Praetorian Fiber Optic Sensing
Power and Data Cable Monitoring
Hybrid Distributed Acoustic and Temperature Sensing for Underground Infrastructure

For more information, please visit
www.hawkmeasure.com
Praetorian Fiber Optic Sensing for Power and Data Cable Monitoring

- High Voltage Underground Power
- Communication Cables
- Fiber Optic Networks
- Hybrid DAS and DTS
The Problem

Underground Infrastructure; once installed needs to stand the test of time. In some cases data cables, wires and power transmission lines can be expected to have an operating life from a few decades up to almost a century without the possibility of a visual inspection.

Monitoring for wear, damage or corrosion of the cable is extremely difficult and often power failure or data outage is the first sign of a problem.

Often, these cables are installed in areas that have multiple uses by various stake holders and in the event of a failure can be logistically difficult and expensive to access for repair.

Due to their lack accessibility, it should also be noted that third party intrusion is a much greater threat to buried power transmission lines. The risk of Arc Flash from live conductors and potential for electric shock is high.

The performance of these cables is constantly degrading over time. This effect although slow, ultimately causes failure of the conductors. The location of these faults is a major challenge and a significant contributor to downtime.

Ultimately to manage these risks, a method of around the clock monitoring is required that can be fitted during construction or retrofitted to existing infrastructure. Due to the long runs transmission cables need to cover, traditional instrumentation would need to be installed at regular intervals along the cable run and require supporting infrastructure (power and communications) to each device, an entirely impractical proposal.

The Solution

To solve this problem a solution would need to do the following:

• Detect issues as a distributed sensor rather than a point sensor
• Require no additional field infrastructure such as power or communications
• Operate in real time
• Low cost per foot
• Autonomous detection with low false alarm rate
• To be preventative rather than reactive

Until the advent of Distributed Fiber Optic Sensing systems, it was almost impossible to achieve any of these technical requirements this application required. The first notice an operator would get would be a disruption to their network.
Principle of Operation

The Praetorian system interrogator unit is connected to one end of a fiber optic cable which is attached to the cable being monitored. The interrogator produces rapidly pulsed laser light set at a precise frequency that excites the fiber and causes it to be responsive to physical changes around it. Some of this light is reflected back (backscattered) to the light source where the interrogator records and analyses, looking for changes to its color relating to physical effects in the application.

Time of Flight

Locations of events are able to be accurately determined by a method called time of flight. The amount of time from sending the laser pulse to receiving a return signal is recorded. Due to the internal properties of a fiber optic cable, the speed of light through a fiber is consistent. The signal return time can be used to calculate a distance on the fiber.

Vibration Detection

In the Praetorian, an optical effect called Rayleigh backscatter is used to observe vibrational effects on a fiber. In a fiber optic cable, backscatter is the light that reflects off natural imperfections within the fiber and returns to the light source. The returned light gets diffracted into different frequencies and Rayleigh backscatter is one of these diffracted frequencies. The amount of compression that vibration from an event (such as intrusion, partial discharge or cable vibration) causes on the cable determines the strength of the Rayleigh component of the backscatter. The intensity and frequency of the vibration is measurable by recording the behaviors of the Rayleigh backscatter component. This change in intensity and frequency is used to determine the presence and position of a disturbance to within 3.2 ft. (one meter).

To being classified as an alarm the amount of time, the dominant frequencies and the relative intensity all need to be present within pre-determined thresholds. This reduces the amount of false signals that classified as alarms.
Functionality

The Praetorian Fiber Optic Sensing system (FOS) uses a combination of Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) to protect underground buried cables. By exciting a fiber optic cable the Praetorian Interrogator is able to utilize the fibers as distributed network equivalent to up to 1.6 Million individual vibration, temperature and strain sensors.

The Praetorian utilizes a number of different sensing methods and it is possible to observe events in a number of physically independent ways, The Praetorian is resistant to taking a given reading and giving a false alarm, due to the requirement for multiple physical effects to simultaneously occur at the same location to signify an event and trigger an alarm.

Through a combination of distributed vibration, temperature and strain monitoring it is possible to determine multitudes of different physical events along a cable, including but not limited to:

- Detection of partial discharge
- Detection of hot spots
- Early alert of third party intrusion
- Conductor break detection
- Ground condition assessment
- Prevention arc flash events from conductor contact
- Detection of optical Loss
- Detection of Fiber Break
- Detection of pit or trench lid being opened
- Determination of network operational status (thermal loading)

The Praetorian also Geo-tags alarms allowing security or maintenance teams to be able to respond immediately.

Distributed Acoustic Sensing (DAS): Third Party Intrusion detection

Often the primary way of preventing damage to buried assets is to prevent them being struck and damaged by third parties. As significant excavations are generally required to unearth buried cables, the process of excavation takes sufficient time so that a warning provided quickly enough can give an operator enough time to alert the third party to the dangers below them.

