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LABORATORY FOR Computational Sensing + Robotics
THE JOHNS HOPKINS UNIVERSITY

Visual Tracking of Surgical Tools in Retinal Surgery using Particle Filtering

Group 14
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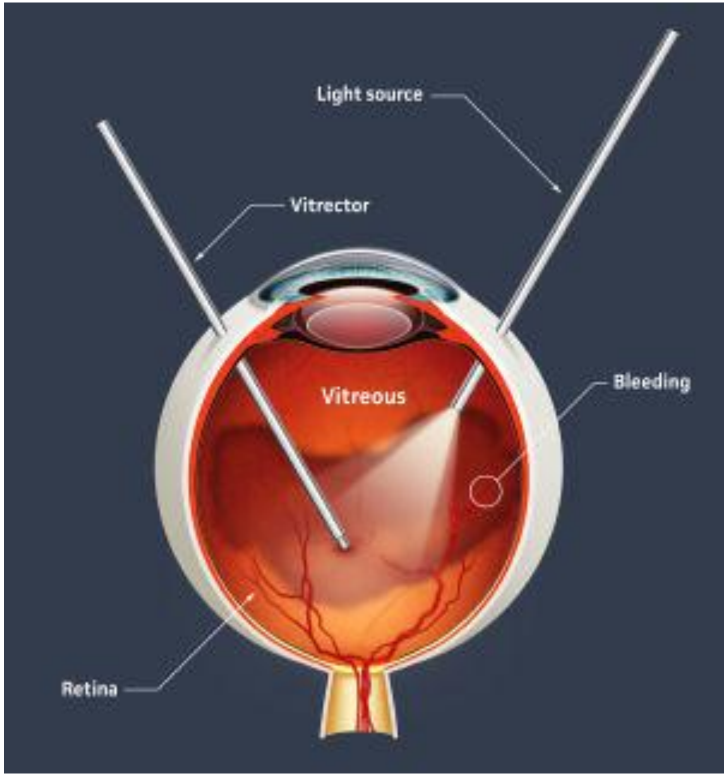
Project Description

- Goal: Develop a direct visual tracking method for retinal surgical tools using particle filtering and mutual information
- Advantages:
  - Particle filter is computationally efficient and robust
  - Mutual information performs better than SSD and NCC in many cases
- Chose an application which could benefit from this new tracking method

Project Background

- Vitreoretinal surgery treats problems with retina, macula, and vitreous fluid
- Many complications due to fragility of retina, indirect visualization, and physiological tremor
- Long operating times and risks of surgical error



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

Research Paper

Adaptive Multispectral Illumination for Retinal Microsurgery

Raphael Sznitman, Diego Rother, Jim Handa, Peter Gehlbach,
Gregory D. Hager, and Russell Taylor
Johns Hopkins University

