A Microsurgical Assistant for Retinal Surgery

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Vitreoretinal Microsurgery


Alcon Vitreosurgery Instrument  
www.eyemdlink.com

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Engineering Research Center for Computer Integrated Surgical Systems and Technology
Clinical Background: Retinal Surgery

- Retinal disease is the leading cause of new blindness in the Western World
- Most frequent indications for retinal surgery include
  - Retinal detachment
  - Vitreous hemorrhage
  - Macular puckers
  - Macular holes
  - Diabetic retinopathy
- Success rates depend critically on difficult technical steps:
  - Removing scar tissue from the retina (e.g., in retinal detachment or macular puckers)
  - Peeling the internal limiting membrane (e.g., macular holes)
  - Cannulation of tiny vessels (e.g., retinal vein occlusion)

Limitations of Current Technology

- Human sensor-motor limitations
  - Hand tremor
  - Force perception
  - Tool-tissue relationships
- Visualization
- Information fusion
- Ergonomics
Microsurgical Assistant for Retinal Surgery

Goals
• Develop technology addressing fundamental limitations in retinal microsurgery
• Integrate into comprehensive system
• Validate performance
• Transfer to clinical use

Team
• **SoM:** J. Handa, P. Gehlbach, E. Gower, N. Cutler
• **CMU:** C. Riviere, B. Becker, R. MacLachlan

Current Funding
• NIH BRP5 R01 EB007969 ($4.8M/5 years)

Microsurgery Assistant Workstation

3D Display with Overlays

Microcope

OCT Display

Microphone

EyeRobot2

Audio Output

FBG Interrogator
Eye Phantom

Rabbit Size

In-Vivo Experiments

- Overall System Performance
- System Ergonomics
- Collect Data
  - Robot / Force / OCT
  - Video / Audio
20-25 gauge tools & sensors (proximity, force, ischemia, OCT, other)

OCT & Spectroscopy System

Multi-spectral light source

Surgical Workstation
- Visualization & display
- Real time image and sensor processing
- 3D modeling and information fusion
- Task representation
- Safety monitoring
- Manipulation assistance and "virtual fixtures"

Modular control & sensing interfaces
- Preoperative images
- Other patient data
- Procedure plans
- Procedure logs

Surgical Workstation
- Visualization & display
- Real time image and sensor processing
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Modular control & sensing interfaces
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Video Overlay Technologies

1. Image Injection
   - Stereo optical microscope
   - Stereo beam splitter
   - C-mount couplers
   - IEEE 1394B cameras
   - Processing hardware
   - Image injection system
   - Optical eyepiece

2. Video Microscopy
   - Stereo optical microscope
   - Stereo beam splitter
   - C-mount couplers
   - IEEE 1394B cameras
   - Processing hardware
   - Stereo display
     - Monitor
     - Video eyepiece
2. Video Microscopy

- Stereo optical microscope
- Stereo beam splitter
- C-mount couplers
- IEEE 1394B cameras
- Processing hardware
- Stereo display
  - Monitor
  - Video eyepiece

Video Microscopes

Hackerman Engineering Lab
Wilmer OR1

- Fire wire HD cameras attached to Zeiss operating microscopes
- Stereo video display with polarized glasses
- Permits easy overlay of information
- Architecture does not depend on technology choice
Retina Mosaicking

Balazs Vagvolgyi, et al.
Tool and Retina Tracking


In-vivo tool tracking

Data from recorded retinal surgery cases at JHU

Recent Progress:
Automatic Initialization by Detection

R. Sznitman, A. Basu, R. Richa, J. Handa, P. Gehlbach, R. H. Taylor, B. Jedynak and G. Hager,
“Unified Detection and Tracking in Retinal Microsurgery”, to appear in MICCAI ’11

Tool and Retina Tracking

Surgical Workstation
- Visualization & display
- Real-time image and sensor processing
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Stereo video

OCT & Spectroscopy System
multi-spectral light source

Hand-held active tremor reduction (MICRON)
Steady hand microsurgical robots

Modular control & sensing interfaces

20-25 gauge tools & sensors (proximity, force, ischemia, OCT, other)

Active Programmable Multispectral Illumination

Surgical Workstation
High Resolution 3D Video Display
Steroscopic Video Microscope
Serial Port Interface
Camera Trigger
PWM
Light Source Control Box
RGB/IR LEDs
Fiber-Optic Light Pipe
Fiberoptic Coupler
Retina

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Engineering Research Center for Computer Integrated Surgical Systems and Technology
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Surgical Workstation
- Preoperative images
- Other patient data
- Procedure plans
- Procedure logs

Stereo video
- Stereo video

Multi-spectral light source
- QCT & Spectroscopy System
- Modular control & sensing interfaces

Hand-held active tremor reduction (MICRON)
- Steady hand microsurgical robots

MICRON active tremor cancellation device
Cameron Riviere, Robert McLaughlin, et al. (CMU)
- Handheld device
- Sense tremulous motion
- Actively move to compensate
- BRP Research goals:
  - Incorporate “endpoint sensing” from vision & other sensors
  - Virtual fixtures
  - Improved device for eventual clinical use

Freehand cannulation
- Tremor cancellation
JHU Steady Hand “Eye Robot”
Russell Taylor, Iulian Iordachita et al.

