Distributed Vibration Monitoring Using Fiber Optic Accelerometers

Optical Accelerometer Technology Enables Unique Solutions for Monitoring Applications

Introduction
Benefits of Fiber Optic Accelerometers
Applications for Distributed Vibration Monitoring
- Structural Health Monitoring
- Perimeter Intrusion Detection
- Event detection and Location
os7500 Fabry Pérot Accelerometer
Configuring a Distributed Monitoring System
Learn More

Introduction

The many inherent benefits of fiber optic sensors for monitoring applications have driven their widespread adoption in many industries, spanning civil infrastructure, geotechnical applications, energy systems and general manufacturing. These applications typically involve monitoring some combination of strain, temperature, pressure and displacement, all mostly static.

Fiber Optic Sensing Feature	Benefit
Electrically passive, non-metallic	• Immune to EMI, lightning and corrosion • Robust operation in harsh environments
Multiplexing on a single fiber	• Distributed measurements over large areas • Minimal cabling required
Simultaneous acquisition	• Large networks of sensors sampled simultaneously • Time-correlation analysis
Multi-parameter system	• Combine vibration, strain, displacement, temperature, etc. on a single system

Table 1. Benefits of fiber optic sensors

Now, new fiber optic accelerometer technology is available that can extend the capabilities of these monitoring systems to include distributed vibration measurements. The ability to easily and economically acquire and synchronize multiple high-precision fiber optic accelerometer measurements brings the benefits of fiber optic sensing to a wide range of dynamic applications:

- Structural health monitoring
- Perimeter security
- Machine vibration monitoring
- Observing vibrational modes of bridges and other large structures
- Detection of underground activity
- Strong motion seismic detection

The os7500 series accelerometers from Luna Innovations feature industry-leading precision and sensitivity. Based on Fabry- Pérot (FP)Perot technology, os7500 accelerometers feature an innovative multiplexing capability that allows the simultaneous interrogation of up to 128 accelerometers with a single HYPERION high-speed interrogator system, powered by the easy-to-use ENLIGHT software.

Benefits of Fiber Optic Accelerometers

The Luna os7500 fiber optic accelerometer brings highly sensitive and precise acceleration measurements to fiber optic sensing systems. Like other fiber optic sensors, such as Fiber Bragg Grating (FBG) sensors. Fiber optic accelerometers benefit from being electrically passive, meaning they are immune from the effects of electromagnetic interference (EMI) and other sources of signal degradation that plague conventional accelerometers when used in more demanding environments. Also, multiple accelerometers can be multiplexed and measured simultaneously on a single optical fiber. This enables the easy and economical distribution of many vibration

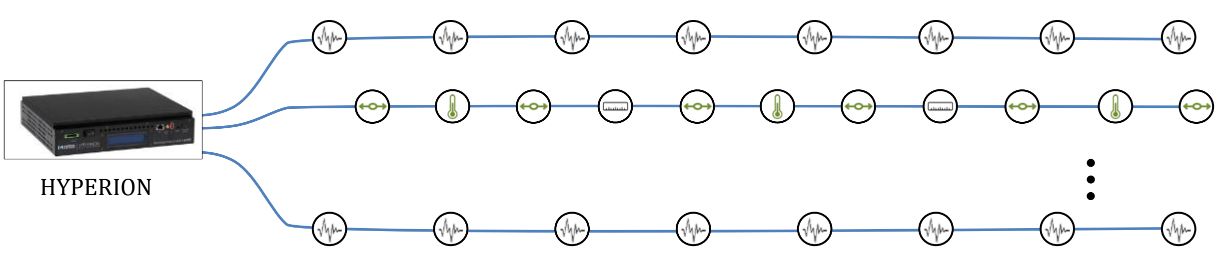

Figure 1. Hundreds of optical sensors, measuring vibration, strain, displacement, temperature, etc. can be multiplexed and interrogated by a single HYPERION measurement system.

measurement points over large areas and across large structures.

Because the HYPERION interrogator system can simultaneously interrogate and capture data from multiple channels, with each channel consisting of multiple sensors, wide-scale measurements are time-synchronized. In addition to minimizing any time skew between sensor measurements, this also enables important applications such as structural modal analysis or the location of vibration or acoustic events through triangulation of detected signals. This can be used to detect the location of a cable strand break or of an intruder crossing a secured perimeter.