Different digging events generate different signals which are picked up by the monitored fiber buried alongside an asset.

Temperature Detection, Real Time Thermal Rating

At the same time that the interrogator is monitoring for vibration, the Praetorian will continuously hunt for temperature spikes along its length. It does this by scanning a separate fiber within the cable and looking for changes to another component of backscattered light called Brillouin scattering. The system can be calibrated to run very fast (a few seconds), lower accuracy (±1°C) scans of the fiber for temperature changes or to take a slower (half a minute) more detailed scan for maximum accuracy (±0.25°C) of temperature to sense even the smallest changes.

Due to the relatively consistent ground temperature it is possible to use dynamic cable temperature to undertake a calculation known as RTTR (Real Time Temperature Rating). Using RTTR it is possible to observe the amount of current flowing through a conductor based on the supply power and the cables mechanical properties. This allows for fine control and monitoring of cable load during stable and emergency scenarios.

RTTR systems are able to indicate whether areas are overheated or have more capacity than originally anticipated. The use of RTTR systems can assist with network load spreading and allow for direct monitoring of cables when running in an overloaded condition. This allows the maximum operating temperatures to be observed and controlled before emergency conditions can occur on the network.

The maximum temperature reading of each configured cable section and the electrical current reading are computed to build the dynamic cable rating of the installation, based on IEC 60287 and IEC 60853 standards.
The key inputs to the RTTR cable rating modeling are required as follows:
• Cable size and type, installation configuration (cable laying formation)
• Soil ambient temperature
• Soil thermal resistivity and cable backfill material thermal resistivity if used
• Real time loading

The outputs from a RTTR used in a buried cable environment include:
• Real time conductor temperature along the power cable
• Emergency ratings – this can be for a range of times from typically 30 minutes to 48 hours+
• Transient calculations for Time/ Current/Temperature

Heat Image under the thermal detection

Temperature Monitoring: Temperature Profiling
The use of distributed temperature monitoring for ground temperature monitoring is a common use of fiber optic sensing DTS systems. These benefits include:
• Monitoring of annual and seasonal changes in ground condition
• Ground freezing and flood monitoring
• Ground water table interaction
• Ground temperature monitoring for material degradation monitoring.

Live Optical Condition Monitoring
By analyzing the resultant return signal from the Praetorians Distributed Acoustic Sensing (DAS) light pulse, a number of optical fault conditions can be detected due to the presence of a loss of return light. Time of flight is used to determine the location of that loss where it occurs. Different optical loss conditions can be detected including (but not limited to):
• Micro-bends
• Macro-Bends
• Connector losses
• Fusion Splice losses
• Impurities
• Fiber Cut
• Moisture and Hydrogen infusion loss.
• Time based Degradation.

Losses are able to be monitored over time and alert thresholds set to allow planned maintenance well ahead of total failure conditions.
Advantages

• The Praetorian can function where the cable cannot be visually inspected (due to burial)
• Fiber Optic Sensing detects not only the presence of the fault of failure but its specific location
• The Praetorian is extremely sensitive, detecting sounds well below the range of frequency human hearing.
• Due to the use of “long haul” single mode fiber the Praetorian is able to detect faults over long distances.
• Existing Fiber optic data infrastructure may be utilized
• System is passive, no electricity is required in the field
• No maintenance or calibration require after commissioning
• Self-diagnostics monitor the unit’s condition and maintain optimum performance
• Not effected by electromagnetic fields (EMF), lightning or weather events
• Easy, low cost installation with cable
• Low cost per foot.

Unique Features

The Praetorian has a number of unique features which make it a market leading technology. The Field Programmable Gate Array (FPGA) allows for ultra-fast parallel processing of the returned signals, The Praetorian does not have to time splice or “skip” sections of time to keep up with incoming signals.

One distinct advantage with the Praetorian system is that it is able to work such that it is immune to the effects of a broken or cut fiber. The unit can be attached as a loop to both channels on independent fibers. In the event of a cut, it will report the damage and continue to monitor the fiber on both sides, up to the cut. Alternatively, if installed in a non-looped fashion, the Praetorian will monitor the position of the fiber end and check for any changes. It can instantly identify a cut to the fiber.

In all distributed acoustic fiber sensors, the detected signal level has certain variations depending on the polarization state of the received signal which produces scattering of the signal. This scattering can be constructive interference or deconstructive interference, and to date there has been no ability to compensate for this scattering which is referred to as signal fading.

HAWK has patented an effective solution to overcome signal fading, where small signals can be detected without fading. Unlike systems restricted by Multimode LED light sources the Praetorian uses a highly stable laser controlled to within ±0.04pm allowing the system to handle two independent sensing channels of up to 25 miles, each without any loss of measurement in switching or time splicing.

The Praetorian’s main technical advantage is its hybrid and modular design. The Praetorian can be configured to monitor a fiber for Distributed Acoustic Sensing (DAS), Distributed Temperature Sensing (DTS) or both Distributed acoustic temperature and Distributed Acoustic Sensing Side by side.

