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 $\lambda_B$.

$$\frac{\Delta\lambda_B}{\lambda_B} = K\varepsilon$$
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.

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

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

Laser tuning
Region where gratings exist
Tuning direction

Laser light
reflector
\( \Lambda \)
\( \Lambda \)
\( \Lambda \)
Loss light
reflected light \( (I_R) \)

L1
L2
L3

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Processing Procedure

Tuning Laser

1548nm 1552nm

Signal Conditioner and A/D

Perform Windowing

Perform FFT

Perform iFFT

Filtering and Centroid

Wavelength Domain

Length Domain

Centroid to Strain Conversion

Processing Procedure
Fiber Strain Sensors in Action
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

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

2002 → 65lbs

2008 → 23lbs

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

2-channel system
~50Hz
~10lbs