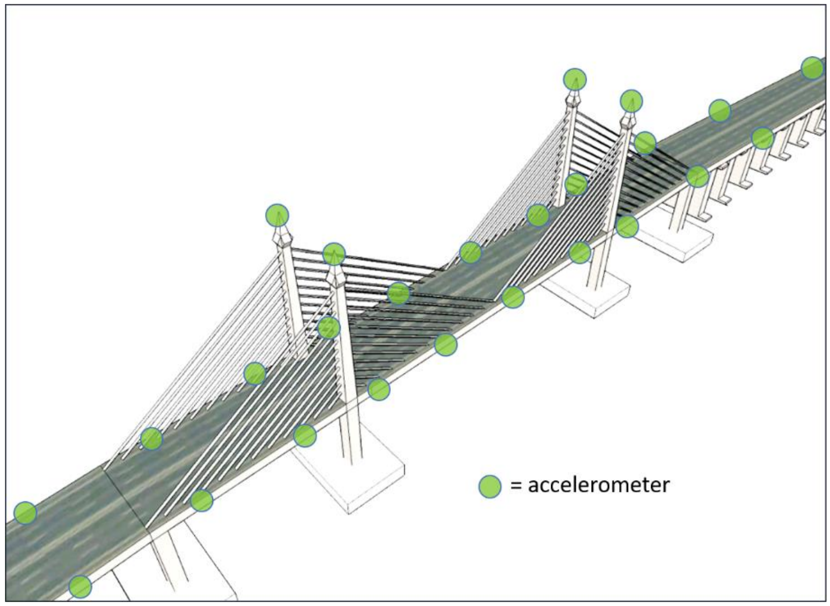

Figure 2. Distributed accelerometers can be used on large structures for general vibration and movement monitoring, modal shape analysis or detection of events such as wire breaks on suspension bridges.

Applications for Distributed Vibration Monitoring

Many applications benefit from the addition of accelerometers and vibration measurements to capture dynamic phenomena. Two key application areas where measuring vibration or acoustic signals over relatively large areas is critical are structural health monitoring and perimeter security.

Structural Health Monitoring

Fiber optic sensors and FBG sensors in particular, have been widely adopted and deployed in many structural health monitoring systems for critical infrastructure, such as bridges, dams and tunnels. Typically, these systems are focused on static strain and displacement measurements for monitoring fatigue damage, detecting and tracking cracks, and monitoring critical locations for structural changes.

Now, with the availability of multiplexed, ultra-sensitive accelerometers, there is a very straightforward method to monitor the dynamic response of a large structure. Because the HYPERION can measure a network of optical accelerometers simultaneously, it can be used to analyze the global dynamic response of a large structure or even precisely detect localized events, such as high-energy wire breaks within tendons, cable stays or suspension cables [1]. By measuring the time of arrival of the acoustic impulse at each sensor installed on a suspension bridge, for example, you can accurately determine the location of the wire break.

Perimeter Intrusion Detection

Another application area where the os7500 accelerometer combined with the HYPERION interrogator is an ideal fit is security, such as

Figure 3. Ultra-sensitive optical accelerometers can be deployed to detect minute ground vibrations.

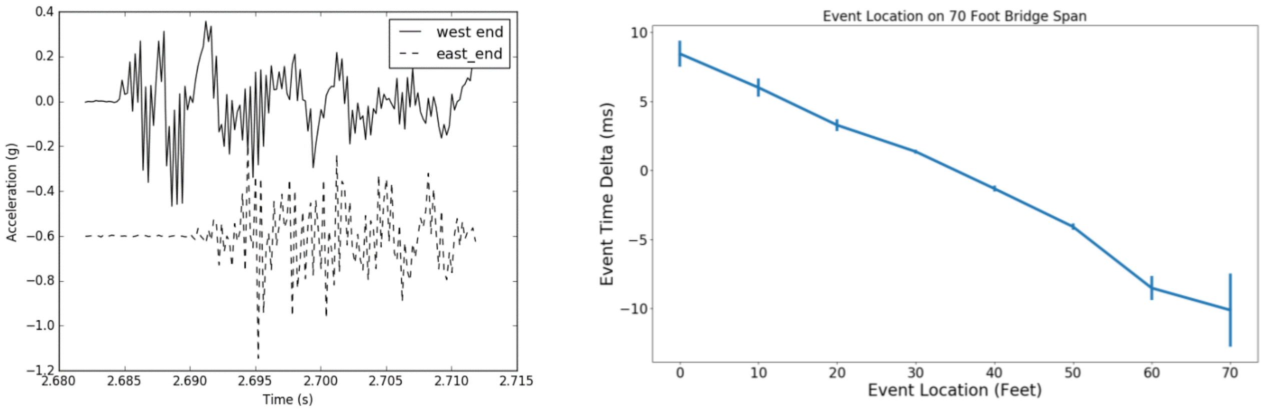

Figure 4. Waveforms from sensors positioned at either end of the conduit and the time deltas for cable strand break events on a bridge from two sensors spaced 70 feet apart. Error bars show the variation in the measured times for 5 events at each location.

