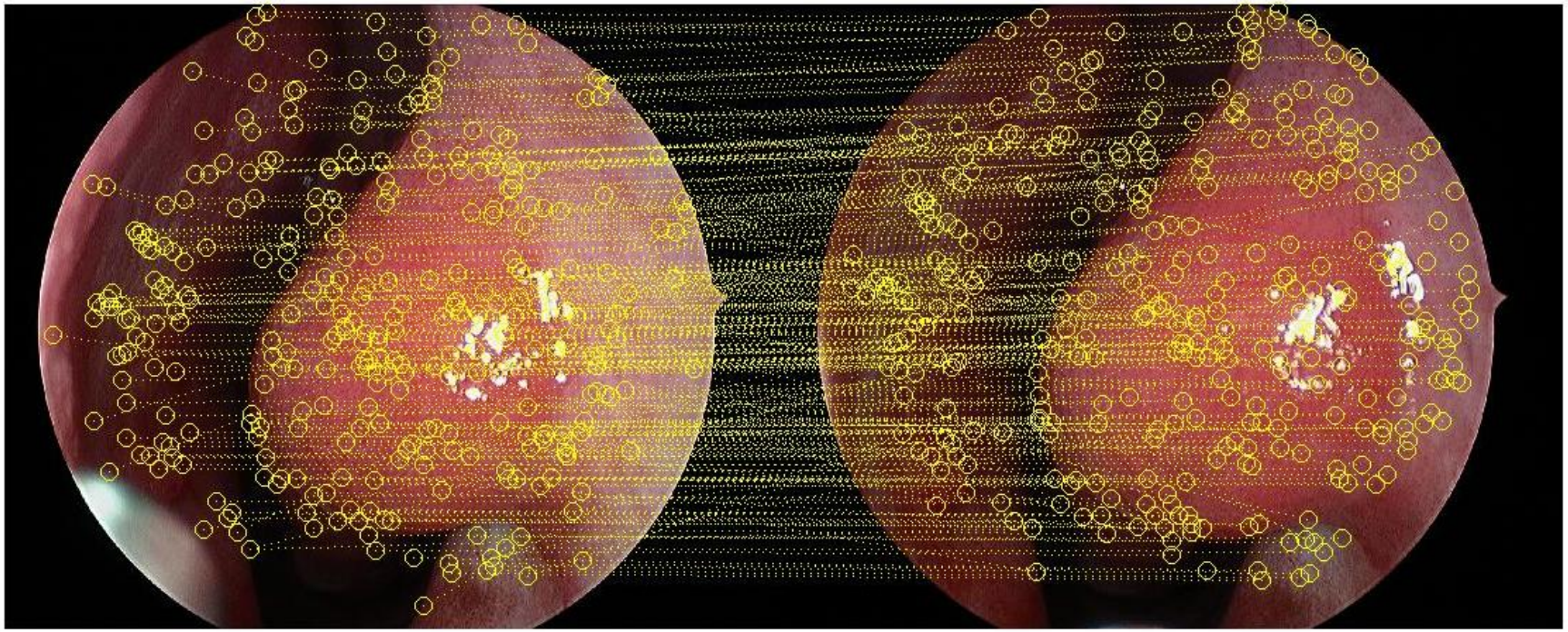


Mirota, Siewerdsen, et al.

# A Few Challenges

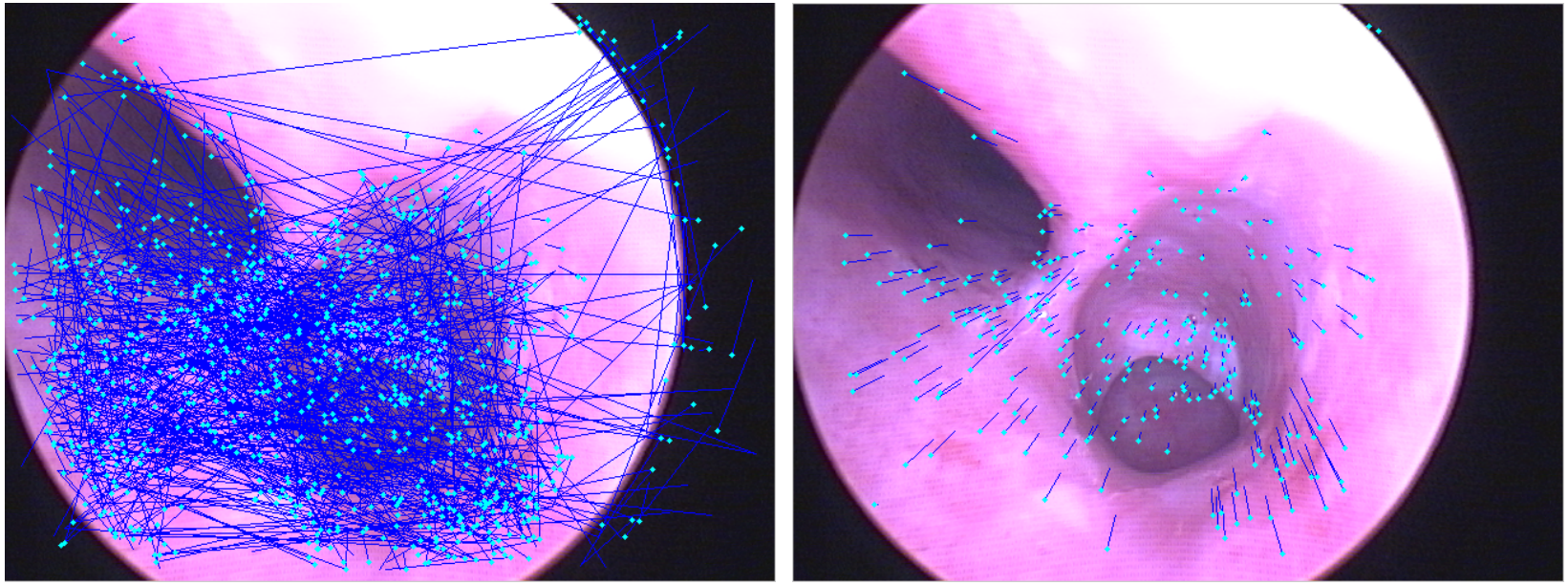


# A Few Challenges



The results of  traditional SIFT matching on a high def pair

# A Solution

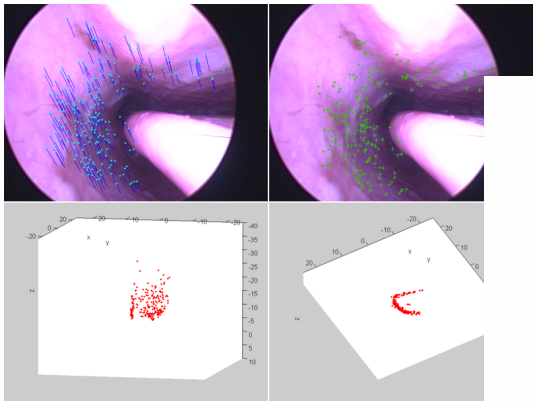


ASKC: A new robust estimation method that is able to detect inliers in highly contaminated data: motion estimation, registration, and motion tracking.

A generalized kernel consensus-based robust estimator, H Wang, D Mirota, GD Hager, PAMI 2010

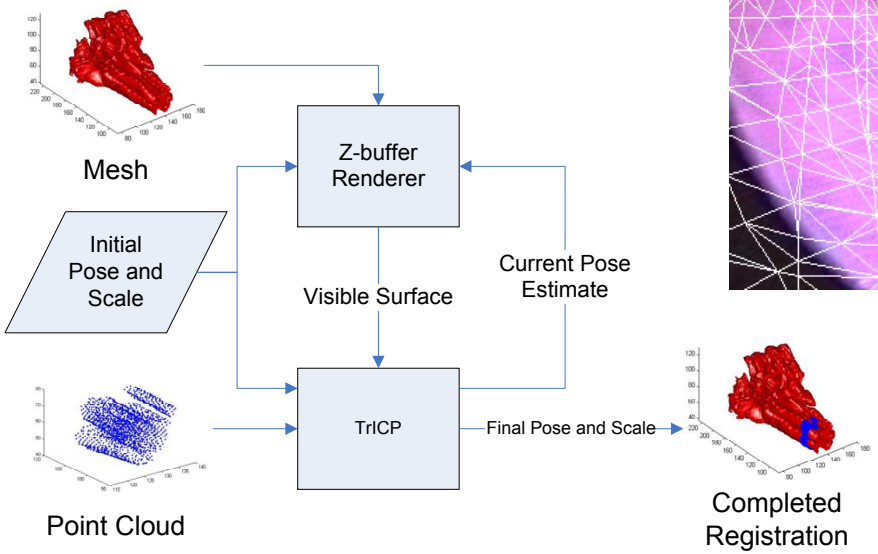
# Multi-Frame Results

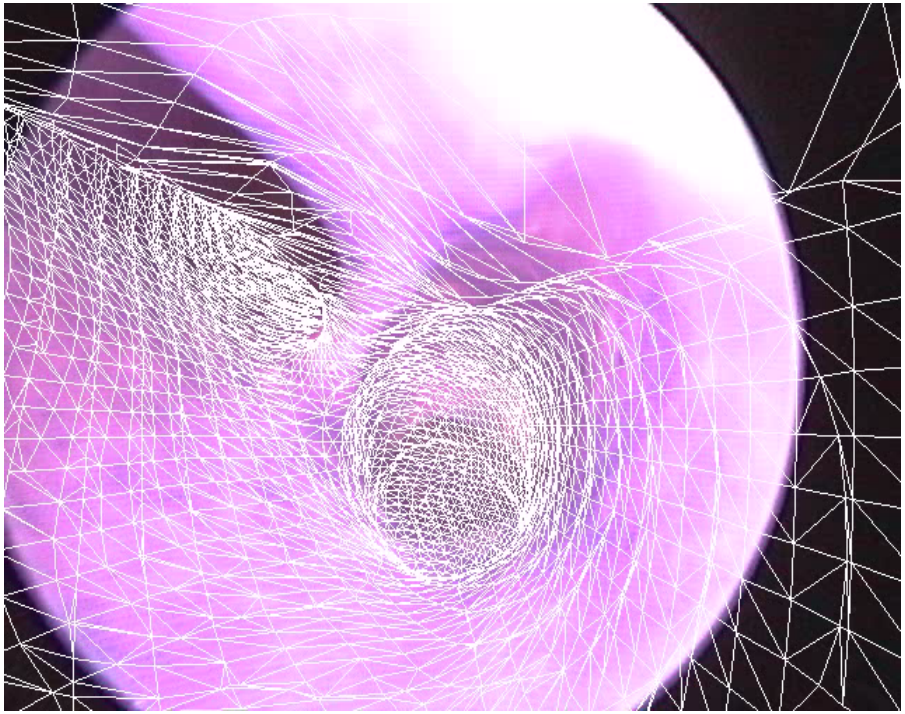
(Wang, Mirota, Ishii, Hager, CVPR 08)