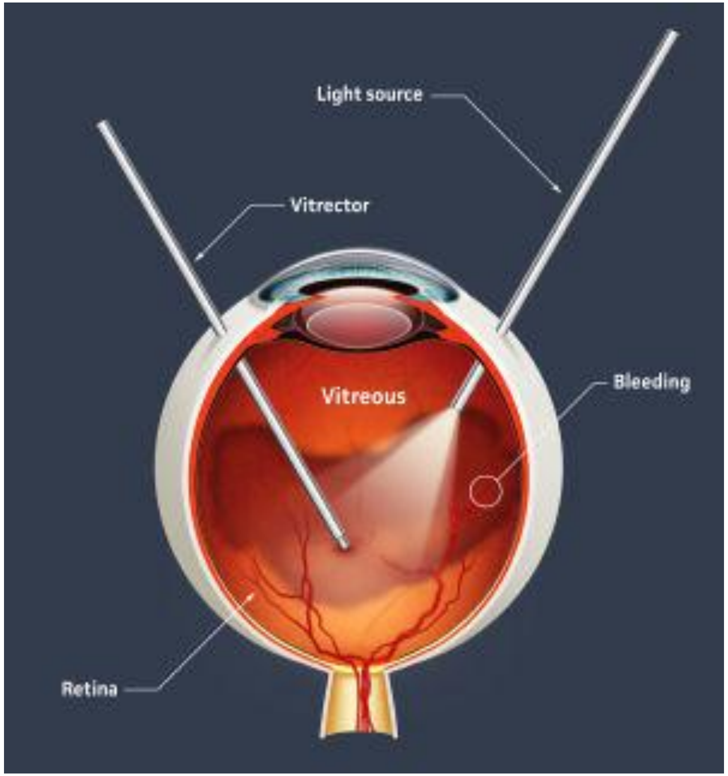
MICCAI 2010

Summary

- Problem:
  - White light causes phototoxicity but is needed for color
  - Current algorithms use constant white-light illumination rate
- Key result: Developed a novel visualization system that significantly reduces the phototoxicity by using a minimization to determine when to use white light.
- Significance:
  - Less white light leads to lower phototoxicity risk
  - Possible quantification of both image quality and phototoxicity

Background

- Current vitreoretinal surgical procedures use constant white-light illumination
  - Reported frequency of phototoxicity: 7% to 28%
- Short wavelengths have greater damaging potential
- Use xenon and mercury



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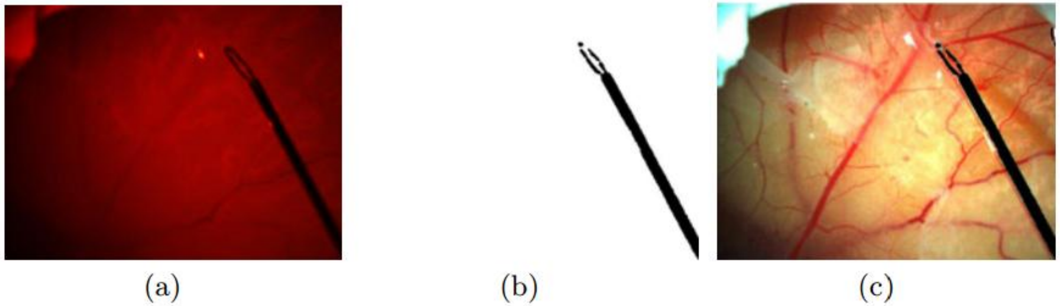
Background

- Visualization system developed by Sznitman et al. to reduce phototoxicity
  - Illumination is deactivated in between frames
  - Some frames are illuminated with red or IR light
- To aid surgeon, a coloring system (ASR) also developed to color monochrome frames



http://www.cis.jhu.edu/~diroth/Research/sznitman2010ipcai.pdf

Background

- Active Scene Rendering coloring algorithm
  - – Compute transformation of eye between frames using SIFT features
  - – Segment out tool using pose estimation
  - – Transform G,B channels from previous color image and add to R channel from monochrome
  - – Add color tool model using estimated pose

Problem + Hypothesis

- Extreme cases using constant white-light rate
  - No movement of retina: too much white light
  - Large movement of retina: too little white light
- Is it possible to vary the rate in an automated manner to minimize both phototoxicity and surgical error?
  - Yes, using cost function analysis

Cost Functions

- Surgeon impairment cost
  - Assumed error in G,B channels same as R channel
  - Above critical value ε_0 image does not deteriorate further

$$S(\epsilon) = \begin{cases} 1 & \text{if } \epsilon > \epsilon^* \\ \frac{\epsilon}{\epsilon^*} & \text{otherwise} \end{cases}$$

$$\epsilon_t^R = ||M_t^R - M_{t_w}^R||_2$$

http://www.cis.jhu.edu/~diroth/Research/sznitman2010miccai.pdf

Cost Functions

- Phototoxicity cost
  - Modeled recent light exposure $\psi(L_t)$ as exponential loss
  - Above threshold value L^*, no further damage can be done

$$T(\mathbf{L_t}) = \begin{cases} 1 & \text{if } \varphi(\mathbf{L_t}) > L^* \\ e^{\frac{-(\varphi(\mathbf{L_t})-L^*)^2}{2}} & \text{otherwise} \end{cases}$$

http://www.cis.jhu.edu/~diroth/Research/sznitman2010miccai.pdf

Cost Functions

- To choose illumination for next frame, minimize sum of phototoxicity and surgeon impairment costs
  - Weighted by λ, adjusted by surgeon to emphasize phototoxicity or video quality
  - Quite simple because there are only two illumination settings for the next frame

$$L_{t+1} = \arg\min_{L} E(\mathbf{L_{t+1}}, \hat{\epsilon}_{t+1}) = \arg\min_{L} \{(1-\lambda)S(\hat{\epsilon}_{t+1}) + \lambda T(\mathbf{L_{t+1}})\}.$$