pipeline security and perimeter intrusion detection. The ultra-sensitive os7520 can be strategically placed to detect minute disturbances caused by a person or vehicle in the vicinity of the sensor network. The advantages of fiber optic sensors – immunity to EMI and lightning, corrosion resistance and the ease of covering large perimeter spans with a single fiber – have led many facilities and organizations to adopt fiber optic based security systems. Now, the HYPERION system can simultaneously monitor FGB strain sensors to detect climbing motion on a wall or pipeline along with minute vibration signals caused by digging, trenching or walking.

Event Detection and Location

In monitoring applications in both structural health monitoring and security, it is often desirable to know when and where an event occurs. For instance, sensors can be placed on either end of a fiber conduit and use the time series data to determine when and where someone tried to tamper with the conduit. An event produces vibrational waves in the conduit that must travel down the length of the pipe. The measured difference in the time of arrival of the vibration at each of the sensors provides the necessary information to locate the event. Example data is illustrated in Figure 4.

Figure 5. Luna's os7500 accelerometer combines ultra-high sensitivity with multiplexing for distributed measurement systems.

LUNA

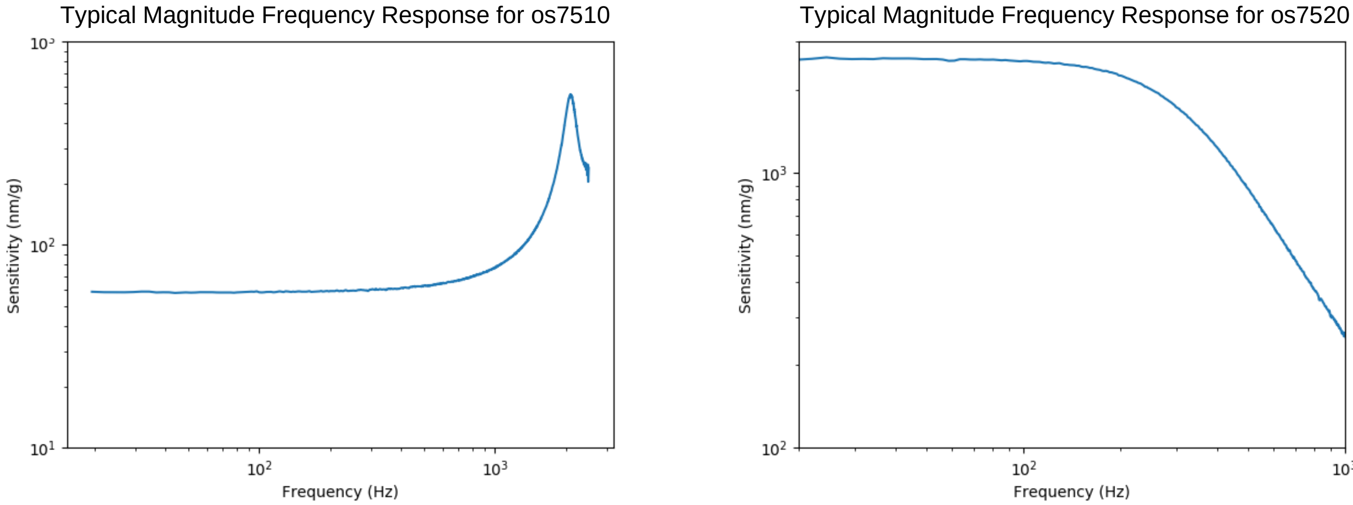

Figure 6. Frequency response magnitude functions for os7510 (left) and os7520 (right).

os7500 Fabry Pérot Accelerometer

Luna's os7500 is a fiber optic accelerometer based on patent-pending Fabry-Pérot (FP) technology. Specifically tuned to address challenging environments, the os7500 provides the user the ability to accurately measure vibrations with frequency ranges up to 350 Hz and with the highest levels of sensitivity.

