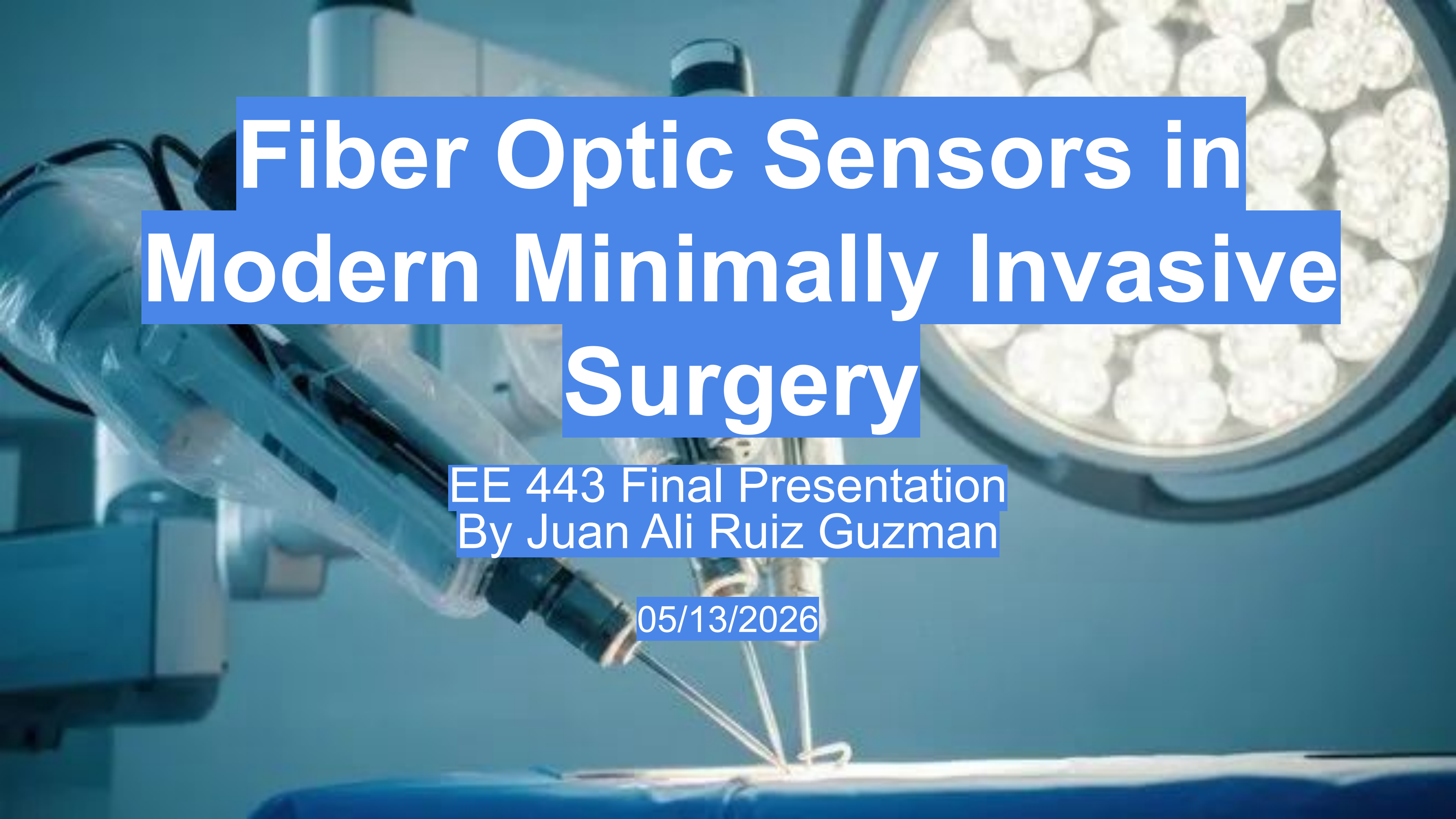

Fiber Optic Sensors in Modern Minimally Invasive Surgery

EE 443 Final Presentation

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What is Minimally Invasive Surgery?

Traditional Surgery

- Large incisions
- Longer recovery time
- Higher infection risk

Minimally Invasive Surgery (MIS)

- Small incisions
- Uses cameras and specialized tools
- Faster recovery
- Less pain and tissue damage

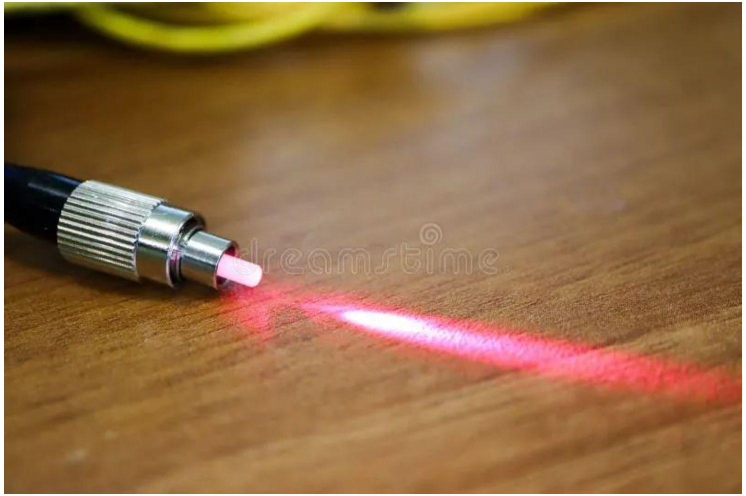
Common Examples

- Laparoscopy
- Robotic surgery
- Catheter-based procedures

Why Fiber Optic Sensors?