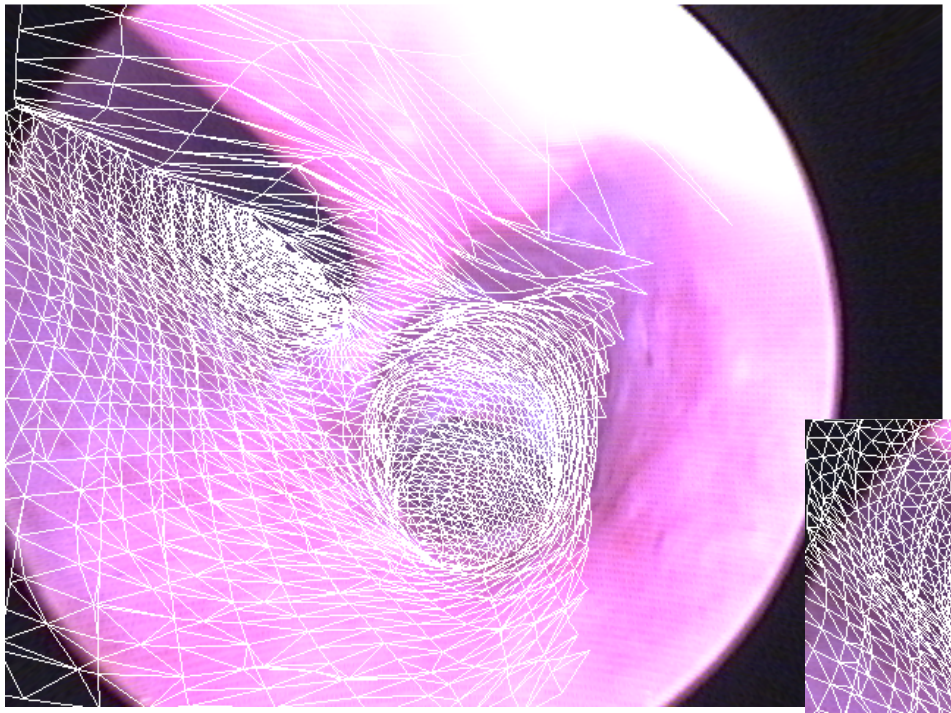
# Registration System

Mirota, Ishii, Taylor, Hager, SPIE 2009



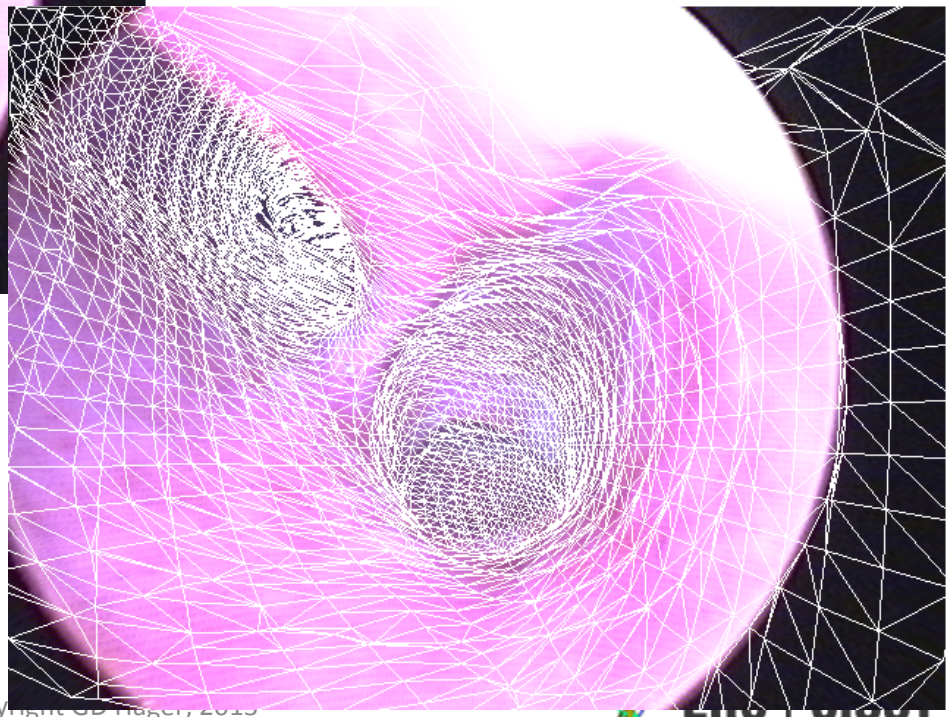



# Some Comparative Results



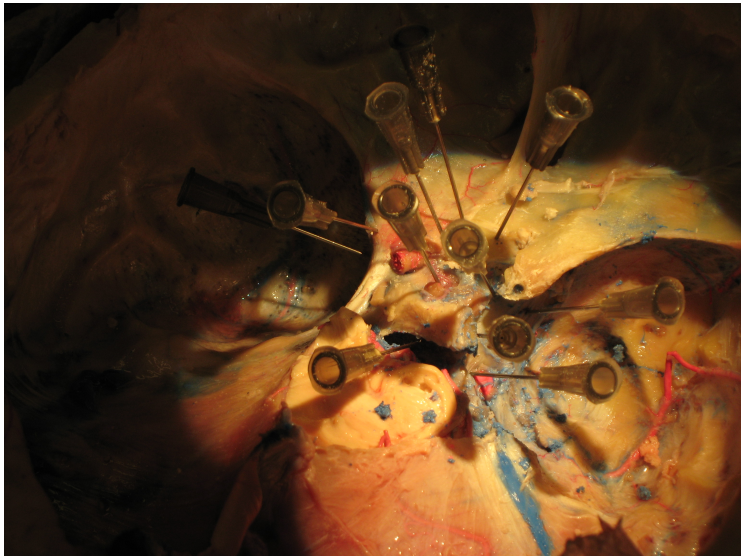
Optotrak

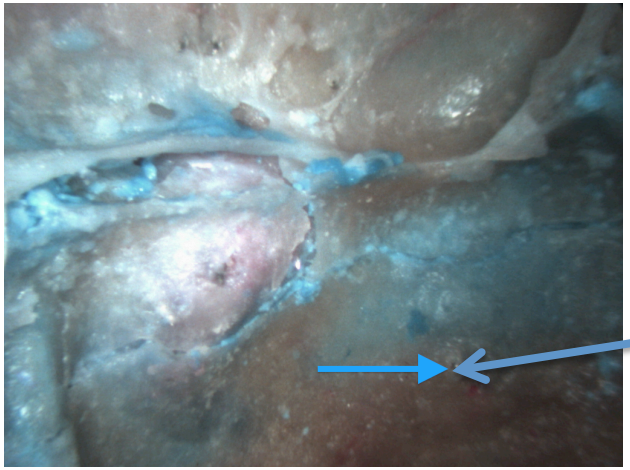
Video-CT

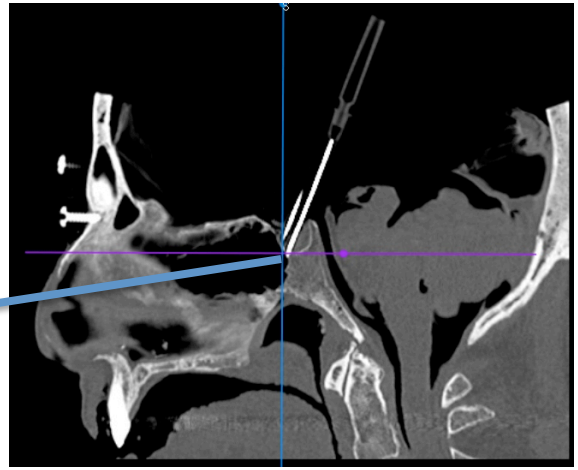


# Validation: Measurement

2D and 3D TRE based on implanted fiducials

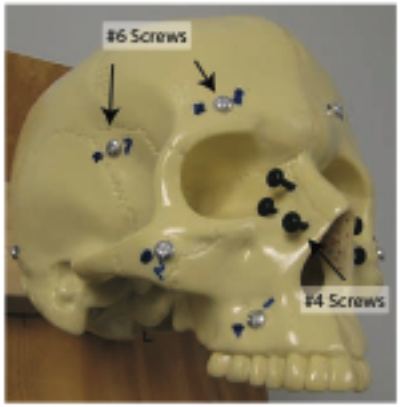


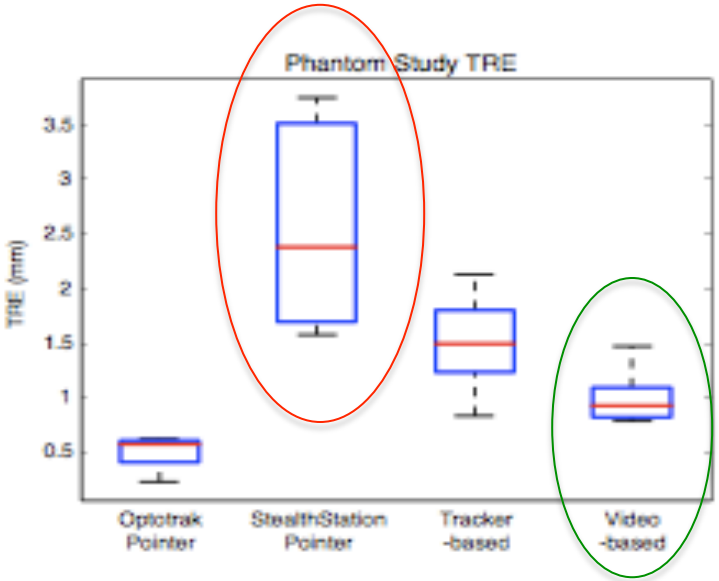


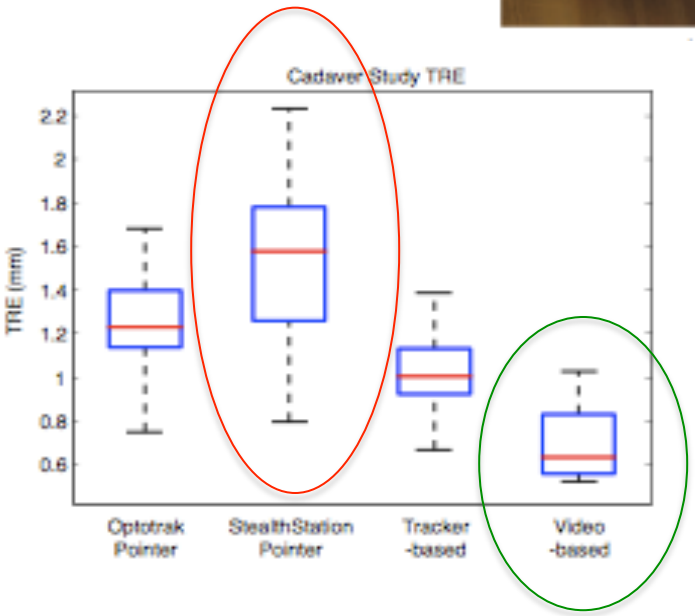


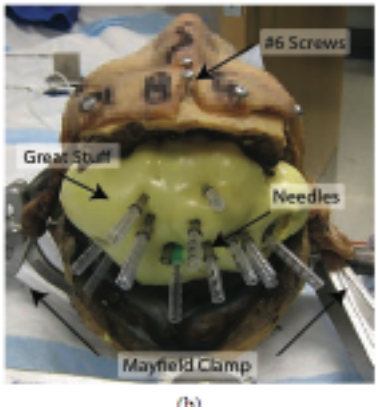
# Validation

Phantom Study




Cadaver Study

A System for Video-based Navigation for Endoscopic Endonasal Skull Base Surgery
Mirota Wang Taylor Ishii Gallia Hager, TMI 2011.

# Tracking Comparative Results

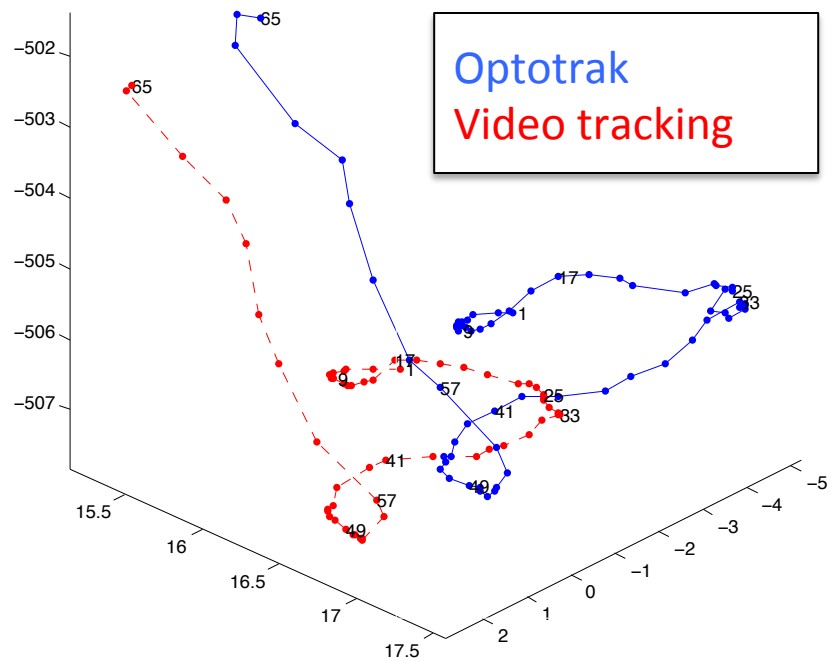



TABLE VI: Head Study Hypothesis Testing [a]

| | Optotrak | StealthStation | Tracker-Based |
|---|---|---|---|
| StealthStation | $\chi^2(1) = 0.04; p = 1.000$ | | |
| Tracker-Based | $\chi^2(1) = 59.59; p < 0.001$ | $\chi^2(1) = 43.83; p < 0.001$ | |
| Video-Based | $\chi^2(1) = 161.72; p < 0.001$ | $\chi^2(1) = 121.48; p < 0.001$ | $\chi^2(1) = 26.80; p < 0.001$ |

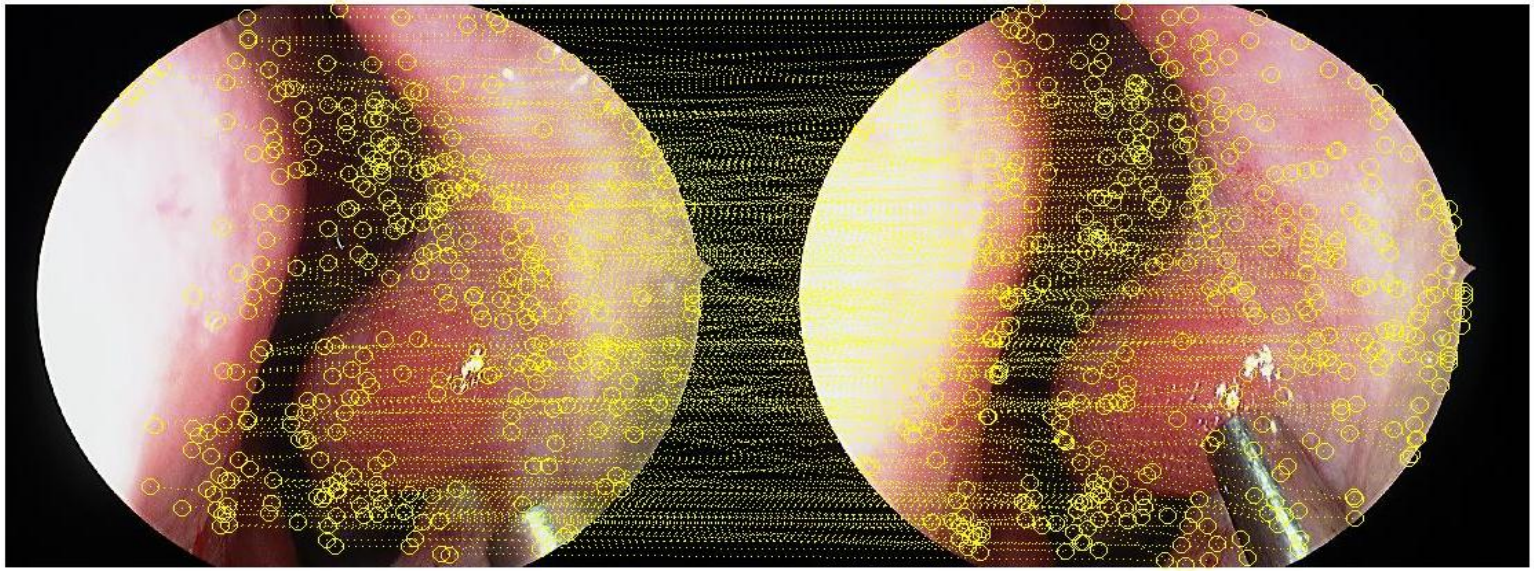
[a] Post Hoc testing, corrected for multiple comparisons with the Bonferroni method.