The FP core of the os7500 consists of an optical cavity that is coupled to a spring-mass system that deflects under applied acceleration. The os7500 employs a unique two-fiber design that enables wavelength division multiplexing of the FP sensors in a daisy-chain architecture. Each sensor only responds to optical signals within a 20 nm band, while passing all other wavelengths in both directions. This allows the multiplexing of up to eight os7500 accelerometers on each optical channel of a HYPERION instrument with a 160 nm wavelength range. The multichannel HYPERION can combine os7500 accelerometers with FBG sensors for strain,

	Accelerometer Model	
	os7510	**os7520**
Frequency Range	350 Hz	100 Hz
Measurement Range	±10 g below 10 Hz 2.5 g above 10 Hz (see Figure 7)	±1 g below 10 Hz 0.1 g above 10 Hz (see Figure 7)
Applications	• Event location (wire breaks, acoustic emissions) in rigid structures • Live load monitoring on bridges and roads • Measurement of machine vibrations (up to 1 kHz)	• Perimeter security monitoring • Observing vibrational modes of bridges and buildings • Detection of underground activity • Strong motion seismic monitoring

Table 2. Two os7500 models are tuned and optimized for complimentary application requirements.

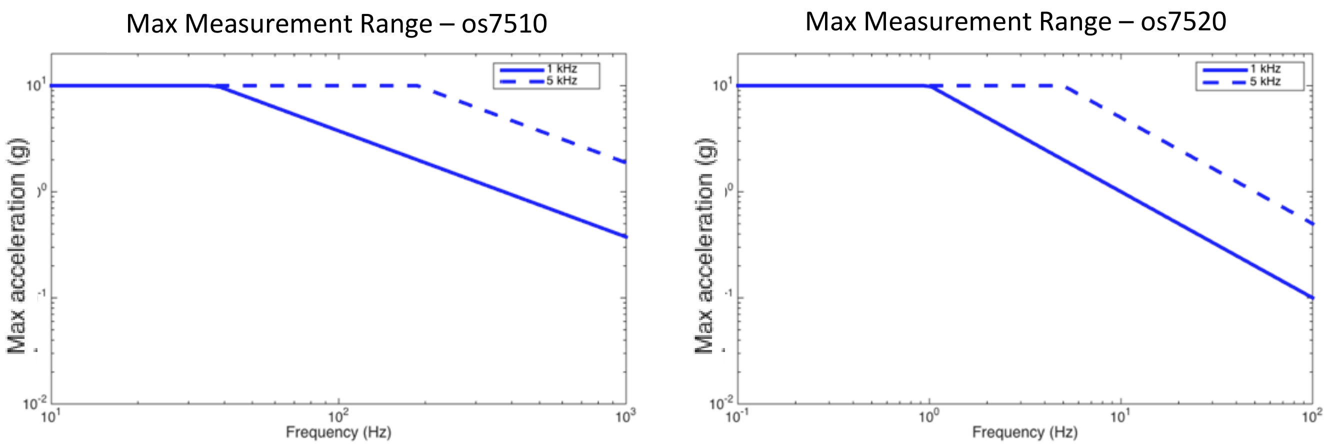

Figure 7. Maximum range for the os7510 and os7520 varies with signal frequency and will increase with acquisition rate.

temperature, displacement, etc. on other channels, all interrogated and acquired simultaneously.

Luna currently offers two different accelerometer models, the os7510 and the os7520. The os7510 is lower sensitivity than the os7520, but it can measure higher peak accelerations and has a wider frequency range. This makes the os7510 the best choice for acoustic event detection, live load and traffic monitoring, and measurements of machine vibrations up to 1 kHz.

The os7520 is approximately 30 times more sensitive than the os7510. It can measure much smaller signals but has a limited maximum range. However, it can still measure multiple-g accelerations at low frequencies. The os7520 is optimal for use in perimeter security monitoring, measuring vibrational modes of bridges and buildings, and strong motion seismic monitoring.

The key considerations in determining which accelerometer is right for a given application are the bandwidth and the maximum acceleration amplitude in the measured signal. Unlike conventional accelerometers, these devices have a maximum range that varies based on the frequency content of the measured signal.

At lower frequencies, it is possible to measure higher ranges of acceleration, due to the nature of the sensing algorithm that translates the optical response into an acceleration. The maximum range will also increase with the acquisition rate, so a sensor on a 5 kHz HYPERION instrument will have more range than if measured on a 1 kHz instrument, as shown in Figure 7.

The measurement bandwidth of the sensors is also an important consideration. Both models of sensors are completely passive devices with a response function that can be described by a simple second-order system that can be fully described by a resonant frequency and a Q-factor.

The os7510 sensor is an underdamped oscillator with a resonance near 2 kHz and a Q-factor of less than 20. The os7520 sensor is a near critically damped oscillator with a Q-factor of less than 2 and a resonant frequency near 350 Hz. Typical response curves are shown below. All sensors are characterized prior to being shipped, and datasheets with response curves are provided with all sensors.