Fiber optic sensors are:

- Extremely small and flexible
- Immune to electromagnetic interference (EMI)
- Highly sensitive and accurate
- Safe for use inside the human body
- Capable of real-time monitoring



Traditional Electrical Sensors	Fiber Optic Sensors
Sensitive to EMI	EMI immune
Bulkier wiring	Very small fibers
Can generate heat	Passive sensing possible
Limited flexibility	Highly flexible

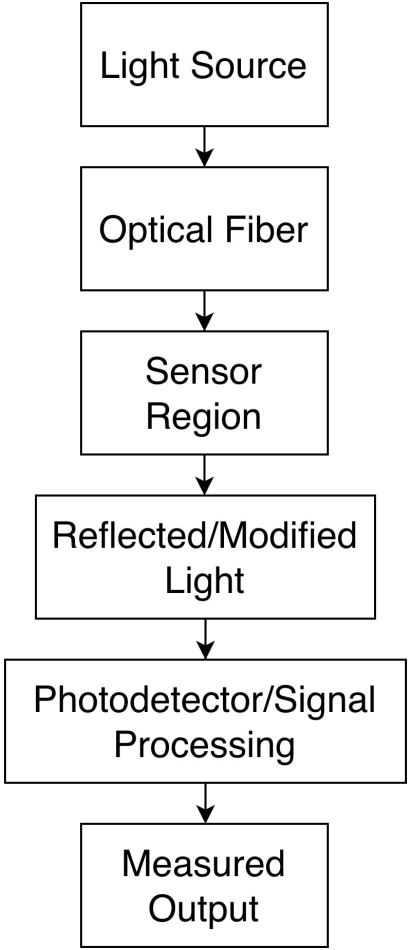
How Fiber Optic Sensors Work

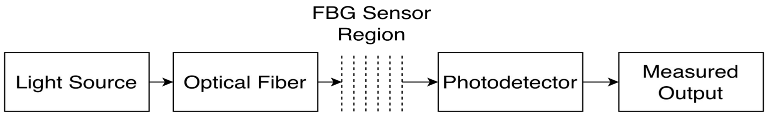
Basic Principle

1. Light travels through an optical fiber
2. External changes affect the light signal
3. The system measures these changes to detect physical conditions

Examples of Measured Changes

- Pressure
- Strain
- Temperature
- Bending
- Displacement





Fiber Bragg Grating (FBG) Sensors

What is an FBG?

A Fiber Bragg Grating is a periodic pattern etched into the core of an optical fiber that reflects specific wavelengths of light.

How It Works

When the fiber experiences:

- strain,
- pressure,
- bending,
- or temperature changes,

the reflected wavelength shifts.

This wavelength shift is measured to determine physical changes in the surgical tool or catheter.

Key Advantages

FBG Sensors Are:

- Extremely small
- Highly accurate
- Lightweight
- Biocompatible
- Immune to EMI
- Capable of multiplexing multiple sensors on one fiber

Multiple FBG sensors can be placed along a single optical fiber for distributed sensing.

Application 1: Smart Catheters

Fiber optic sensors can be embedded directly into medical catheters to provide real-time measurements inside the body.

Measurements Possible

- Pressure
- Blood flow
- Catheter bending
- Position tracking
- Force against vessel walls

Benefits

- Improved navigation through blood vessels
- Increased surgical precision
- Reduced risk of tissue damage
- Better patient safety

Real Medical Applications

- Cardiac catheterization
- Stent placement
- Brain aneurysm treatment
- Minimally invasive vascular surgery

Fiber optic sensing allows doctors to safely navigate complex internal pathways with greater accuracy.

Application 2: Surgical Robotics

Robotic-assisted surgery improves precision, but surgeons often lose direct tactile feedback during operation.

Fiber optic sensors help restore this feedback by measuring:

- Force
- Tool bending
- Tissue interaction
- Instrument movement

Benefits

- Prevents excessive force on tissue
- Improves surgical precision
- Reduces accidental damage
- Enhances surgeon control

Real Applications

- Robotic laparoscopic surgery
- Microsurgery
- Remote robotic surgery
- MRI-compatible robotic systems

Technical Note

FBG sensors can be integrated into robotic surgical instruments without significantly increasing tool size.

Fiber optic sensing enables safer and more intelligent robotic surgical systems.

