Using the Luna ODiSI: High-Density Strain and Temperature Data Improves Testing and Process Monitoring

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Senior Applications Engineer
- PhD Mechanical Engineering from MIT
- Part of the Luna team since 2011
- Projects:
  - New sensor design, testing, and validation
  - Temperature monitoring of battery packs
  - Embedding sensors in composites for structural testing
- Supports:
  - Customer training and applications
  - Product testing

Aida Rahim
Senior Applications Engineer
Luna Innovations

- Founded 1990
- NASDAQ: LUNA
- Fiber-optic-based sensing, measurement, testing and control products for:
  - Aerospace & Defense
  - Automotive
  - Communications
  - Infrastructure
  - Process control
  - Security
  - Silicon photonics
  - Transportation

Luna Offices
Customer sites
Mission: Enhance the safety, security and connectivity of people...

Aerospace, Automotive, Infrastructure
Safety & Security, Process Control

- Enabling next generation designs in aerospace and automotive through better measurement
- Protecting infrastructure and perimeters through smarter sensors and systems
- Enhancing process control & non-destructive testing (NDT) with Terahertz technology

Communications and Defense

- Enabling next generation high speed optical networking through faster, better measurements
- Enhancing optical systems and instruments through high quality, precise control of light
Luna Innovations Portfolio

Sensing
Measurement Systems and Sensors

- ODiSI
- T-Ray
- HYPERION

Photonic Test, Measurement & Control
Optical Measurement and Control Systems

- Luna 6415
- OVA
- OBR

Polarization Measurement and Control
Lasers, Filters, Polarization Modules, Delay Lines, Detectors, etc.

https://lunainc.com/events/learn-luna-explainer-webinar-series
Standard Electrical Sensing

Multiple Copper Wires Per Sensor

- 2-3+ wires per sensor
- Multiple DAQs
- Low resolution
- Bulky, metallic wiring

Foil strain gages, thermocouples, RTDs, etc.

Limited Data (Low Sensor Count)

Bulky Sensors and Cabling

Susceptible to Electromagnetic Interference

Selected Sensor Locations

Data (Low Sensor Count)
Fiber Optic Sensing

High-Speed Distributed Sensing

- Single optical fiber
- Static and dynamic measurements
- Long range (km’s)
- Easy to install

High-Definition Distributed Sensing

- Single optical fiber
- 1000’s of sensors
- Ultra-high spatial resolution
- Easy to install
Fiber Optic Sensor Advantages

Works in harshest environments

- Passive
- Immune to EMI
- Chemically inert
- Intrinsically safe

Can measure *where* you need data

- Very small, low profile (easy to embed)
- Lightweight
- Flexible
- Distributed

Provides more data, more insight

- High-definition mapping of strain/temperature
- Distributed sensing over large areas
Optical Distributed Sensor Interrogator (ODiSI)

- High-definition fiber optic sensing (HD-FOS) for strain and temperature
- Ultra-high spatial resolution
  - Gage pitch (spacing) down to 0.65mm
  - >1,500 sensor locations per meter of fiber
- Multi-channel system
  - 1, 2, 4 or 8 HD-FOS sensor channels
  - Sensors up to 50 m in length each
- NIST-traceable strain measurements
- Network connectivity with IEEE 1588 PTP
- Easy-to-use software
  - Sensor/gage configuration and management
  - Acquisition and data logging
  - Real-time 2D and 3D visualization software

Sensors

- Light, flexible fiber (155 µm)
- Static and quasi-static applications
- Strain and temperature

1000’s of sensing locations per fiber

1 to 50 m
Consider a composite coupon with three holes drilled in the center

- Fiber optic sensors are installed onto the coupon along the edge of the holes
- A standard foil gage is installed onto the coupon on one end

High-Definition Fiber Optic Sensing (HD-FOS) allows users to capture data and events that might be missed if only a few gages were available or not placed near event locations
HD-FOS Addresses Key Challenges in Test and Evaluation