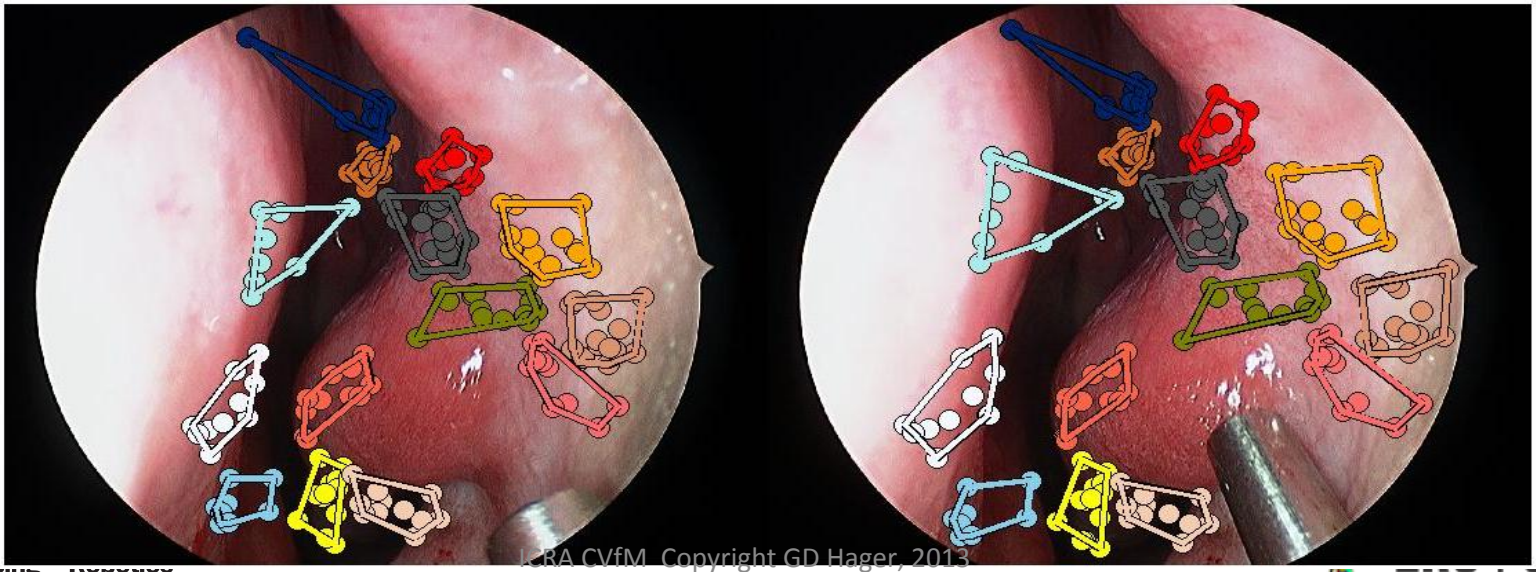
# Current Work: Scaling Up

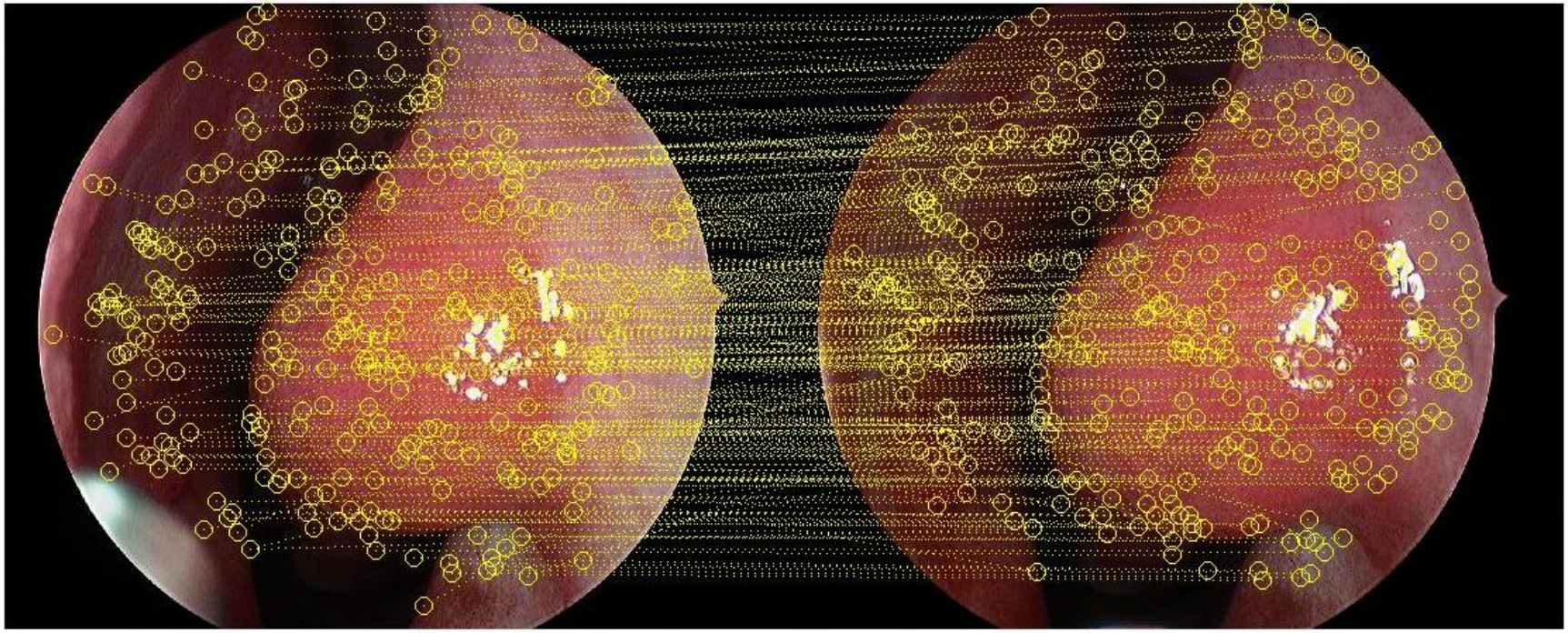
- Integrate registration, navigation, reconstruction into clinically usable system.
- Perform retrospective evaluation on patient data.
- First 6 data sets; 250 Gb of video.

