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Applied Human Factors Research in Minimally Invasive Surgery

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Applied Human Factors Research in Minimally Invasive Surgery

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March 22, 2013
Dept of Physics Seminar
"You should've seen the look on our faces when we realized that we'd been looking at the x-rays backward for the first hour of surgery."
Ergonomics in Remote Environments Laboratory
(EREL)

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- Broad Medical Research Grant
- SAGES Research Award
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Minimally Invasive Surgery

Visuomotor coordination

Spatial orientation

Haptic perception

Communication

Applications
- navigational aids
- decision aids/information displays
- simulation training
- performance metrics
- sensory augmentation
- robotics/surgical device design
- team training
Current Research Projects

• Design and validation of VR surgical simulators
• Haptic feedback in laparoscopic surgery
• Modelling skill acquisition and decay in laparoscopic surgery
• Navigational guidance in colonoscopy
• Optimised port placement in robotic surgery
• Team communication in robotic surgery
Surgical Technology

Traditional open surgery

Minimally invasive surgery

Robot-assisted surgery
Endoscopic Surgery

• Advantages
  – Trauma and scarring
  – Complication rates
  – Hospital stay
  – Health care cost

• Disadvantages
  – Degrees of freedom
  – Depth perception
  – Hand-eye coordination
  – Haptic feedback
Natural Orifice Transluminal Endoscopic Surgery (NOTES)
Endoscopic Surgical Skill Training

• Skills different from open surgery
• Highly demanding in time and costs (patients, animals, simulators)
• Method for effective training lacking
Fundamentals of Laparoscopic Surgery (FLS)
Fundamentals of Laparoscopic Surgery (FLS)
**FLS vs. VBLaST**

**Fundamentals of Laparoscopic Skills (FLS) Trainer**
Physical box-trainer consisting of five basic surgical tasks
- Require large supply of consumables
- Time-consuming to administer
- Provide primarily subjective skill assessment

**Virtual Basic Laparoscopic Surgical Trainer (VBLaST)**
Virtual version of FLS
- Save on consumables
- Haptic feedback to aid learning
- Objective performance assessment
Surgical Simulator & Training

• Surgical simulator playing increasingly important role in surgical skill learning
  ➢ Allow trainee to practice in safe environment
  ➢ Avoid cost associated with animal model

• Virtual reality surgical training shown to transfer effective technical skills to operating room
  ➢ Enable objective scoring criteria for skills assessment
  ➢ Enable repeated trials of normal and adverse situations
  ➢ Enable exposure to common scenarios and rare events
  ➢ Implementation of force feedback
Haptics in Surgical Simulation
Haptics in Simulator Training

ProMIS simulator

MIST-VR simulator

Cognitive capacity for processing haptic information?
Haptics and Performance

- Peg transfer task with simultaneous mental multiplication task
- Better performance with haptics, p<0.001
- Subjects took advantage of haptics to improve speed and accuracy of performance

Cognitive Loading

- Cognitive loading using mental multiplication problem
- Cognitive loading extended performance time, $p<0.001$
- Speed-accuracy tradeoff

• Less experienced surgeons can take advantage of haptics
• Haptics counters the effect of cognitive loading

Summary

- Haptic feedback improves the accuracy and speed of the performance, and counters the effect of cognitive loading.

- Haptics is beneficial to less experienced surgeons, but more experienced surgeons are able to better take advantage of haptics.

- It may be worthwhile to include haptic feedback capabilities in surgical training simulators.
Human Sensory Modes

Multiple Sensory Theory

- Amount of information a human can process increases with multiple input sensory modes (Miller, 1956)

- Human task performance improves with multiple input sensory modes (Wickens, 2002)

Auditory stimulus can be a disturbance

Visual mode used extensively in MIS

Electric shock can be painful/dangerous

Vibrotactile Feedback is viable option
Vibrotactile Stimulation – Amplitude Modulation

Compliance Differentiation in Needle Insertion

Maximum Force

Time to Detection

Vibrotactile Stimulation – Frequency and Spatial Modulation

Compliance Differentiation in Needle Insertion

- Subject who preferred frequency feedback

- Subject who preferred combination feedback

Vibrotactile Stimulation – Amplitude, Frequency and Duty Cycle Modulation

Error in Tumor Detection

Correlation between confidence and performance accuracy

Summary

- Vibrotactile stimulation is a useful sensory augmentation for haptic information in laparoscopic surgery
- Double-modulated vibration signal contains more information than single modulated signal
- Triple-modulated signal provides redundancy, but not more information transmitted
- Advantage of information redundancy needs to be balanced with complexity of signal and device design
Colonoscopy
Colonoscopy

Advantages
• Colon cancer
  – Third leading cause of cancer-related death in the US (Cokkinides et al. 2009)
• Colonoscopy: gold standard for colon cancer screening and diagnosis

