# Demonstration of Real-Time AI-Enabled Smart Fault Detection using State-of-Polarization Monitoring

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***Abstract*—In this demo, we present a real-time, machine-learning-driven framework for early fault detection in optical fiber networks, leveraging continuous State-of-Polarization (SOP) monitoring and angular speed (SOPAS) analysis. By extracting polarization fingerprints from a Polarimeter and feeding them into a trained ML classifier, our system detects and categorizes physical anomalies, such as small hits, slow shake (oscillations), and fast shake (oscillations) on the fiber, before they escalate into service disruptions. This proactive mechanism enables timely alerts and a direction towards dynamic traffic rerouting, preserving network integrity. The demonstration showcases a fully functional remote pipeline that integrates AI-based sensing, classification, and automated response, laying the foundation for self-monitoring optical infrastructures.**

***Index Terms*—SOP, machine learning, anomaly detection, SOPAS, proactive restoration**


## I. Overview

The widespread deployment of optical fiber networks in both terrestrial and subsea environments in using pre-installed optical fiber infrastructures for environmental monitoring has become more prevalent in recent years [1]. State-of-Polarization (SOP) monitoring is imperative for detecting any physical tampering, on the optical fiber. Since optical fibers are inherently sensitive, they are particularly vulnerable to physical layer attacks, including malicious vibrations, physical tampering, and any other mechanical stress that

could cause fiber damage and interrupt service [2]. These physical attacks must be identified and addressed in advance to enable proactive counter-measures. Since SOP gives the polarization characteristics of light signals moving through

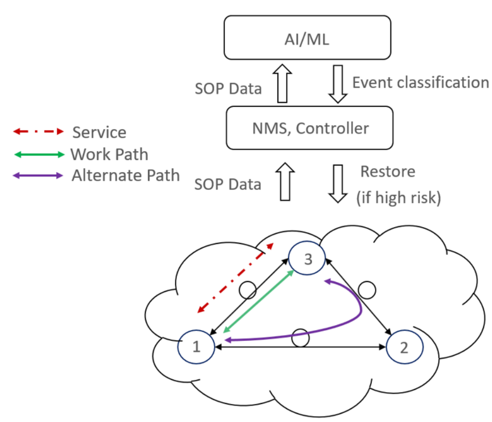



Fig. 1: Alternate path provisioning in response to high-risk network events

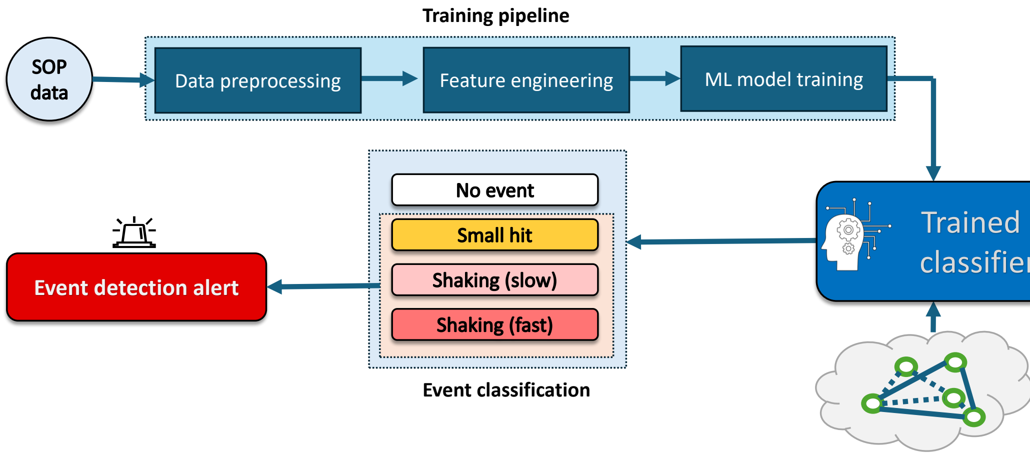



Fig. 2: Implementation workflow for ML-based vibration detection and alerts;

the network, it is ideal for identifying early warning indicators. Using this extremely sensitive property of SOP, we have used it a sensing device to identify mechanical disruptions in optical fiber networks in real-time. Given this, a resilient solution is crucial to continuously monitor the network and enable early detection of potentially risky events, which would allow proactive mitigation measures to reduce their impact.