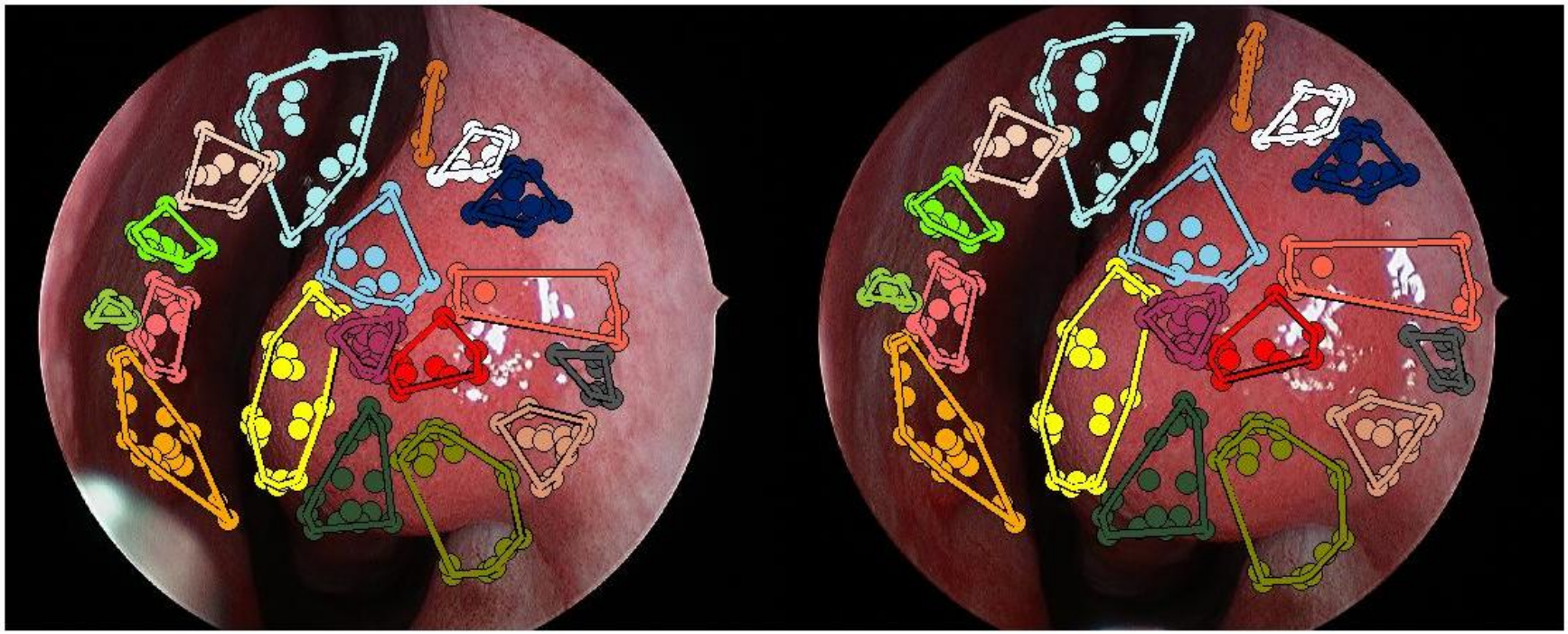
# Improved Matching with HMA

Mariottini et al. (UT Arlington), MICCAI 2012



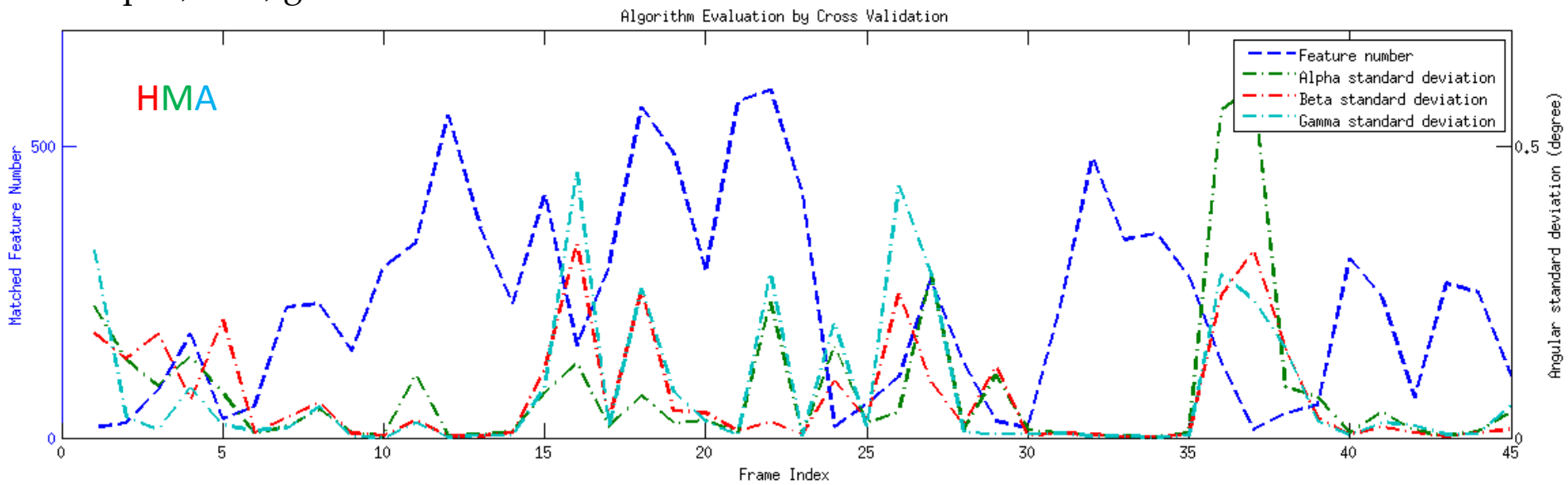


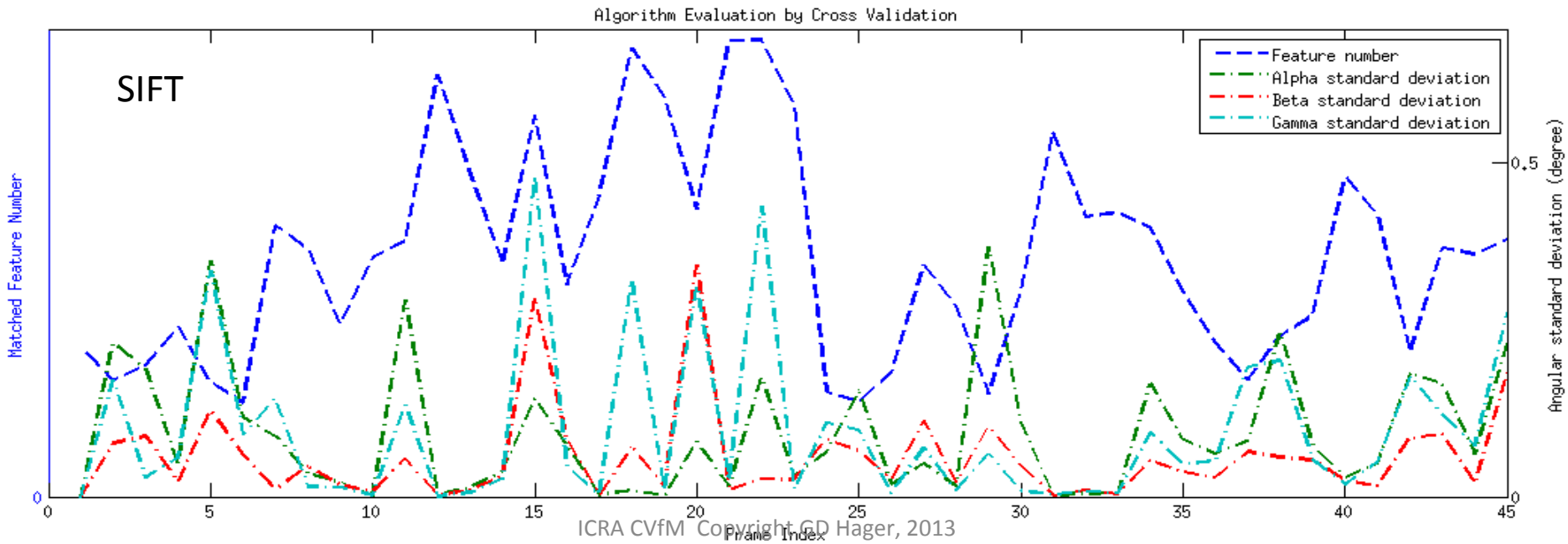




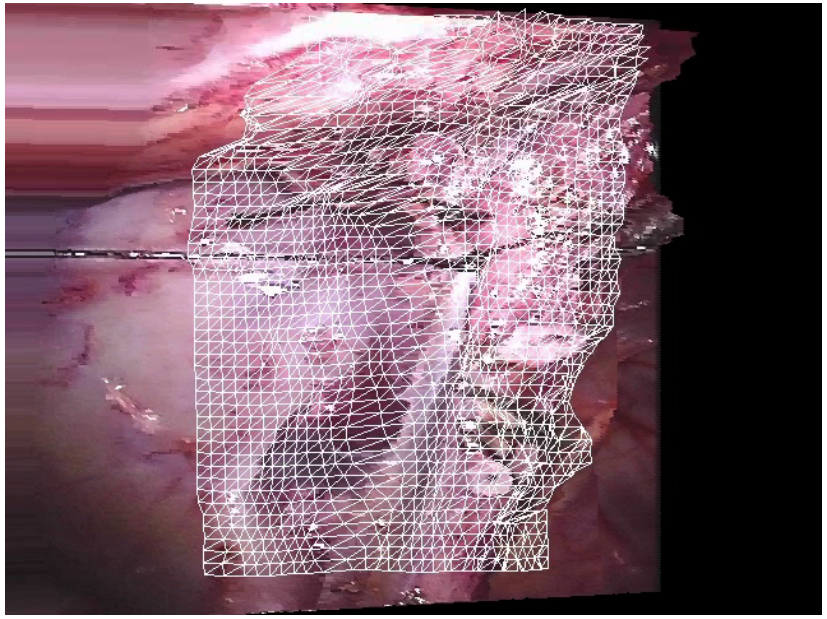
# Cross-Validation Results

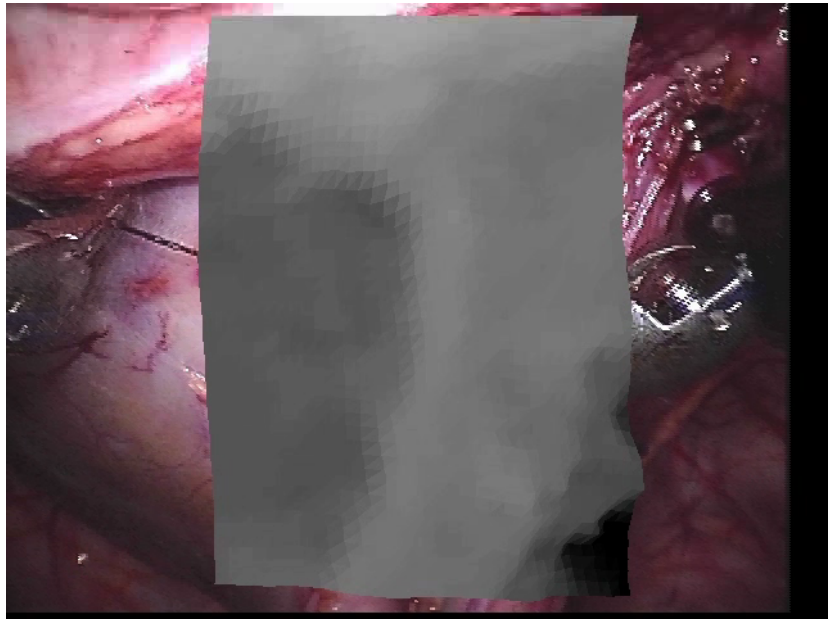
Alpha, beta, gamma with feature number



# An Aside: The Advantages of Stereo

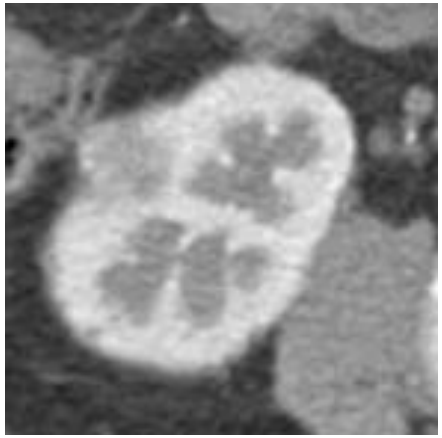


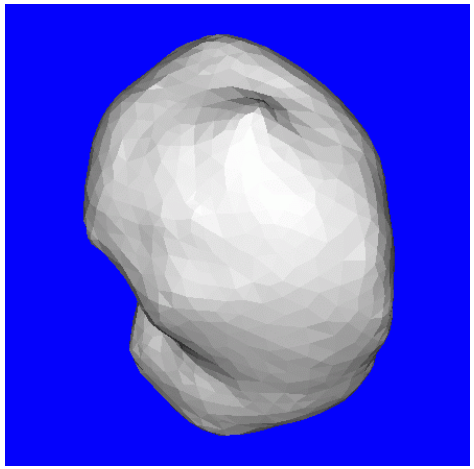


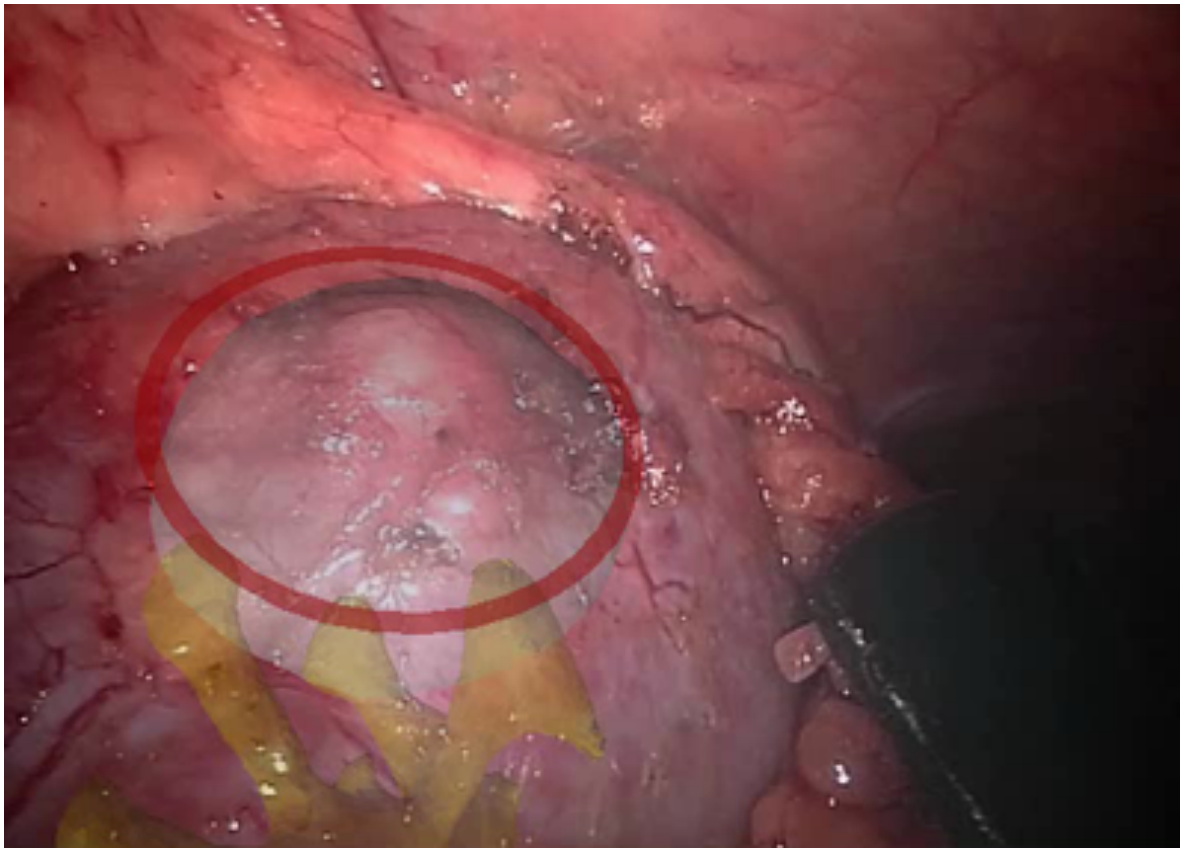
Real-time dynamic programming stereo + deformable registration
Final registration error of < 1mm without tool in image

# CT Registration To Live Stereoscopic Video

Vagvolgyi, Hager, Taylor, Su, Journal of Urology, 2009







Real-time importation and display of preoperative information in
in the surgeon field of view

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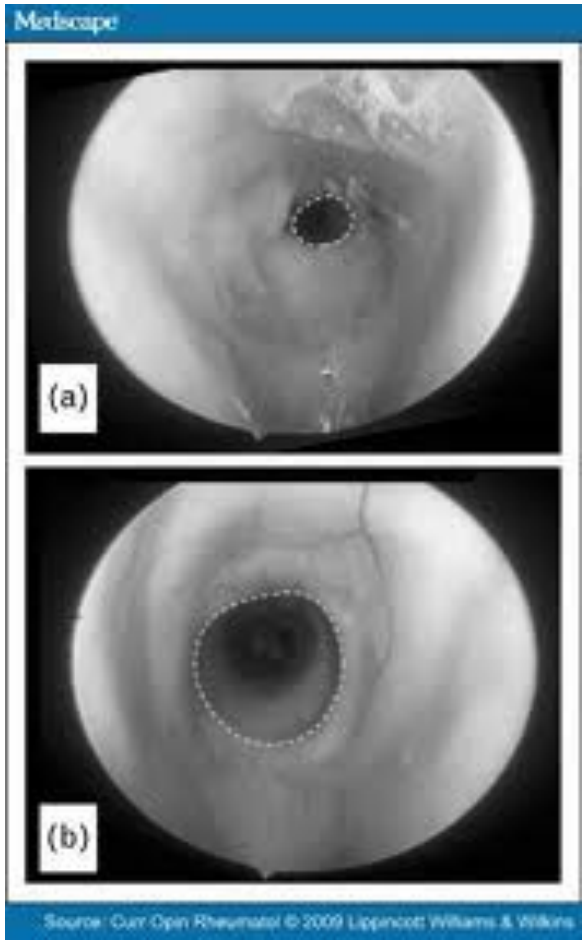
# A Second Example: Subglottic Stenosis

Why does this ….

… lead to this?