Disadvantages
• Near blind navigation procedure
• Disorientation
  – Missed tumor detection
  – Incorrect localization
• Looping
  – Distort natural colon shape
  – Pain for the patient (Cao & Milgram, 2000)
Flexible Endoscope

- Flexible, plastic tube
- Light source and lens
- 4 dof bimanual control:
  - In/out using hand
  - Twist using hand
  - Left/right using dial
  - Up/down using dial
- 5-10 cm of tip controlled
Need for Navigational Aid

Display containing shape, location, and direction information reduces localization errors (Cao, 2001)

Goal: Endoscopic Shape Tracker

- Provide real-time, 3D map of scope shape & location
- Integrated with colonoscopy video
- Reduce disorientation
- Reduce looping
Navigational Aid Design Concept
Fibre Optic Shape Tracker

Figure 7. Fiber sensor inserted into the biopsy channel of colonoscope.
**Tracking Technology**

### Optical fibers
- Transmit light through core
- Lose light when bent → Bend loss

![Optical fibers](https://edmundoptics.com)

### Quantum dots
- Semiconductor nanocrystals
- Narrow fluorescence emission band
- Advantages over organic fluorescent dyes

![Quantum dots](https://edmundoptics.com)

### CMOS sensor
- Complementary metal-oxide semi-conductor
- Photosensitive chip for imaging
- Used in digital cameras

![CMOS sensor](https://edmundoptics.com)
\[ \alpha_B = \alpha_l \times \alpha_c \]

where \( \alpha_l = I \exp\left(-\frac{R}{R_c}\right) \)

\[ \alpha_c = C \exp\left(-\frac{R}{R_c}\right) \]

Figure 5. Fluorophore emission due to fiber bending.
Testing: Bending fiber

Fluorescence as a function of bending

0° fiber rotation

Fluorescence Intensity Change

-50% 0% 50% 100% 150% 200% 250%

Wavelength (nm)
0.02 mm\(^{-1}\) Cylinder Curvature
0.04 mm$^{-1}$ Cylinder Curvature, 0° Rotation
QD Fluorescence of One Sensorised Region

![Graph showing fluorescence intensity change at different wavelengths for different angles. The graph displays peaks at various wavelengths with labels for 0, 120, and 240 degrees. The x-axis represents wavelength in nm, and the y-axis represents fluorescence intensity change with percentages.]

- Green line: 0 Degrees
- Pink line: 120 Degrees
- Yellow line: 240 Degrees

Wavelength (nm) vs. Fluorescence Intensity Change
Quantum Dots for Spatial Imaging

Endoscope

Shape sensing

optical fiber

Quantum Dots
3-Fiber Bundle

Bundle Composition

- 3 Sensorized optical fibers
  - Each fiber: a uniquely-located sensorized region
  - Each sensorized region:
    - Three QD zones embedded in the cladding
    - Spaced 120° apart circumferentially

- Bend Location
- Fluorescing fibers in bundle identified
- Bend occurs at sensorized regions ⇒ locations are known
Figure 10. Bundling 3 fibers using heat-shrink tubing.
3-Fiber Bundle

Bend Direction
• Fluorescence color indicates direction

Bending Curvature
• Fluorescence intensity increases with curvature
  • Low curvature
  • High curvature
Image Processing

Raw Data Capture

- LabVIEW program
  - Displays CMOS image in real-time
  - Averages per-pixel intensity value across a fiber face (region of interest)
  - 3 average values obtained per fiber: one per filter

- 20° increments
Integrated System
Localisation Error and Confidence

\[ r = -0.82 \]

Confidence Rating/Error (mm x 100)

- Rearview + Compass
- Rearview
- Radar + Compass
- Compass
- Radar
- No aid

Confidence Non-Rigid Colon
Error Non-Rigid Colon
Error Rigid Colon
Confidence Rigid Colon
Rating of Usefulness

Usefulness

Displays

- Rearview +Compass
- Rearview
- Radar+Compass
- Compass
- Radar
- No aid

Usefulness ratings range from 0 to 10.
Evaluation Studies

• Navigational aid display concept (shape + location + direction information) is useful for spatial orientation in colonoscopy
  - reduced localisation error
  - reduced uncertainty in localisation
  - reduce perceived workload
• Training tool for novice endoscopists
• “Valued proposition” compared to currently available technology

Computer-Assisted Port Placement in Robotic Surgery
Patient Model
Current Research Projects

• Haptic feedback in laparoscopic surgery
• Modelling skill acquisition and decay in laparoscopic surgery
• Navigational guidance in colonoscopy
• Optimised port placement in robotic surgery
• Team communication in robotic surgery
Take-Home Message

“If technology doesn’t work for people, then it just doesn’t work.”