Fiber Optics Instrumentation Development

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National Aeronautics and Space Administration
Dryden Flight Research Center
Introduction: Why Use Fiber?

- Immunity to electromagnetic interference, radio-frequency interference, and radiation.
- Compact, lightweight, ruggedized device for smart structure
  - Embedded into structure
  - Harsh environment (under water)
- The ability to be multiplexed. (100s of sensors on a single fiber).
- Ease of installation and use (single fiber vs. multitude of lead wires).
- Potential low cost as a result of high-volume telecommunications manufacturing.
- WEIGHT SAVING vs Strain gauge
Background: A Piece of Glass!

- Fiber Bragg Grating (FBG) sensor is that a change in strain state will alter the center wavelength ($\lambda$) of the light reflected from an FBG.
- A fiber’s index of refraction ($n$) depends on the density of the dopants it contains.
- FBGs are created by redistributing dopants to create areas that contain greater or lesser amounts, using a technique called laser writing or dopant modulation.
- The index of refraction is modulated throughout the length of the grating.
- This grating reflects a narrow spectrum of light that is directly proportional to the period of the index modulation ($\Lambda$) and the effective index of refraction ($n$).
- The Bragg wavelength ($\lambda_B$), is expressed by $\lambda_B = 2n\Lambda$.
- Because change in temperature ($\Delta T$) and strain ($\Delta \varepsilon$) directly affect $\Lambda$ and $n$, any change in temperature or strain directly affects the $\lambda_B$.

$$\Delta \frac{\lambda_B}{\lambda_B} = K \varepsilon$$
NASA Grating Modulation Multiplexing Method

- Multiplex 100s of sensors onto one fiber.
- All gratings are written at the same wavelength.
- A narrowband wavelength tunable laser source must be used to interrogate sensors.
- Sensor size can be from 0.1mm to 100mm gage lengths.

\[ I_R = \sum_i R_i \cos(k2nL_i) \quad k = \frac{2\pi}{\lambda} \]

- \( R_i \) – spectrum of \( i \)th grating
- \( n \) – effective index
- \( L \) – path difference
- \( k \) – wavenumber

**Diagram:**
- Laser light reflected light (\( I_R \))
- Laser tuning
- Region where gratings exist
- Tuning direction
- Loss light

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Processing Procedure

- Tuning Laser
  - 1548nm to 1552nm

- Signal Conditioner and A/D
  - S/C
  - A/D

- Perform FFT
  - Wavelength Domain
  - Length Domain

- Perform Windowing

- Perform iFFT
  - Length Domain
  - Wavelength Domain

- Filtering and Centroid

- Centroid to Strain Conversion

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Fiber Strain Sensors in Action

[Graph showing fiber optic strain data with red and yellow lines representing deflection and strain, labeled 'Ikhana wing span'],

[Graph showing tip deflection over time with a range from 0 to 500 on the x-axis and y-axis scales for deflection and strain]
Fiber Optics Wing Shape Sensing System (FOWSS) for Ikhana

- Fiber count: 4
- Max Fiber length: 40 ft
- Max sensing length: 20 ft
- Max gages/fiber: 480
- Total gages/system: 1920
- Sample rate: 50 Hz @ 2 fibers
  30 Hz @ 4 fibers
- Power: 28Vdc @ 4 Amps
- Weight: 23 lbs
- Size: 7.5 x 13 x 13 in
Fiber Optics Instrumentation Development System for NASA Composite Crew Module

- Fiber count: 4
- Max. fiber length: 40 ft
- Max. sensing length: 20 ft
- Max. sensors / fiber: 480
- Total sensors per system: 1920
- Min. grating spacing: 0.5 in
- Sample rate: 2 fibers @ 50 sps, 4 fibers @ 24 sps
- Interface: Gigabit Ethernet
- Power: 120 VAC
- Weight: 12 lbs
- Size: 9 x 5 x 11 in
Fiber Optics Instrumentation Development System for Global Observer

- Fiber count: 8
- Max Fiber length: 80 ft
- Max sensing length: 40 ft
- Max gages/fiber: 1000
- Total gages/system: 8000
- Sample rate: 0-50 Hz
- Power: 28Vdc
- Weight: 28 lbs
- Size: 7.5 x 13 x 18 in
Recent Development
Shape Sensing using fiber strain sensors

- From collaboration with NASA LaRC, shape sensing using fiber strain sensors has been realized
  - Initial research focuses upon 3-core fiber
  - This speciality fiber can be replaced with 3 conventional fibers superposition from one another at 120°

- From knowing the strain value of each fiber, the 3-dimensional position of the fiber can be accuracy rendered in real-time
  - Strain → 3D Position
Prototype – Hexagon strain rod
Prototype – Shape sensing fiber
Conclusion

• NASA DFRC has successfully develop fiber optics strain sensors technology from laboratory to real-world application

[Images of technology evolution: 2002 → 65lbs to 2008 → 23lbs]

2010 and beyond
8-channel system
>100Hz
~30lbs

2-channel system
~50Hz
~10lbs

• Current status
  – Dryden FBG system are installed on Ikhana and Global Observer UAV for real time strain sensing
  – Real-time fiber shape sensing is currently being developed

• Potential application of technology beyond aeronautics
  – Automotive Sector
  – Energy Sector
  – Biomedical Sector