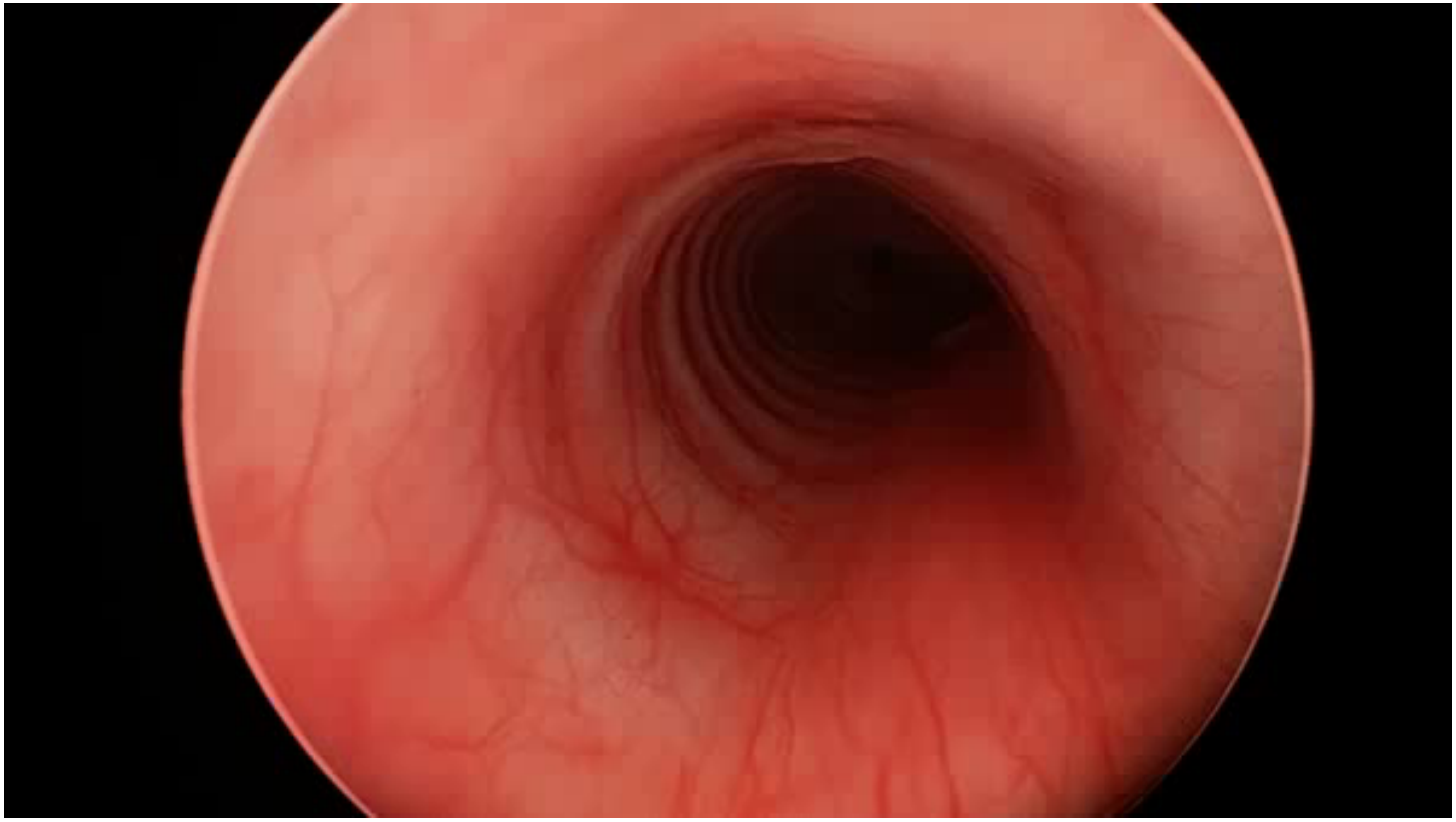
NIH R21 EB008490

# Subglottic Stenosis




# Quantitative Endoscopy: Reconstruction

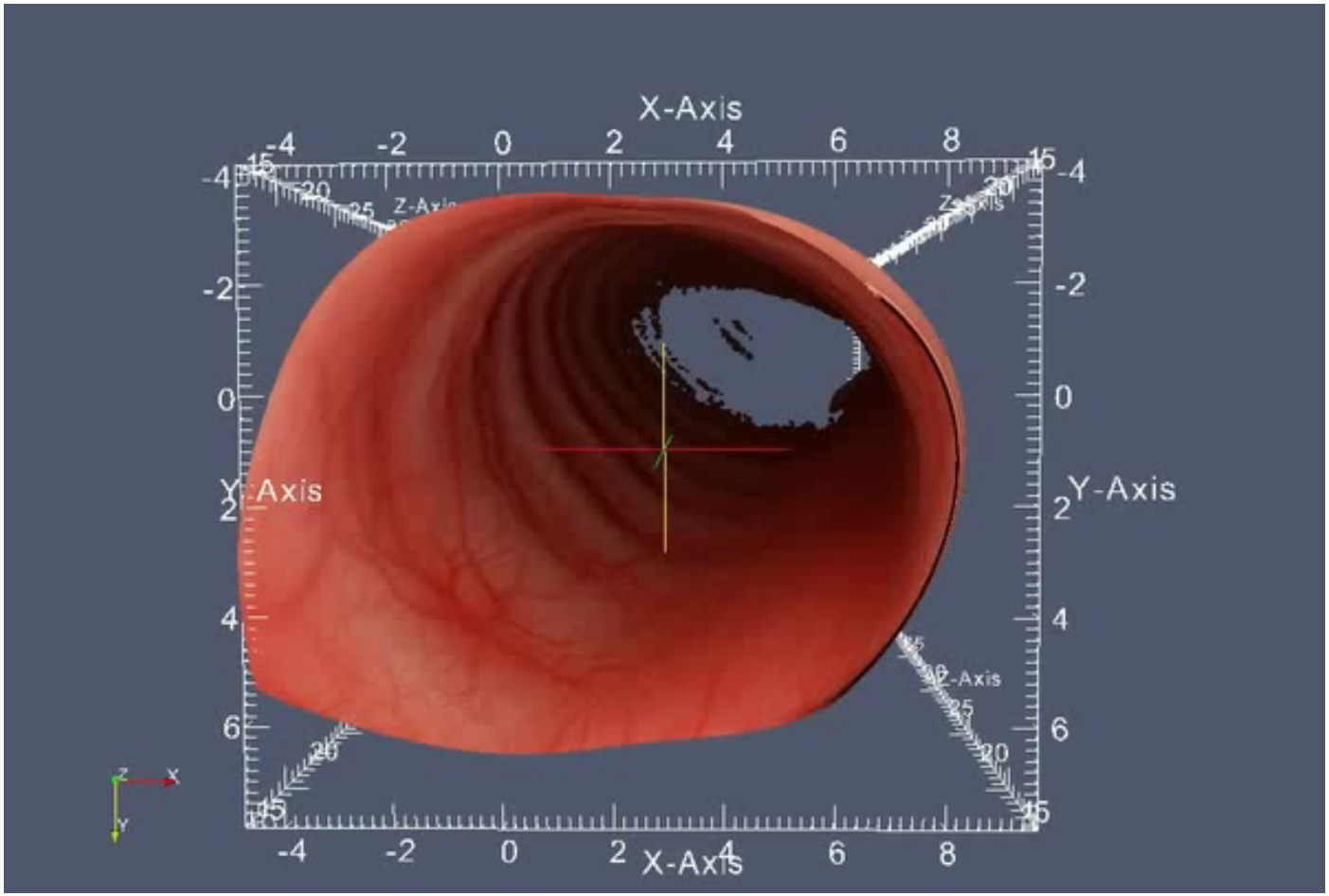
(with Masaru Ishii, MD, Eric Meisner, Haluk Tokgozoglu)



Can we measure noninvasively?

# Quantitative Endoscopy: Reconstruction

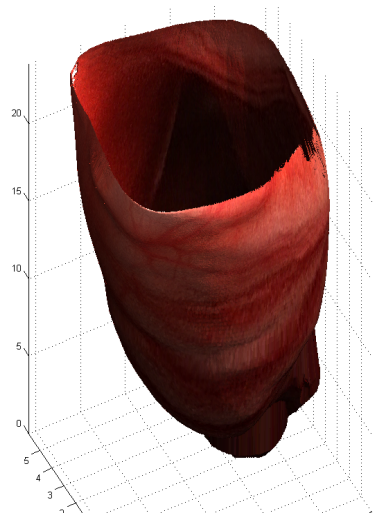
(with Masaru Ishii, MD, Eric Meisner, Haluk Tokgozoglu)




Can we measure and evaluate noninvasively?

# An Idea: Hybrid Reconstruction

- Multiview reconstruction provides a globally correct shape
- SFS (assuming we deal with the albedo problem) provides locally correct shape
- Can we produce a hybrid reconstruction that is globally + locally correct?



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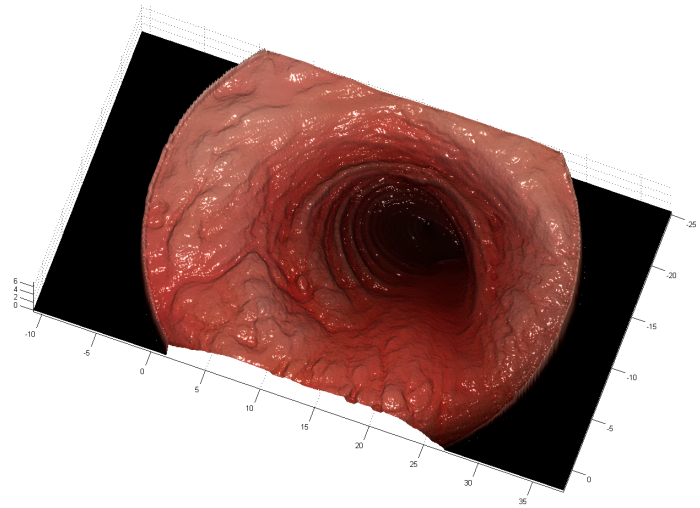
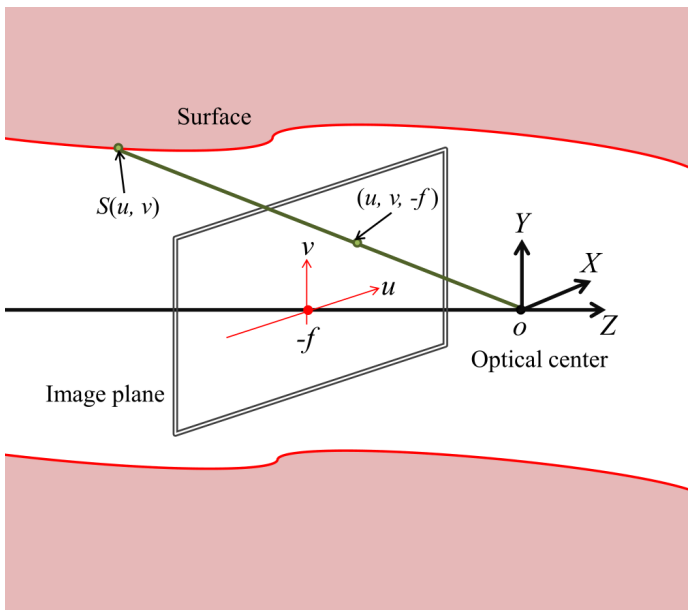


# Aside: Perspective SFS in the Airway

- Light source is at camera center (endoscope)
- Lambertian reflectance: $I = \eta \frac{cos\theta_i}{r^2} = \eta \frac{N \cdot L}{r^2}$

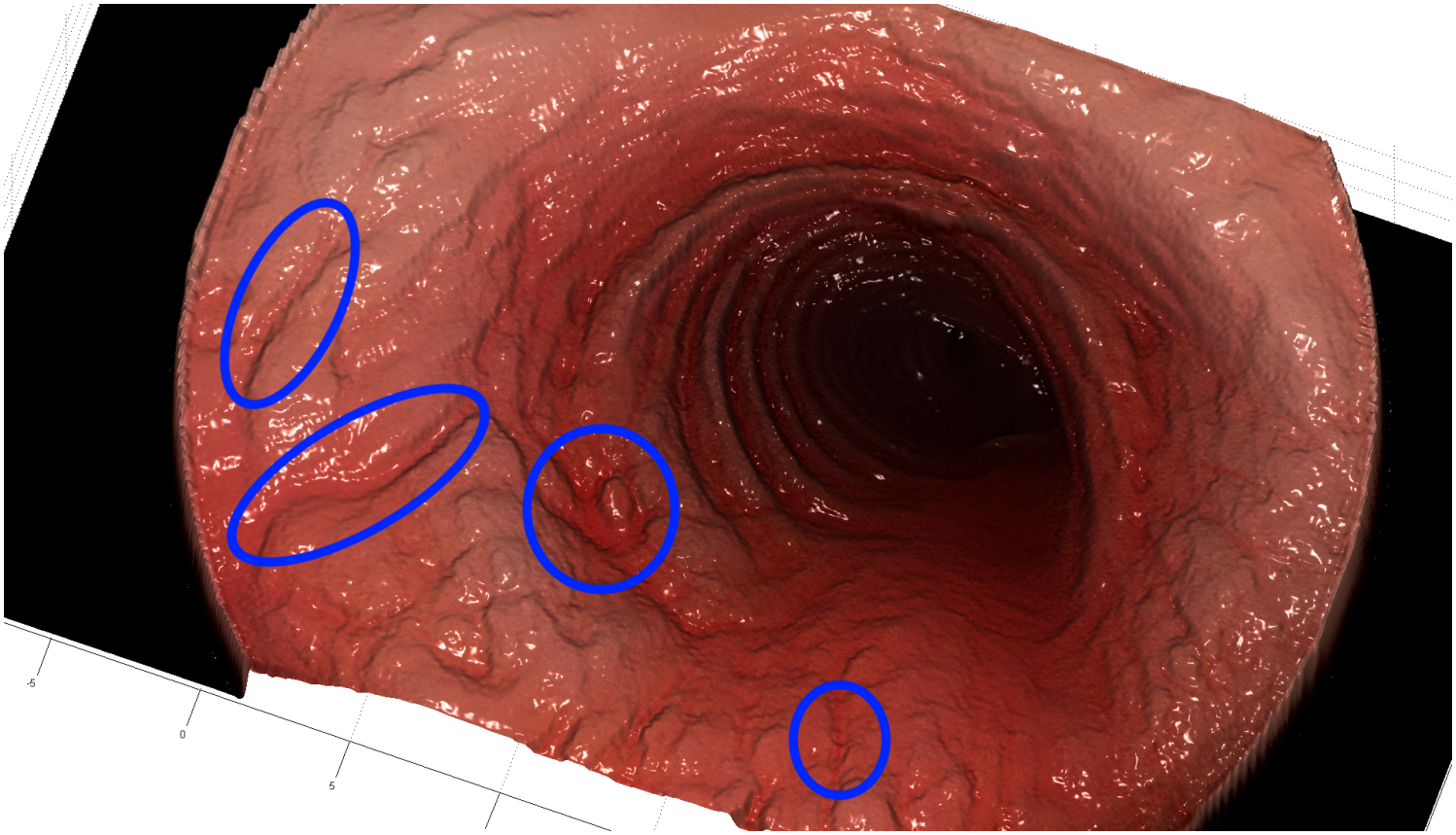



- Characterize the object in terms of pixel coordinates using perspective projection:

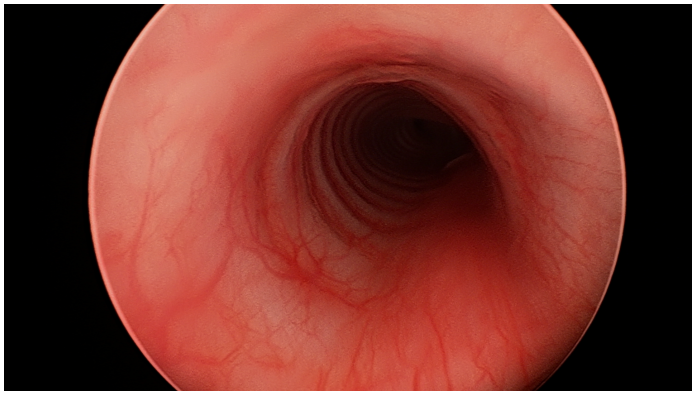
$$S(u,v) = u\frac{z(u,v)}{f},\ v\frac{z(u,v)}{f}$$

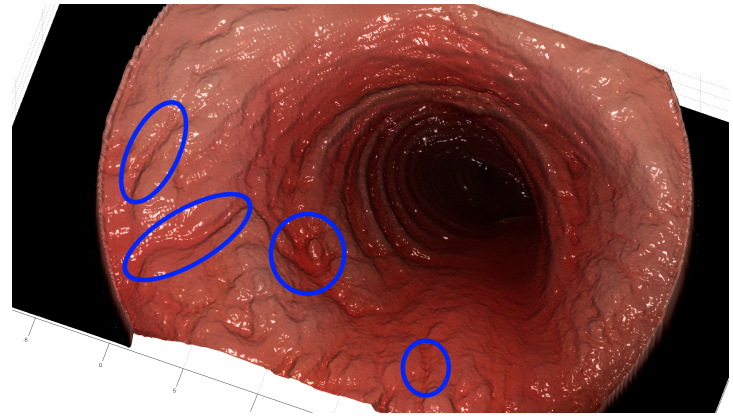
- We need $N$, $L$, $r$

# A Slight Problem …..



# Intensity Variation Minimization





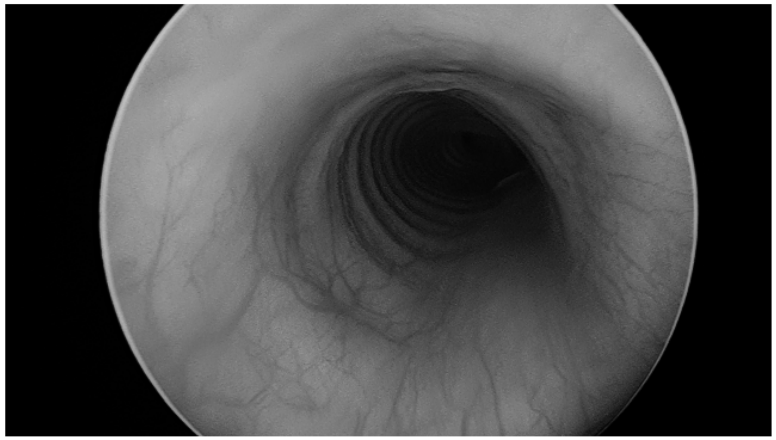
- Our approach: find $w$ such that:

$$\min_{w} \sum_{i \in P} \sum_{j \in N(i)} \| w^T v_i - w^T v_j \|^2$$

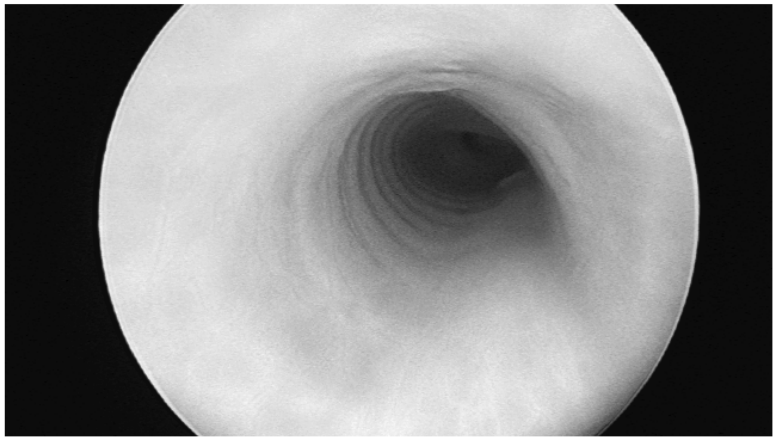
- Where $P$ is the set of marked pixels, $N(i)$ is a set of pixels in a neighborhood of $i$ with size $\gamma_i$ and $v_k \in \mathbb{R}^{3x1}$ is the *RGB* values at pixel $k$