$$(1-\lambda)S(\hat{\epsilon}_{t+1}) + \lambda(T([L_t;1]) - T([L_t;0])) \geq 0$$

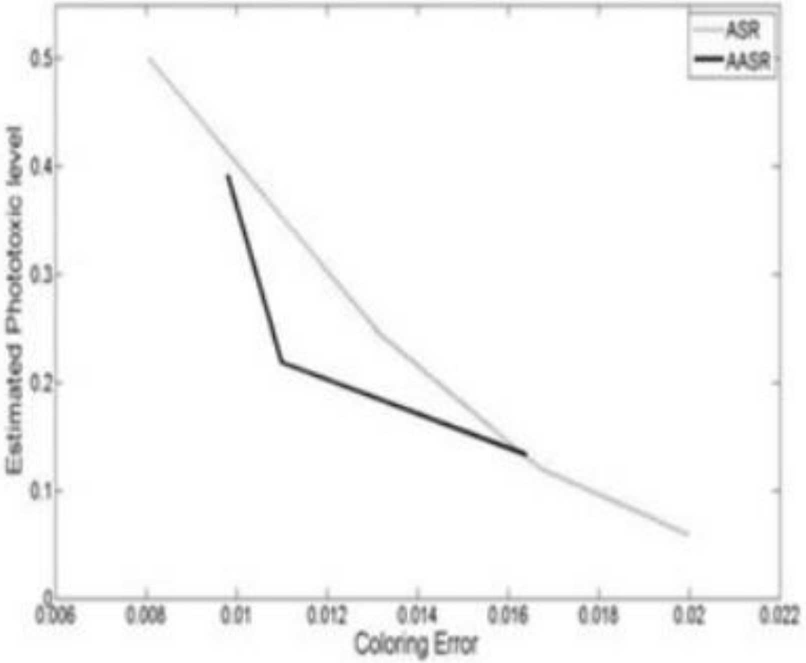
http://www.cis.jhu.edu/~diroth/Research/sznitman2010miccai.pdf

AASR Coloring Algorithm

- Adaptive active scene rendering
- Detect and segment the tool using a 3D tool model + pose estimation
- Add the G,B channels from the previous color image to R channel from monochrome
- Estimate errors and choose illumination type (white light vs. red light) for following frame

Validation and Analysis

- Recorded 5 image sequences of membrane peelings on phantom eyes using white light
  - Ran AASR with three settings and ASR with four settings
  - Surgeon impairment error: Mean squared error
  - Phototoxicity error: Proportion of white light used



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Conclusion

- Effective automatic minimization of both phototoxicity and error from coloring differences using cost functions and the AASR coloring algorithm
- Weighted sum of phototoxicity cost and surgical impairment cost can be altered by surgeon for individual operation control

Personal Thoughts

- Positive comments
  - Innovative method
- Areas for improvement
  - Improvement on experimental validation
  - Pose estimation for tool may be too inefficient

Future Research

- Parameters can be adjusted to possibly empirically determine specific cost functions rather than models
- Incorporation of particle filtering using mutual information to improve in vivo tool tracking and segmentation
  - Tool tracking required for many applications, key method

Reading List

- Sznitman, R., Rother, D., Handa, J., Gehlbach, P., Hager, G.D., Taylor, R.: Adaptive multispectral illumination for retinal microsurgery. In: Jiang, T., Navab, N.,Pluim, J.P.W., Viergever, M.A. (eds.) MICCAI 2010. LNCS, vol. 6363, pp. 465–472. Springer, Heidelberg (2010)
- Sznitman, R., Billings, S., Rother, D., Mirota, D., Yang, Y., Handa, J., Gehlbach, P., Kang, J., Hager, G., Taylor, R.: Active multispectral illumination and image fusion for retinal microsurgery. In: Navab, N., Jannin, P. (eds.) IPCAI 2010. LNCS, vol. 6135, pp. 12–22. Springer, Heidelberg (2010)
- Ham, W.J., Mueller, H., Ruffolo, J.J., Guerry, D., Guerry, R.: Action spectrum for retinal injury from near-ultraviolet radiation in the aphakic monkey. Am. J.Ophthalmol. 93, 299–306 (1982)

Questions?