Configuring a Distributed Vibration Monitoring System

The os7500 accelerometer features a unique multiplexing capability that allows up to eight sensors to be multiplexed on a single channel of a HYPERION interrogator. Every os7510 sensor has a 20 nm wide wavelength band response and has two fibers (“In” and “Out”) for daisy-chaining the sensors on a single fiber. Because the HYPERION interrogator implements wavelength division multiplexing (WDM), the wavelength band of the os7500 series accelerometer on a given fiber channel should be chosen so that there is no wavelength overlap. Figure 8 is a plot of the spectrum of eight os7510s multiplexed on a single 160 nm channel of the HYPERION.

The ENLIGHT Sensing Analysis Software is included with HYPERION interrogators and provides a single suite of tools for data acquisition, computation and analysis of optical sensor networks. ENLIGHT combines the useful features of traditional data acquisition and data logging software with the specific needs of using optical sensors.

The ENLIGHT software includes easy-to-use features, such as scaling of optical parameters to engineering units, real-time processing of sensor data, data storage and display, alarming and general management of the optical sensor system.

With the ENLIGHT software, the os7500 accelerometers are easily configured and ready for use. Figure 9 shows an example standard data chart of real-time data collected from an os7510 accelerometer, while Figure 10 shows an alternative view of the real-time FFT of vibration data.

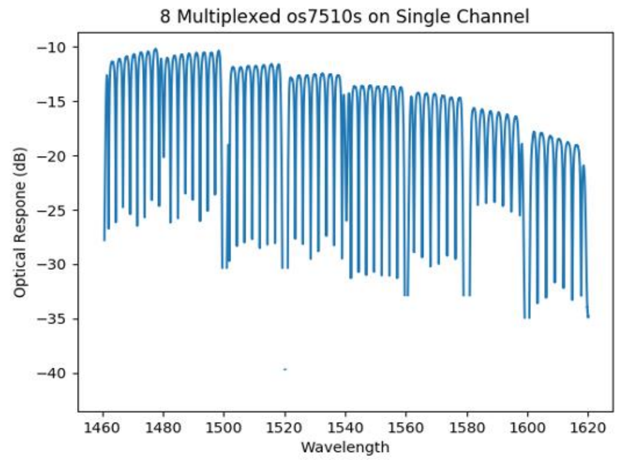

Figure 8. Eight os7500 sensors multiplexed on a single fiber channel on a 1 kHz HYPERION interrogator.

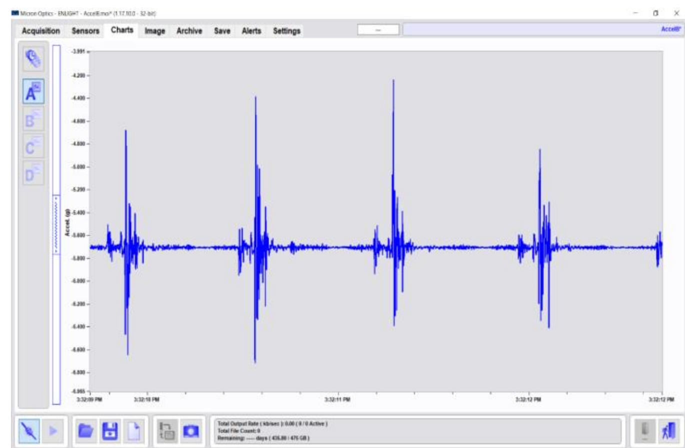

Figure 9. Real-time acceleration data from an os7510 in ENLIGHT software.

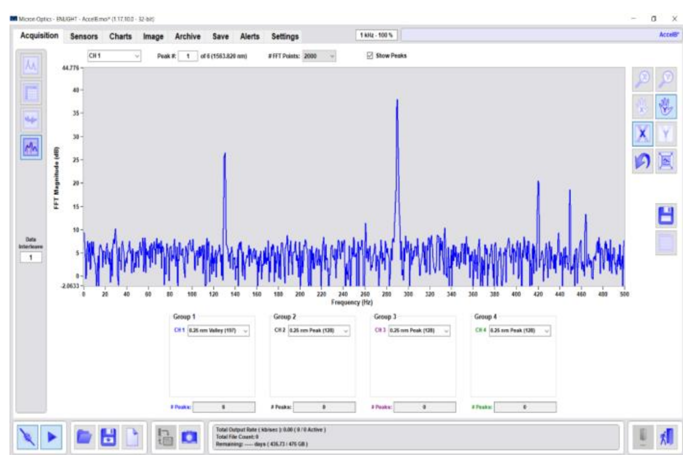

Figure 10. Real-time display of FFT analysis of os7500 acceleration data, acquired and displayed in ENLIGHT software.

Learn More

More information, data sheets and case studies for the os7500 accelerometer are available online at https://lunainc.com/product/os7500.