# Results of Color Variation Reduction

Grayscale

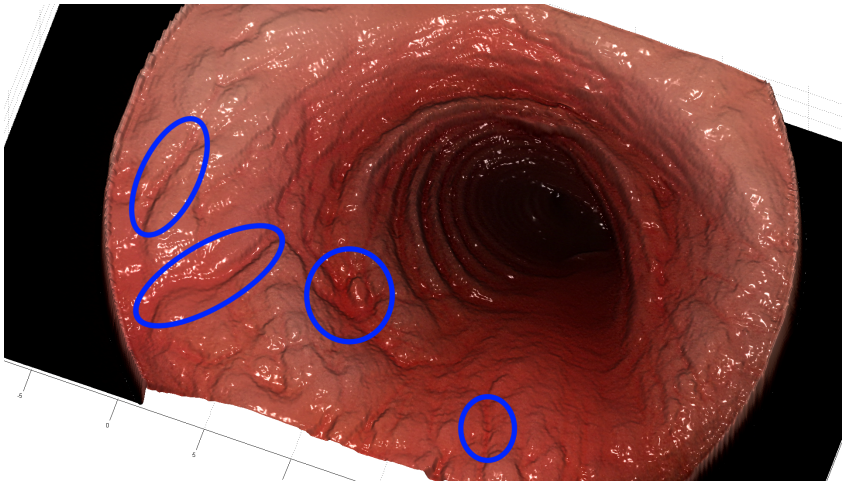


Projected color

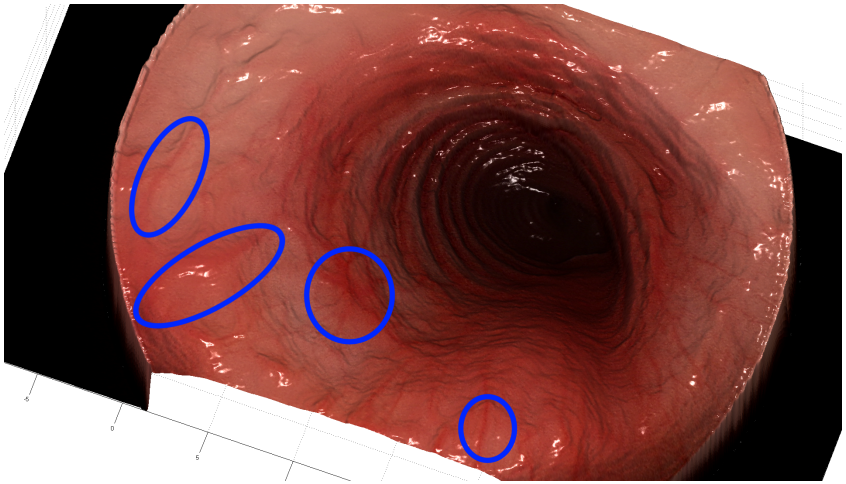


# Results of Color Variation Reduction

Grayscale

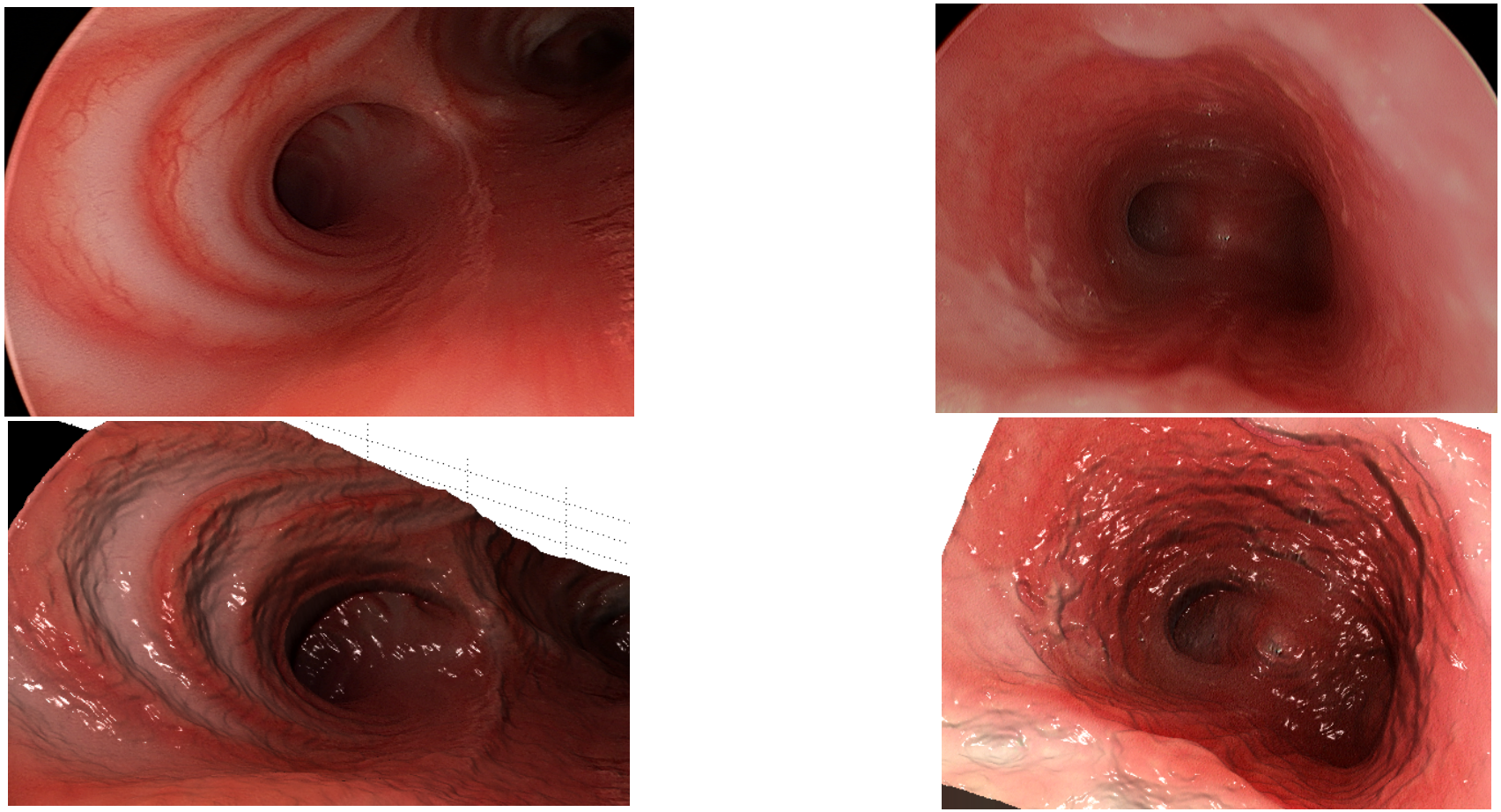


Projected color

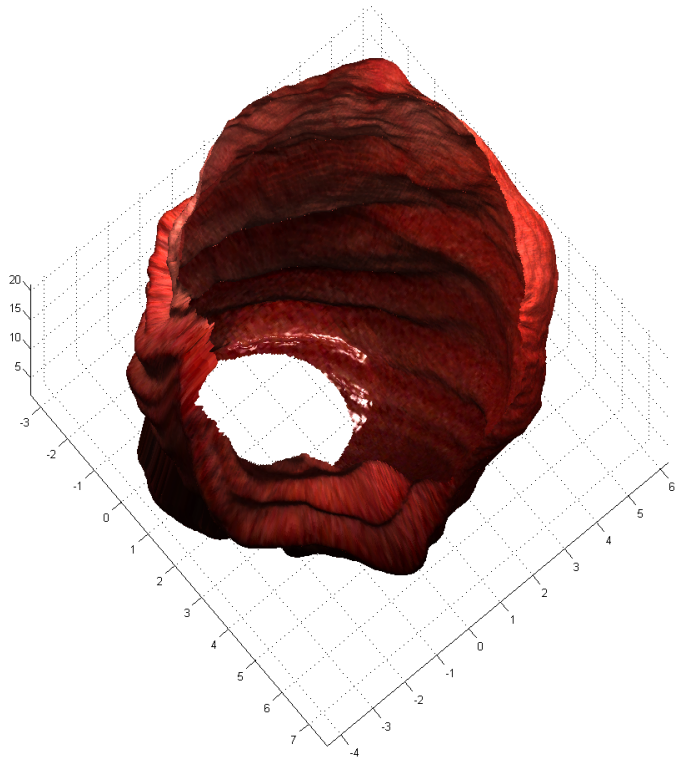


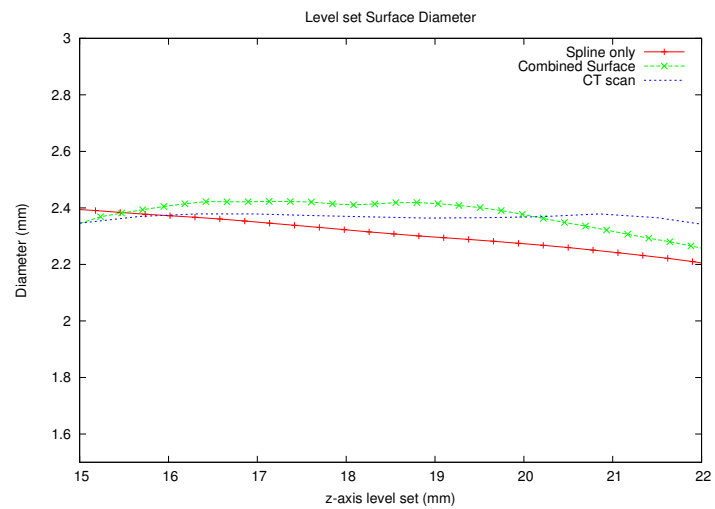
- Geometry (like rings) is preserved!

# More Results



# Quantitative Comparison





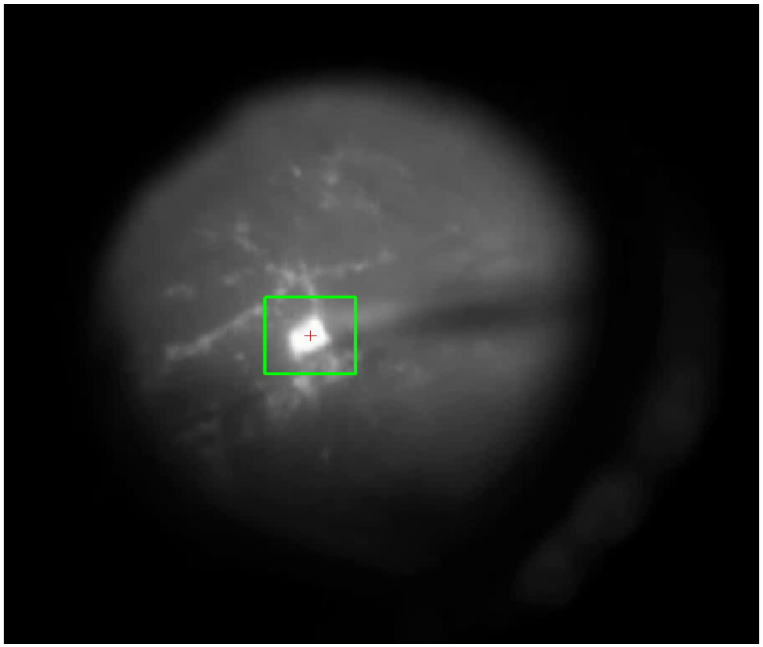

Comparison of Hybrid Reconstruction diameter to CT and Multiview

**Millimetric accuracy based on a simple digital endoscope!**

# Retinal Surgery


**Team**

- **WSE:** R. Taylor, G. Hager, J. Kang, P. Kazanzides, I. Iordachita
  **SoM:** J. Handa, P. Gehlbach, E. Gower
- **Current Funding:** NIH BRP



# Tool Tracking as Detection

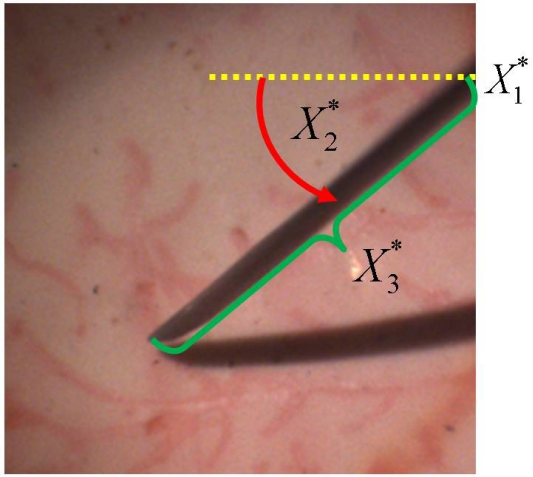
[1] Jedynak, Frazier, Sznitman. **Twenty questions with noise: Bayes optimal policies for entropy loss.** J. of Applied Probability: 49 (1), 114-136 (2012)

Let us find the tool pose in an image [1]:

- Let $X^* = (X_1^*, X_2^*, X_3^*)$ be a discrete random variable that defines the tool pose.
- Let the space of possible tool locations be:

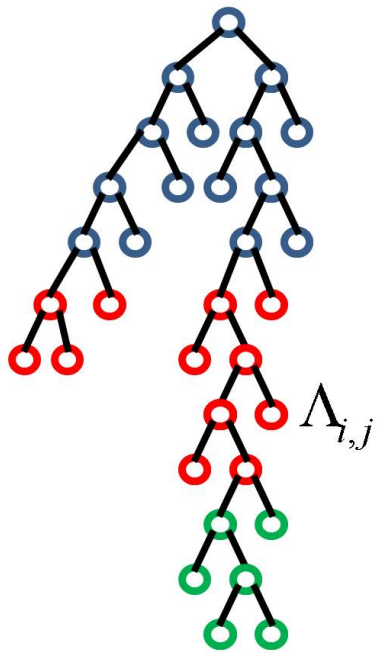
$$\mathcal{S} = [0, P] \times [-\pi/2, \pi/2] \times [\delta, L]$$