**FEA Model Verification**
- Calibrate/verify model
- Measure complex geometries
- Comprehensive structural test data
- More complete strain data

**Structural Testing**
- Measure structural integrity
- Test to failure including failure mechanism
- Life cycle testing
- Fatigue testing

**Material Joining & Welding**
- Verify adhesive performance
- CTE mismatch effects
- Weld quality
- Weld temperature
- Post process residual strain

**Manufacturing Processes**
- Real-time thermal or strain mapping
- Curing temperature
- Weld temperature

**Smart Parts (SHM)**
- Embedded sensing for life cycle mgt.
- Composite damage detection
- Crack propagation
- Structural integrity monitoring
ODiSI Demonstration
Sensors

**Strain Sensor**
- **Prepare:** Abrade and clean the surface for bonding
- **Plan:** Identify the sensor path
- **Apply:** Lay out the sensor in its intended path
- **Bond:** Epoxy the sensor in place

**Temperature Sensor**
- **Prepare:** Clean the surface
- **Plan:** Identify the sensor path
- **Apply:** Lay out the sensor in its intended path
- **Affix:** Hold down sensor to surface using tape, adhesive, or brackets
Complex Instrumented Articles

**Sensor Layout and Placement**
- Sensor
- Carrier
- Direct weave by machine
- Image courtesy of Bally Ribbon Mills, 2014
- Filament wind the sensors in the carbon fiber overwrap and in the fiberglass outer shell
- Manufacturing by SCI

**Ingress / Egress Protection**
- Small patch of pre-preg
- Chandarana et al. SHM2019
- PTFE tube
- Place embedded sensors by hand

**Processing Parameters – Temperature & Pressure**
- Connector 150°C
- Sensor body 300°C
- Oven feedthrough: silicone rubber stopper, glass wool
- Pressure feedthrough

- Force (f)
- Bonded Length (L)
- Swagelok Compression Fitting
- Tubing
- Fiber
- Epoxy Seal

Processing Parameters:
- Temperature & Pressure
- Temperature: 150°C
- Pressure: 300°C
- Oven feedthrough: silicone rubber stopper, glass wool
- Pressure feedthrough:
  - Force (f)
  - Bonded Length (L)
  - Swagelok Compression Fitting
  - Tubing
  - Fiber
  - Epoxy Seal
System Components
System Components
System Components
System Components

High-Definition Fiber Optic Strain Sensor

LC/APC Connector

Sensor Key
System Components

Instrumented Aluminum Beam

Bonded Sensor Path
System Components
System Components
Launch the software by double-clicking the “OD6” icon on the desktop.

It will take a few seconds to complete initialization.

Once the initialization is complete, the user will be able to change settings, view sensors, or collect data.
## ODiSI Software – Manage Files

### Test Configuration

<table>
<thead>
<tr>
<th>Channel</th>
<th>Sensor</th>
<th>Status</th>
<th>Detected Sensors</th>
<th>Remote Module</th>
<th>Sensor Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>--</td>
<td>Identifying...</td>
<td>Standard</td>
<td>-- --</td>
<td>-- --</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>No remote module connected</td>
<td>-- --</td>
<td>-- --</td>
<td>-- --</td>
</tr>
<tr>
<td>3</td>
<td>--</td>
<td>No remote module connected</td>
<td>-- --</td>
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<td>-- --</td>
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<tr>
<td>4</td>
<td>--</td>
<td>No remote module connected</td>
<td>-- --</td>
<td>-- --</td>
<td>-- --</td>
</tr>
</tbody>
</table>

Measurement Rate Per Channel: 62.50 Hz

ODiSI 6104

Save test data to file:
- Test Name: ODiSI 6000 Test
- Notes: 
- Directory: ODiSI Test Home

Status: Ready

Loaded Test Configuration: NONE LOADED
ODiSI Software – Configurations

- Save and load configurations
- Configurations remember user preferences such as operating mode or trigger options
Export to, or import from, an external drive (USB or CD)
ODiSI Software – Interact with Test Data
ODiSI Software – Generate Test Data TSV