Application 3: Temperature Monitoring

Some medical procedures use:

- lasers,
- radio frequency (RF) energy,
- or thermal ablation techniques.

Excessive heat can damage surrounding tissue.

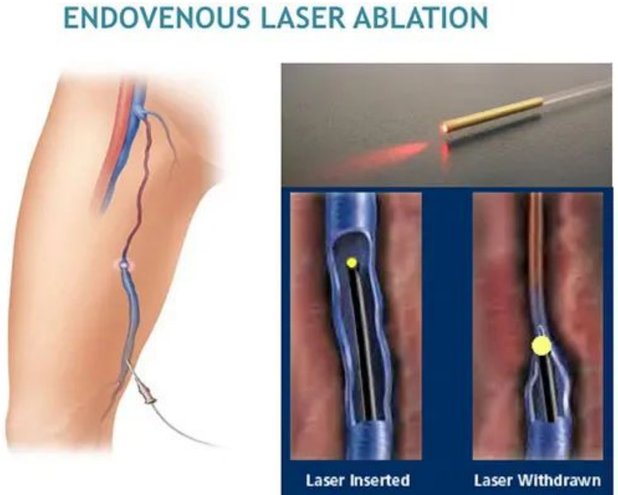
Fiber optic temperature sensors allow real-time thermal monitoring during these procedures.

Common Procedures

- Tumor ablation
- Laser surgery
- Cardiac ablation
- MRI-guided procedures

Why Fiber Optic Sensors Are Useful

- Immune to electromagnetic interference
- Highly accurate
- Very small and flexible
- Safe near MRI systems
- Real-time monitoring



Advantages and Challenges

Advantages

- Extremely small and lightweight
- High sensitivity and accuracy
- Flexible and biocompatible
- Immune to electromagnetic interference (EMI)
- Real-time monitoring capability
- MRI compatible
- Multiple sensors can be multiplexed on one fiber

Challenges

- High system cost
- Complex signal processing
- Fragile optical fibers
- Calibration requirements
- Difficult manufacturing and integration
- Sterilization and long-term reliability concerns

Although challenges remain, fiber optic sensing continues to advance rapidly in modern medical systems.

Future of Fiber Optic Surgical Sensors

Emerging Technologies

- AI-assisted surgical systems
- Smart robotic surgical tools
- Shape-sensing catheters
- Wearable medical fiber sensors
- Real-time surgical feedback systems
- MRI-compatible robotic instruments

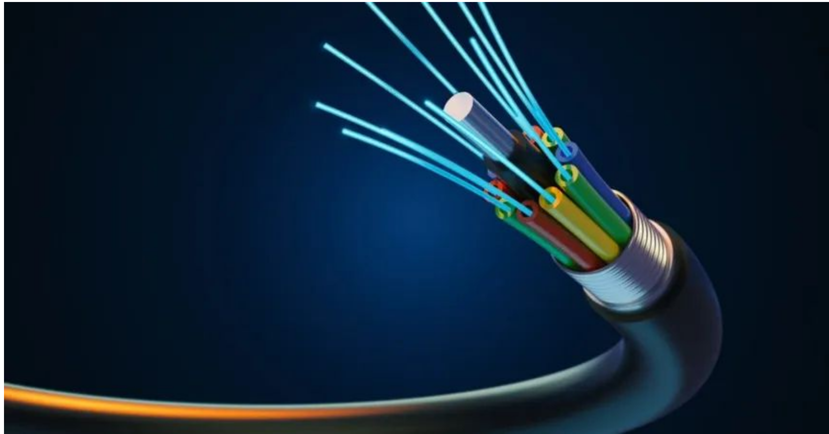
Potential Developments

- Improved robotic precision
- Remote robotic surgery
- Fully sensorized surgical instruments
- Smaller and more flexible medical devices
- Better patient monitoring and outcomes

Fiber optic sensing is expected to play a major role in the next generation of intelligent medical devices.

Conclusion

- Fiber optic sensors are improving minimally invasive surgery
- FBG sensors provide precise real-time measurements
- Applications include:
  - smart catheters,
  - robotic surgery,
  - and temperature monitoring
- Fiber optic sensing improves:
  - surgical precision,
  - safety,
  - and patient outcomes



Questions?

Appendix

FBG Operating Principle

Bragg Equation

$$\lambda_B = 2n_{eff}\Lambda$$

- λB = reflected Bragg wavelength
- neff = effective refractive index
- Λ = grating period spacing

- strain changes Λ
- temperature changes neff and Λ
- both cause wavelength shift

FBG sensors encode information through wavelength shifts rather than electrical voltage changes.

Typical Wavelengths Used in Medical Fiber Optic Sensing

Common Operating Wavelengths

Wavelength	Common Use
850 nm	Short-range sensing
1310 nm	Medical sensing / low dispersion
1550 nm	FBG sensing / telecom-grade components

Why 1550 nm is so popular?

- low fiber attenuation,
- mature telecom components,
- high-quality lasers/detectors available,
- compatibility with FBG interrogators.

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