- Let $p_0 \sim U(\mathcal{S} \cup \{\square\})$




- More complicated density: need a way to organize

# Basic Idea




- At each node $\Lambda_{i,j}$, can evaluate a question type: $k = 1, \ldots, \mathcal{K}$
- A question $X^k_{i,j}$ asks: "is $X^* \in \Lambda_{i,j}$" by computing a function $k$ of the image:

$$X^k_{i,j} : I_{\Lambda_{i,j}} \mapsto R$$

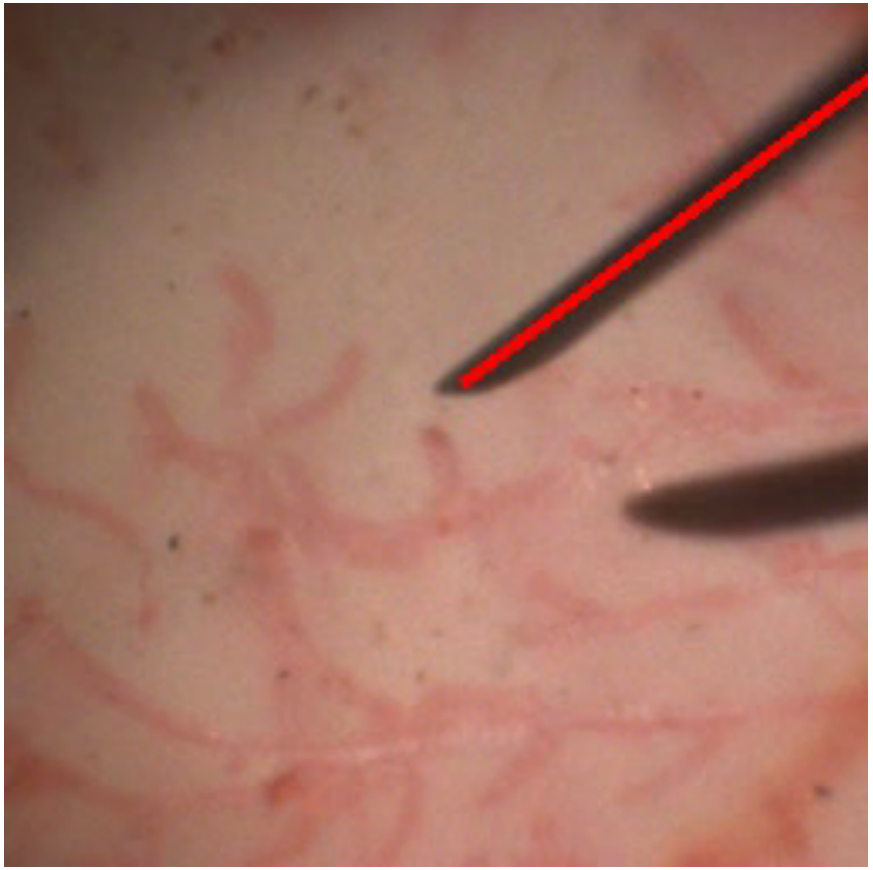
- Answer $Y^k_{i,j}$ is random,

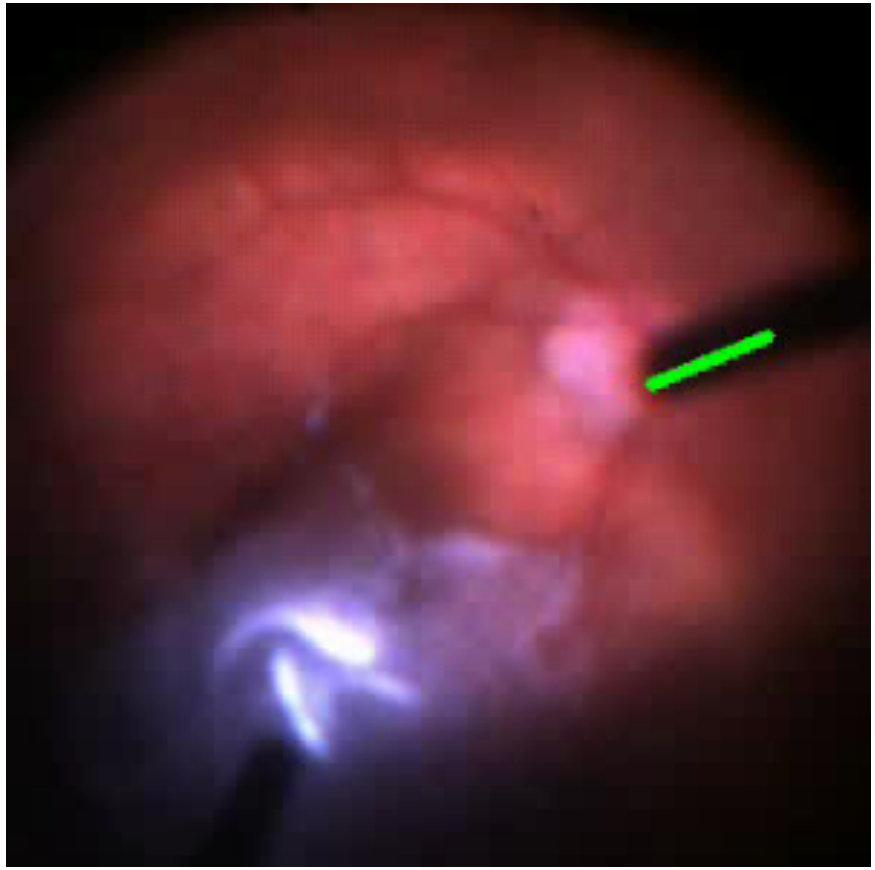
$$Y^k_{i,j} = \begin{cases} f_1(\cdot; i, j) & \text{if } X^* \in \Lambda_{i,j} \\ f_0(\cdot; i, j) & \text{if } X^* \notin \Lambda_{i,j} \end{cases}$$

$(f_1, f_0)$ are estimated from labeled training data.

# Some Results

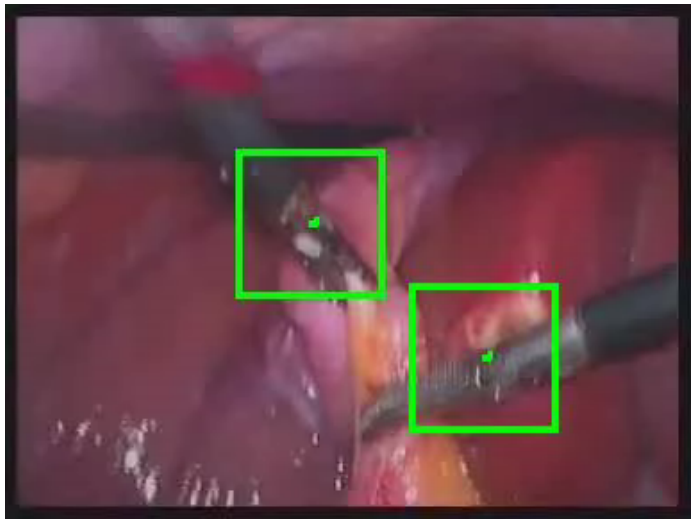
Sznitman, Raphael, et al. "Unified detection and tracking in retinal microsurgery." *Medical Image Computing and Computer-Assisted Intervention–MICCAI 2011*. Springer Berlin Heidelberg, 2011. 1-8.

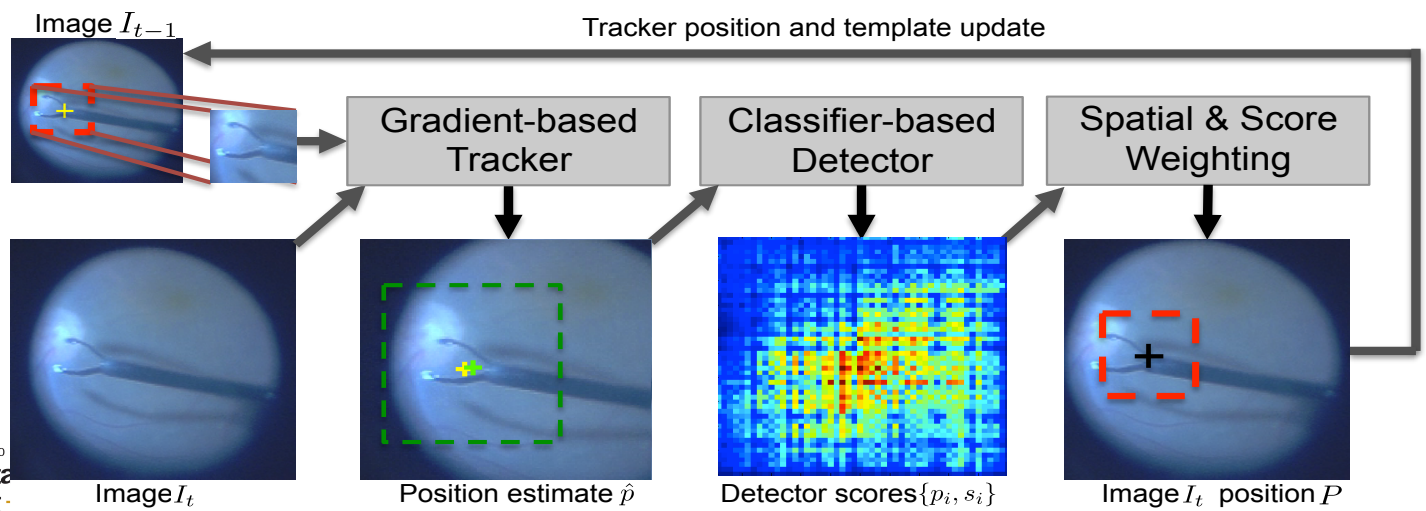




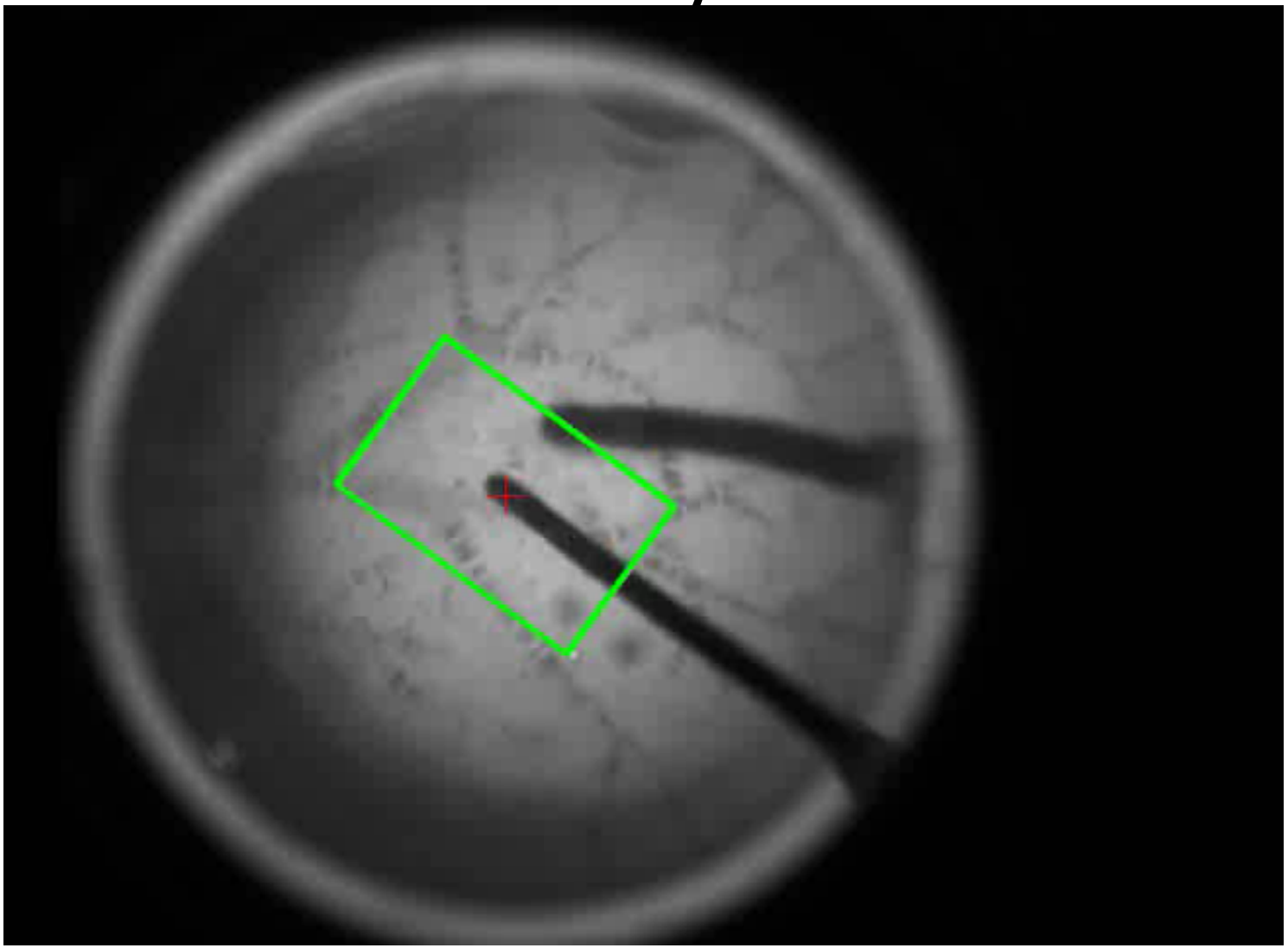
# Data-Driven Visual Tracking in Retinal Microsurgery

Raphael Sznitman[1], Karim Ali[1], Rogerio Richa[2], Russell H. Taylor[2], Gregory D. Hager[2] and Pascal Fua[1]
1. École Polytechnique Fédérale de Lausanne, Switzerland
2. The Johns Hopkins University, Baltimore MD, USA