Thus, in order to provide early warnings prior to dangerous events, a real-time monitoring system model is required that integrates monitoring of SOP and SOP Angular Speed (SOPAS) [3] with Machine Learning (ML) and detects anomalous events nearby fiber cable. Upon detecting a potentially disruptive event, the system model will send an alert, notifying the controller. This promptly redirects the traffic to an alternate optical path, thereby preserving network integrity as observed in Fig. 1.

Therefore, in this demo, we implement real-time detection and classification of critical or anomalous events like ”small hit”, ”slow shaking” and ”fast shaking” by integrating ML with SOP data, and extract unique SOP signature of each event from a Polarimeter. This is achieved through an Artificial Intelligence (AI) that operates seamlessly to safeguard network reliability. This demo is limited to automatic detection and identification of faults occuring within the monitored fiber segment. We will remotely connect with the Polarimeter to capture the SOP and use ML in real-time to categorize and forecast the events, minimizing the quantity of hardware that needs to be transferred to the ICTON demo room.

## II. Innovation

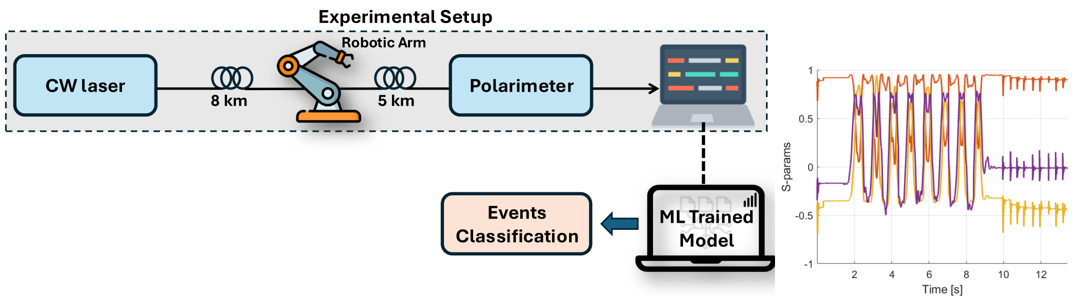
This demo presents a practical innovation by combining real-time SOP monitoring with machine learning to detect and classify fiber disturbances before they cause network disruption. Unlike prior SOP-based systems focused solely on detection, [4], our approach goes a step further by feeding this data into a trained ML model in real-time, that not only detects but also categorizes mechanical events based on their severity, using learned event signatures, enabling dynamic mitigation.

The novelty lies in using SOP as a continuous sensing signal, where changes in polarization, especially the angular speed SOPAS, are analyzed to differentiate between normal environmental shifts and potentially harmful disturbances. These include events like small hits, slow shaking, and fast shaking, which are common in real-world physical interference scenarios. These events are further explained in Fig. 2. By training the model with these event types, we enable early detection and more precise classification compared to traditional threshold-based or binary systems.

This work builds on our earlier studies [5], where we demonstrated the potential of SOP-based sensing. Here, we extend that by embedding it into a real-time processing pipeline. Fig. 2 illustrates the end-to-end workflow of the proposed ML-based anomaly detection system using SOP data. The process begins with the continuous acquisition of SOP data from the polarimeter, capturing real-time polarization changes in the optical fiber. This raw data undergoes preprocessing to filter relevant data and standardize the input for the ML model. Subsequently, domain specific features, derived from SOP, are extracted to capture subtle polarization dynamics induced by mechanical disturbances. These engineered features are then used to train the ML model, which effectively discriminates between normal disturbances and critical anomalous events. Upon identifying a

critical anomaly, the system autonomously generates an alert, prompting to the network controller. The controller, then reroutes dynamic traffic to an alternate fiber path, maintaining uninterrupted service continuity.