In addition the Praetorian can be configured in either a dual or single channel configuration. The dual channel configuration is available in Dual DAS, Dual DTS or the most popular configuration the Hybrid DAS/DTS configuration.
## Technical Specifications

<table>
<thead>
<tr>
<th>Category</th>
<th>Parameter</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>General</strong></td>
<td>Sensing Element</td>
<td>Fiber Optic Sensing Cable</td>
</tr>
<tr>
<td></td>
<td>Number of channels</td>
<td>1 or 2</td>
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<tr>
<td></td>
<td>Interrogator operating Temperature</td>
<td>32°F-122°F (0-50°C)</td>
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<td></td>
<td>Unit operating Humidity (max)</td>
<td>85% non-condensing</td>
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<td></td>
<td>Dimensions</td>
<td>4RU 19” Rack Enclosure 7in x 24in x 19in (190x600x490mm)</td>
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<td></td>
<td>Weight</td>
<td>55lbs (25kg)</td>
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<td></td>
<td>Power Supply</td>
<td>110-240VAC (50-60Hz), 24VDC</td>
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<td></td>
<td>Power consumption</td>
<td>&lt;200W</td>
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<tr>
<td><strong>Performance</strong></td>
<td>Sensing Range (DAS)</td>
<td>Up to 40km per channel</td>
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<tr>
<td></td>
<td>Sensing Range (DTS)</td>
<td>Up to 50 miles (80km Loop Per channel)</td>
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<tr>
<td></td>
<td>Spatial Resolution</td>
<td>10in or 20in (250 or 500mm)</td>
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<td>Frequency Response</td>
<td>1Hz-120kHz (Range Dependent)</td>
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<td></td>
<td>Dynamic Range</td>
<td>50dB</td>
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<td></td>
<td>Temperature sensing range (cable)</td>
<td>-418°F to 1,292°F (-250°C to 700°C)</td>
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<td><strong>DTS Performance</strong></td>
<td>Accuracy</td>
<td>+/- 0.27°F (+/- 0.25°C)</td>
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<td></td>
<td>Resolution</td>
<td>+/- .01°F (+/- 0.01°C)</td>
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<td>Scan Time</td>
<td>1-2 Minutes (Depending on Temperature Parameters)</td>
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<td>Temperature Sensing Range</td>
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<td><strong>Technical</strong></td>
<td>Light Source</td>
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<td>Laser Wave Length</td>
<td>1550.12nm (nanometres)</td>
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<td>Laser Stability</td>
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<td>Acquisition rate</td>
<td>400MHz</td>
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<td>Processor Acquisition Rate</td>
<td>64Bit (Ultra high speed)</td>
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<td>Operating System</td>
<td>Linux</td>
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<td>Output</td>
<td>Modbus Ethernet TCP/IP (Standard), Relay, USB, SCADA or User Specified</td>
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<td>Remote Interfacing</td>
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<td>Processor architecture</td>
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<td>Data Storage (Removable)</td>
<td>2x 2TB HDD (removable)</td>
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<td>Data Storage (Internal)</td>
<td>128GB Solid State Drive</td>
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Other Uses

This document covers the use of the Praetorian Fiber Optic Sensing system utilizing the underground cable protection / monitoring software suite and hardware. However there are a large number of other applications the Praetorian is well suited to monitor.

These include but are not limited to:
- Perimeter Intrusion Detection System (PIDS) Security
- Pipeline Leak Detection System (LDS)
- Conveyor Malfunction and Fire Detection
- Fire Detection Including Road and Rail Tunnels
- Infrastructure Strain and Stress Monitoring
- Borehole Condition Monitoring
- Solutions for Railways and Metro
- Hot Spots & Insulation Damage on Process Equipment

Part Numbering

<table>
<thead>
<tr>
<th>Model</th>
<th>FOS</th>
<th>Praetorian Fiber Optic Sensing Interrogator</th>
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<tr>
<td>Power Supply</td>
<td>B</td>
<td>24VDC</td>
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<td></td>
<td>U</td>
<td>110-240VAC</td>
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<td>Sensing Method</td>
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<td>Distributed Acoustic Sensing</td>
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<td>TXX</td>
<td>Distributed Temperature Sensing</td>
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<td>Hybrid Distributed Acoustic and Temperature Sensing</td>
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<td>02</td>
<td>Dual Channel</td>
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<td>1M</td>
<td>Single Channel with Multiplexer</td>
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<tr>
<td></td>
<td>2M</td>
<td>Dual Channel with Multiplexer</td>
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<td>Four Channel</td>
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<td>Modbus TCP/IP</td>
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<td>Cable Monitoring System</td>
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<td>Version</td>
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<td>HAWK</td>
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Additional product warranty and application guarantees upon request.
Technical data subject to change without notice.