- Convert measurement data from binary data files into human readable tab-delimited data files
- TSV files can be opened in Excel, Matlab, Python, LabView
ODiSI Software – Play Back Test Data

- Run through a test that has already been completed
- Jump to any point during the data set
- Change playback speed
ODiSI Software – Help

- Look at new features
- Refer to User’s Guides
- Send feedback to Luna
ODiSI Software – Navigate Software Main Tabs

- Gage Plot: Measurement vs Time
- Sensor Plot: Measurement vs Length
- Sensor Properties: Displays status of the system, channels, sensors, access settings
ODiSI Software – Navigate Software Main Tabs

- **Gage Plot:** Measurement vs Time
- **Sensor Plot:** Measurement vs Length
- **Sensor Properties:** Displays status of the system, channels, sensors, access settings
ODiSI Software – Settings

- Adjust Channel Settings, Streaming Properties, Trigger settings, Strain or Temperature settings, and Sampling Rate
Measurements Mode: Standard (up to 20 m sensor) or Extended (up to 50 m sensor)

Gage Pitch: select 0.65mm for high strain gradients

Performance Mode:
- Full Optimization for highest quality data
- Maximum Rate for fastest rate
Each sensor has a unique key that enables the system to automatically recognize the connected fiber.

Sensor keys can be installed, uninstalled, deleted, renamed.

Once a sensor is plugged into the remote module, the system will automatically recognize the sensor.

<table>
<thead>
<tr>
<th>Test Configuration</th>
<th>Channel</th>
<th>Sensor</th>
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<th>Detected Sensors</th>
<th>Remote Module</th>
<th>Sensor Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>View 1</td>
<td>1</td>
<td></td>
<td>Identified</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>View 2</td>
<td>2</td>
<td></td>
<td>No remote module connected</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>View 3</td>
<td>3</td>
<td></td>
<td>No remote module connected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>View 4</td>
<td>4</td>
<td></td>
<td>No remote module connected</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ODiSI Software – Run Test

- **Tare**: Zero out measurements before test start
- **Arm**: Prepare system for logging
- **Start**: Start logging data
- **Select gages to display in Gage Plot**
Identify specific gages of interest using freeze spray or soldering iron set to low
ODiSI Software – Start Test

- Display Strain vs Length
ODiSI Software – Sensor Plot

- Display Strain vs Length
- Monitor entire sensor throughout test
ODiSI Software – Gage Plot

- Display Strain vs Time
- Monitor individual gages over time
ODiSI Software – Play Back Logged Data

- Run through a test that has already been completed
- Jump to any point during the data set
- Change playback speed
ODiSI Software – Convert to TSV

- Convert measurement data from binary data files into human readable tab-delimited data files
- TSV files can be opened in Excel, Matlab, Python, LabView
ODiSI Data Analysis

- Strain or temperature data is recorded in a 2-dimensional matrix where each row is a separate scan in time and each column is a location along the sensor.

- Tab delimited data files can be read into Excel, Matlab, Python, LabView, etc.
3D Data Visualization

- Display data as color map over test article image or 3D model
Summary: How to Use an ODiSI

- Install a keyed sensor onto a test article
- Use the ODiSI software to identify gages of interest
- Select data logging parameters
- Log data during a test and/or stream to a network location
- Play back data post-test
Fiber Sensing Advantages

Luna’s high-definition fiber optic sensing solution allows materials, structures and systems to be seen like never before:

- Instrument complex geometries to validate models
- Embed fiber sensors in composite structures and monitor structural health and aging
- Provide feedback control for manufacturing processes
- Create smart parts through sensor integration
- Implement predictive maintenance through embedded sensors
Learn More

- Luna’s Website:
  - https://www.lunainc.com

- ODiSI 6000 web page:
  - https://lunainc.com/product/odisi-6000-series

- ODiSI 6000 Data Sheet:

- ODiSI 6000 User’s Guide:
Thank you!  Questions?

Q&A

solutions@lunainc.com

https://lunainc.com/events/learn-luna-explainer-webinar-series