Furthermore, the system is designed to avoid unnecessary alarms by triggering alerts only for events that meet learned severity conditions, such as sustained high-amplitude




(a) Real-time sensing prototype with robotic arm setup

(b) SOP execution in real-time

Fig. 3: Hardware setup for Demo

vibrations. This helps reduce false positives and supports more stable operations. What distinguishes this approach is the integration of real-time sensing, intelligent classification, and automated response within a unified framework. Rather than passively recording SOP disturbances or reacting post-failure, the system leverages the optical fiber as an active sensing medium, enabling continuous monitoring and early identification of physical anomalies. Through accurate event classification and immediate response, the framework supports the transition towards self-monitoring and self-healing optical networks. This functionality becomes increasingly critical as network infrastructures expand in scale and face greater exposure to physical-layer vulnerabilities in real-world deployments.

## III. Demo Content and Implementation

This demonstration offers an experimental proof for the real-time identification of various fiber events, in optical fibers, as potential anomaly early warning indicators. Our hardware for the smart fault detection is shown in the Fig.3a. It consists of a sensor fiber, which is exposed to a continuous-wave laser source with a 6 dBm power output that produces light at 1530 nm. The testbed consists of two G.652 Single-Mode Fiber (SMF) segments that are attached to a portion of the SMF that the robotic arm manipulates. The Arduino-based arm, driver board, and Arduino UNO R3 are all included into a custom printed circuit board (PCB) for increased stability.

In this demo, we use a Polarimeter (Novoptel PM1000), to capture the SOP temporal fluctuations. The polarimeter examines the orientation of scattered light as represented on the Poincaré sphere. These SOP variations are represented by the stoke parameters $\{S_0, S_1, S_2, S_3\}$, which characterize the polarization state of light. Every event corresponds to a unique polarization signature [6]. The robotic arm manipulates the fiber to produce three mechanical events. A fiber hit occurs when the fiber is physically touched once every second, producing a slight impact. For slow shaking, the robotic arm shakes the fiber up and down at a frequency of 5 Hz and an angle of deviation 90°. On the other hand, fast shaking is a representation of the fiber's rapid oscillations at a frequency of 10 Hz. Our ML model is trained using polarization fingerprints of these events, allowing us to employ only the pre-trained model for testing at the demo zone due to its faster processing time.

Our lab, Links Foundation, will be equipped with this hardware in Turin, Italy, (refer to Fig.3), and we will remotely stream the real-time SOP data, by connecting to the robotic arm that begins manipulating the fiber. We will then obtain the SOP data live, as shown in Fig.3b, and feed it into our pre-trained ML model, which will preprocess the SOP data, apply feature engineering, and ultimately detect and classify those events. In this demonstration, the audience can choose a specific fiber event executed by the robotic arm and witness the ML model accurately classify the event in real-time with low latency. This hands-on interaction highlights the end-to-end detection process and the identification of critical fiber disruptions as they occur.

## IV. Conclusion

In conclusion, this demonstration showcases a machine learning-powered framework for real-time detection of critical events in optical fibers, using the Polarimeter to exploit the polarization fingerprints. This keeps uninterrupted services dependent on the integrity of the fiber connections. By integrating SOP monitoring with ML-based classification, the system is capable of identifying three distinct physical disturbances on the fiber after a sentence ending with polarization fingerprints. This allows the system model to classify potential threats and trigger alerts for rapid traffic rerouting, improving service continuity. This work sets the foundation for the integration of AI into optical network management, pushing toward a truly self-healing and adaptable infrastructure, a key enabler for next-generation resilient communication systems.

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