# Proximity Alert



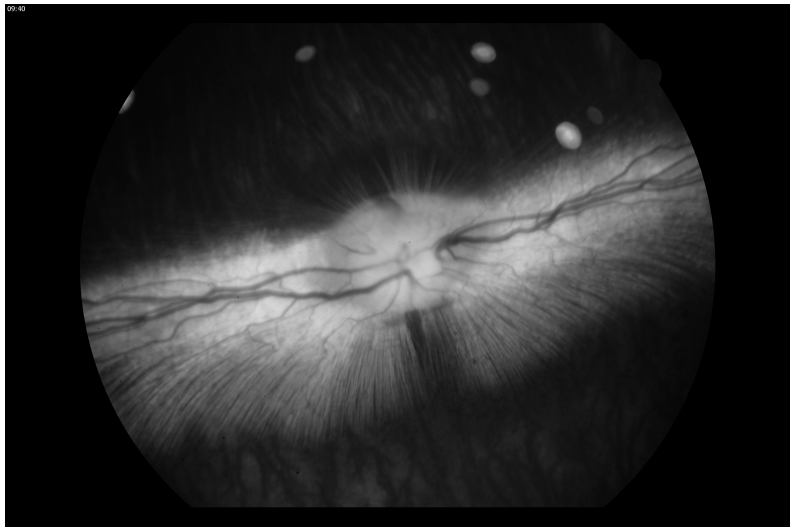
**Rogerio Richa, Balazs Vagvolgyi, Raphael Sznitman, Greg Hager, *et al.***

LABORATORY FOR Computational Sensing + Robotics THE JOHNS HOPKINS UNIVERSITY

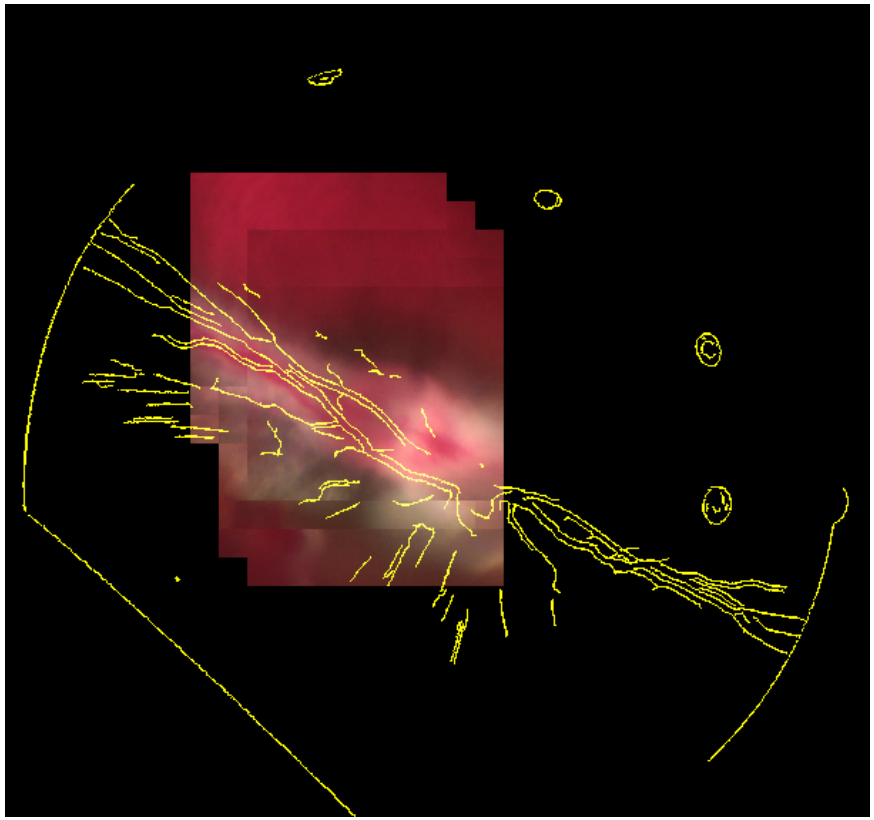
ERC | CISST

# Retinal Image Registration

- How to **reliably** create/register high-resolution fundus images from a microscope or slit lamp?

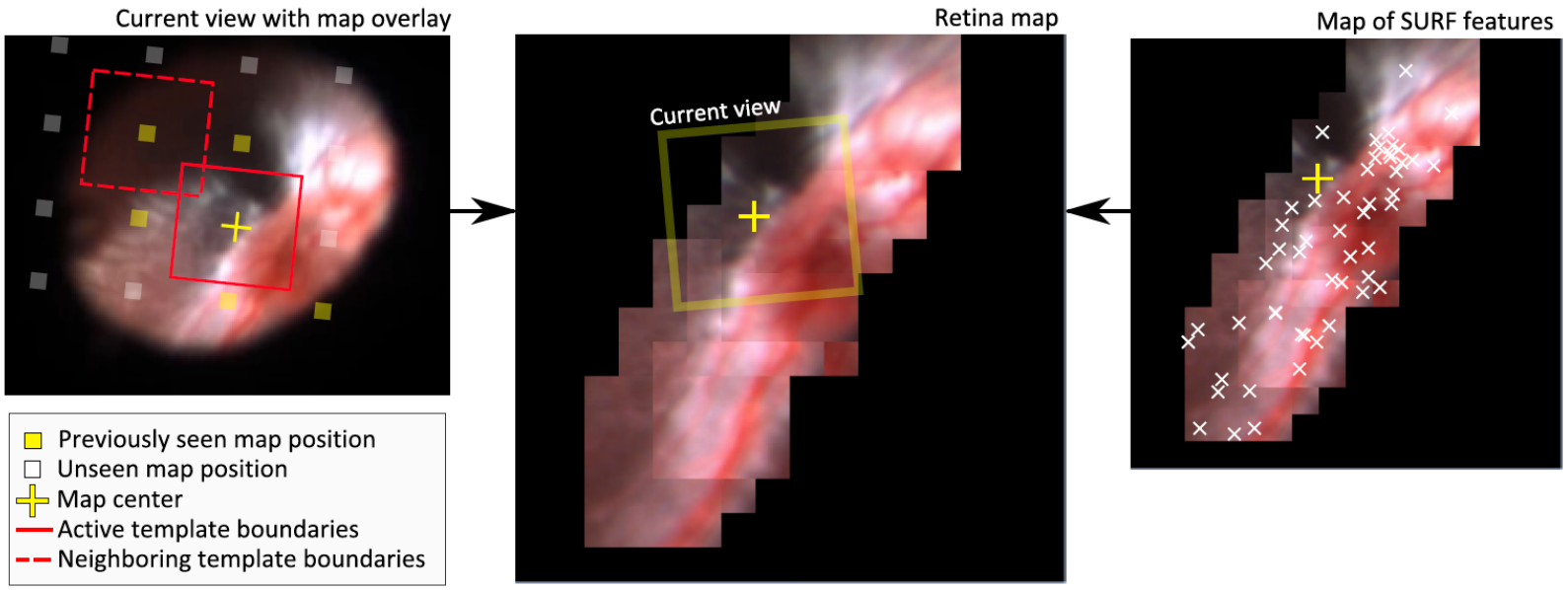


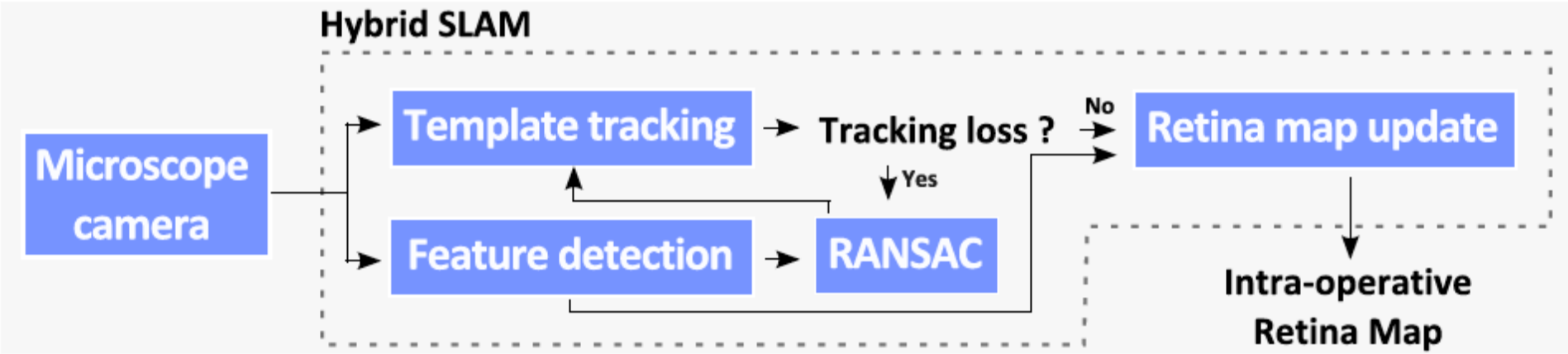
**Rabbit Fundus image**



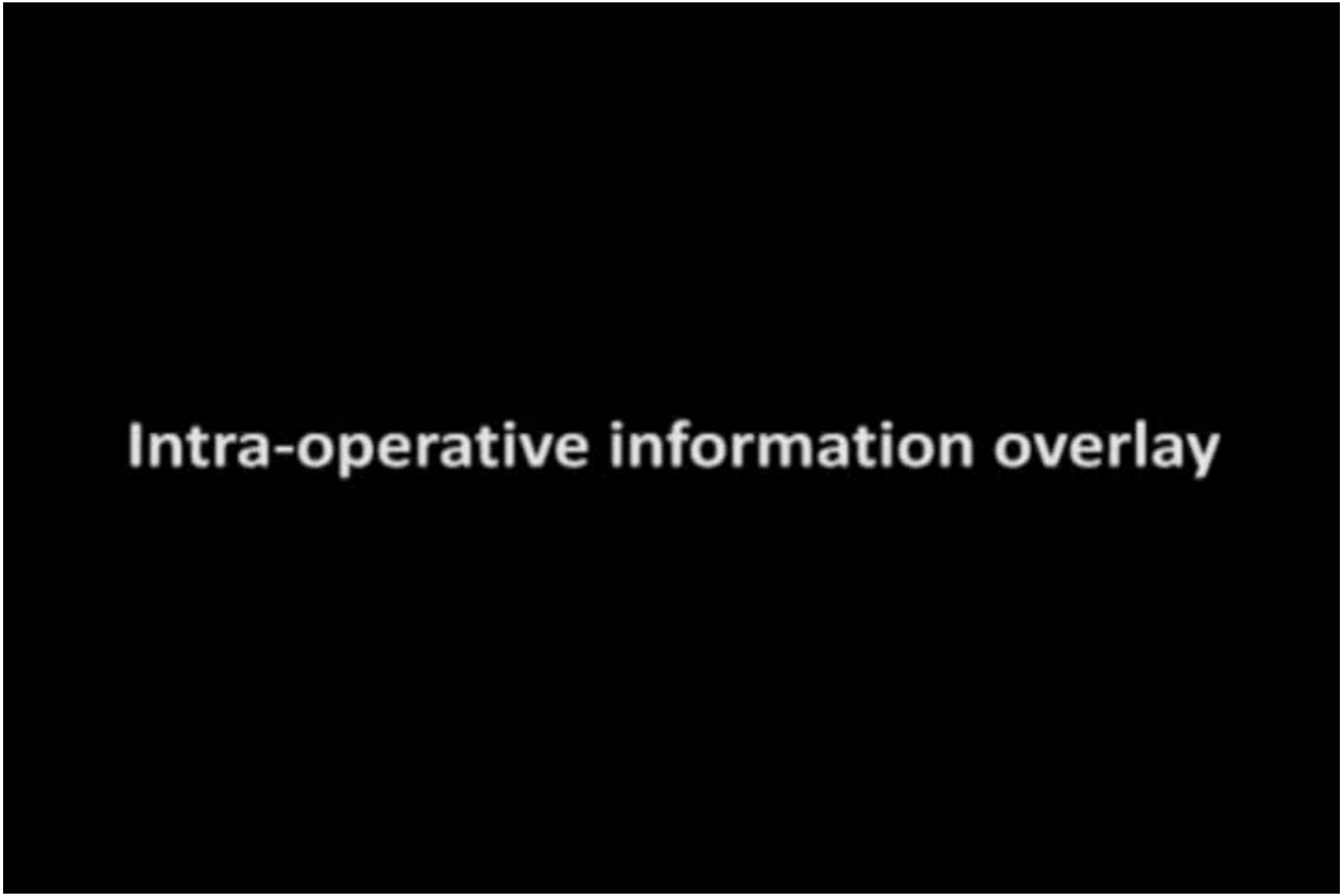
**Fundus edge map overlay**

# Tracking and Mosaicking



# TRACKING AND MOSAICKING THE RETINA DURING SURGERY

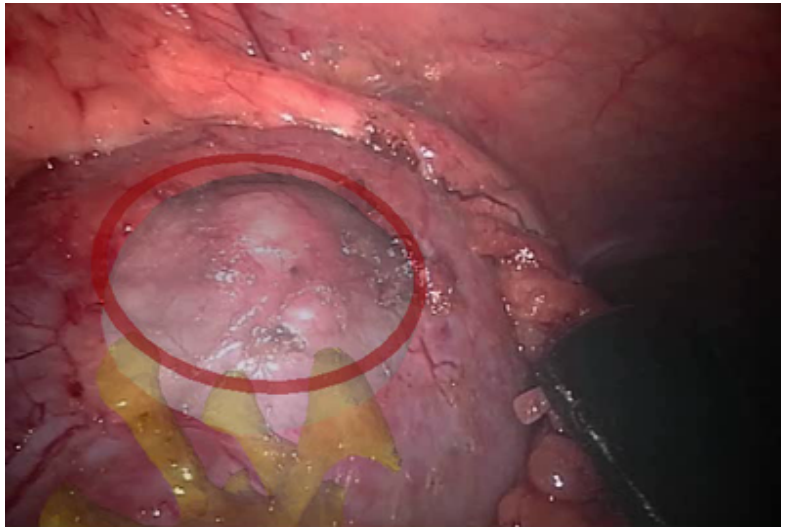



Courtesy Rogerio Richa, Balaz Vagvolgyi

[Richa12a]

# QE Opportunities and Challenges

- **Opportunity:** Make medicine better
  - Quantitative non-irradiating measurement
  - Cost-neutral
  - Always available
  - New science of studying surgery



- **Challenges:**
  - Reliable methods at scale
  - Online assessment and feedback
  - Deployment in clinical workflow

# Acknowledgements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  - Gary Gallia MD
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