- Highly precise robot
- Hands-on cooperative control or teleoperation
- Several generations in lab

- Precise, stable platform for developing “smart” surgical instruments and sensors
- Virtual fixtures and advanced control
Freehand cannulation

Steady hand robot cannulation

Sclera insertion (on phantom) Membrane peeling (on phantom)

Stereo video

Surgical Workstation

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Hand-held active tremor reduction (MICRON)

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Procedure logs

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Force Sensing Surgical Instruments

- Incorporate fiber optic force sensors into 0.5 mm diameter surgical tools
- 0.25 mN force sensitivity

2 DOF Tweezers tool
I. Iordachita

Current Tool - 3D CAD model
(Alcon modified design)

2DOF Force Sensing Tool (tweezers like)
current implementation
In-Vivo Experiments

2DOF FBG Tool

GUI Interface

Stereo Microscope

FBG Interrogator

Pull/Tear Retina Forces

S. Sunshine, M. Balicki, X. He, K. Olds, J. Kang, P. Gehlbach, R. Taylor, I. Iordachita, J. Handa

3 DOF force sensing tools (in progress)

Xingchi He, Iulian Iordachita

Sense axial force outside eye

Sense axial force inside eye

Lateral force sensing here

Axial force sensing here

Scleral friction forces for different speeds

125/60 μm FBG

80 μm FBG

FEA of designs

Fabrication and evaluation

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Imaging (OCT) Built Into 0.5mm Surgical Tool
M. Balicki, J. Han, X. Liu, I. Iordachita, P. Gehlbach, J. Handa, R. Taylor, J. Kang.

- Fourier Domain Common Path OCT (FD CPOCT)
- Combined Superluminescent Diodes
- Functional and structural images

B-mode scans of rabbit retina
Integration of online sensor data & display

Semi-transparent overlay of "A-mode" OCT scan data tracked with tool & penetration into retina

Overlay of incipient tear warning status indicator

Overlay of current tip force (mn)

Auditory sensory substitution and alarms

Picture-in-picture "B-mode" OCT Image

Scan direction
Laser Spot Tracking

Tracks Centroid of the OCT Laser Projection

Processing Time ~ 1ms

Tracking Indicator

Image Processing Debug Window
EyeRobot - OCT Safety Barrier (300um) + OCT Laser Spot Tracking

MicroForce Overlay
MScan Freehand – No Background Tracking
M-Scan

- 10 second M-Scan
  - ~ 80,000 A-Scans (555 pixels)
  - ~ 40 MGpix Image + Thumbnail Image
    - ~120 MB uncompressed
    - ~10MB Compressed
- Spectrum
  - 900MB uncompressed
- A-Scan Timestamps
- False color representation to enhance contrast
Audio Sensory Substitution

Example Audio Response to Force Input

Freehand Trials

25-35 Medical students, residents, and ophthalmologists

5 Membrane peels w/o auditory feedback

10 Peels with warning and alarm sounds

10 Peels with alarm sounds only

10 Peels with warning and alarm sounds

5 Peels w/o auditory feedback

Nathan Cutler, M. Balicki, I. Iordachita, X. He, R. Taylor, J. Handa, et al.
**Preliminary Results**

“Effects of Auditory Force Feedback on Simulated Ophthalmic Membrane Peeling Surgery”

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<table>
<thead>
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<th>Std dev for ave force</th>
<th>Total median</th>
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<td>10.44</td>
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</tbody>
</table>

Number of times potentially dangerous forces are applied during single peel

Nathan Cutler, M. Balicki, I. Iordachita, X. He, R. Taylor, J. Handa, et al.

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**Micro-force Sensing in Robot Assisted Membrane Peeling**

**Goal:** Lower applied forces in simulated retinal membrane peeling.

**How:** Use end-point micro-force sensing with cooperatively controlled robot
Enhanced Cooperative Control Peeling Algorithm

The algorithm biases operator-robot interaction towards the direction of least tissue resistance while limiting forces.

Tape Phantom Peeling

Inner Egg Shell Membrane Peeling

Peeling angles converge to 45°

A. Uneri, M. Balicki et al.
Submitted to BioRob2010

Tissue Behavior Characterization

– Membrane tensile testing
– For characterizing of peeling task dynamics
– Potentially provide real-time tissue behavior In-Vivo
– Results used in task specific robot control algorithms

Human Tendon (for comparison)

http://www.shoulderdsc.co.uk/article.asp?article=1029&section=419
Autonomous Surface Following (150 µm)

M. Balicki et al.

![Image of autonomous surface following](image1)

Noise Rem. /Thresholded/Canny

* 500 µm/s Velocity Limit

Handheld Micron OCT Scanning

“Dot Matrix” Scan (0.4x0.4mm), ~3 Sec, ~3K A-Scans

Spiral Scan (0.8 mm dia), 1 Sec ~ 25K A-Scans

4 Scotch tape layers with 2 human hairs

Hair on mirror

M. Balicki and E. Meisner
System Component View

Note: Automatically generated using cisst & uDrawGraph
Practical Additions

- **USB Pedal Switches**
  - Very useful for development
  - Generates keystrokes when pressed
  - Great for development: can be “tied” to button clicks.

- **Audio Recording / Playback**
  - 44 kHz – 16Bits application
  - AV/CAI formats – CAI uses internal timestamps to prevent drift.
  - With wav format has synchronization drift of ~1 sec/hr

-- cisstDataPlayer

Note: Work by Marcin, Anton & Joshua
iPad - Nurse Console

Goals:
• iPad application to control EyeSAW component settings for

Significance:
• Provide a centralized and easy to use device to control all components without the clutter of computer peripherals

Results:
• Incorporated the cisst libraries and ICE into an iPad application that communicates with the cisst Scenario Manager to change various component settings
• Detailed tutorial for future development of iOS applications that integrate with SAW

CIS2 Project: Hanlin Wan and Jonathan Satria

iPhone – System Start/Shutdown

Video - Microscope

EyeRobot + MicroForce

OCT
Discussion