# Fiber optic temperature and vibration sensor for underground power cables

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*Temperature and vibration monitoring of underground cables plays a key role in asset management for power networks. In this context, a low-cost fiber optic monitoring system is proposed. Coherent light is launched at one end of a fiber buried close to the underground cable. Spatial distribution of field intensity in the core, also called speckle, is processed by a FPGA-driven 5 Mpixel CMOS sensor. Transmitted speckle and reflected speckle are statistically processed in order to provide information about perturbation nature and intensity. Following this preliminary work, on-site validation and back-scattered speckle processing are also scheduled.*

## Introduction

Asset management in electrical power network pushes the need for cable monitoring. Investments protection, client satisfaction and lifetime estimation are some of the key issues. Fiber optic instrumentation plays a major role in high-voltage networks via the use of Fiber Optic Current Sensors (FOCS -[1]) in substation and cable embedded Distributed Temperature Sensors (DTS - [2]). Advantages like electrical insulation, distributed sensing, low-loss transmission and high sensitivity promote fiber optic as an alternative to competing techniques.

In mid-voltage networks, decentralized production like wind or solar farms is also driving an interest for distribution cable monitoring. Cable over-exploitation and changes in sizing procedures for decentralized production are indeed some of the reasons for higher failure rates. In this context, a collaboration has been established since 2010 between Belgian partners : UMONS (Faculté Polytechnique), HELHa (Haute Ecole Louvain en Hainaut), ORES (Distribution network manager in Wallonia) and LABORELEC (Technical competence center). The aim of the project is to test and validate low-cost cable monitoring equipments for distribution network in the Belgian context. In this paper, we describe low-cost sensing solutions proposed for an experimental field trial in Leuze-en-Hainaut. The local IT architecture in which the system is integrated is also developed.

## Needs analysis and proposed solution

Temperature and vibration are the major environmental measurands targeted by network managers. Temperature is useful to check sizing, installing techniques and cable power capacity in its underground environment. Vibration monitoring allows mechanical damage and partial discharges detection. A vast choice of distributed temperature sensing systems are available on the market using Raman/Brillouin OTDR or OFDR setups. On the other hand, distributed vibration and acoustic sensing system are quite rare and are mainly using Coherent OTDR techniques. Identified needs allow us to rather focus on event detection than on precise measurements. Moreover, only low spatial resolution (100 m) of the perturbation localization is required as a first sensor development stage. In this context, a modal interferometric solution is proposed through speckle video processing integrated with transmission/back-scattering localization techniques. Low-cost equipments (video processing), high sensitivity and possible localization techniques were the key drivers for the proposed solution.

## Low-cost sensing solution : on the theory of speckle

Historically treated as a drawback for fiber optic telecommunications, speckle has been extensively studied from the modal noise point of view ([3], [4], [5]). When coherent light is launched into a multimode fiber, power is distributed among different modes. If coherence conditions are satisfied, these latter interfere and create at the output of the fiber a pattern called speckle (see figure 1). Individual modal propagation constant and phase change with external physical conditions like temperature and vibration. As a consequence, the pattern changes also in shape and contrast. With spatial filtering (e.g. a fiber misalignment in a connector), signal amplitude can be modulated by the physical distortion of the fiber. This signal fluctuation is called modal noise. Due to its strong sensitivity to external physical conditions like temperature and vibration, this phenomenon has been exploited for sensing techniques.

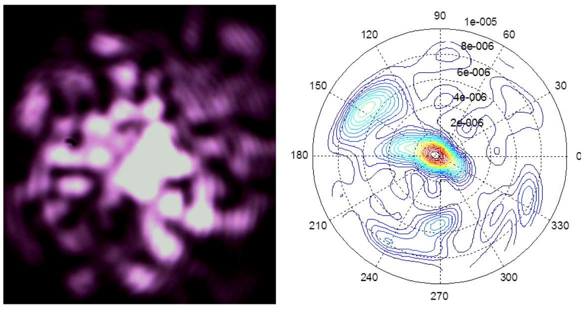


Figure 1: left : sampled speckle pattern - right : computed speckle pattern

This technique has been widely described and applied to vibration measurements ([6], [7], [8]). Physical consequences on the fiber have been classified under mode coupling and phase modulation ([9]). Mode coupling occurs with less coherent sources and expresses power conversion between modes due to bending for example. On the other hand, phase modulation occurs with highly coherent sources and expresses modal phase modulation due to acoustic pressure variation on the fiber for example. Temperature action on the fiber lead to a third phenomenon through propagation constant and path length modulation. On this basis, a propagation and interference model was built for the project purpose. Speckle is computed at different point along the propagation path and sensitivity to mode coupling and phase modulation can be assessed (see figure 1).

## Experimental setup

The following simple demonstrator shown in figure 2 has been designed in order to validate sensitivity and functional requirements. A coherent and stabilized 850 nm source is coupled to a 2 km G.652 fiber. Transmitted speckle is projected on a Micron MT9P031

5 Mpixel CMOS Image Sensor. A FPGA processing unit and a frame recorder allow for real-time and post data treatment.

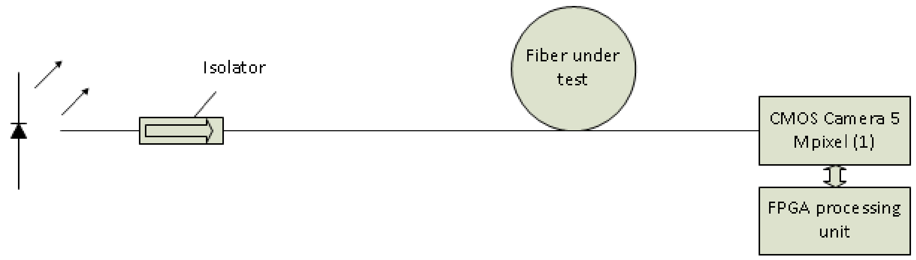


Figure 2: transmitted speckle setup

Figure 3 shows patterns obtained during the action of a 2 K/minute temperature change applied on a 5 m long section of the fiber. The rate at which the speckle changes in contrast and shape depends on applied temperature variation and considered fiber length. Statistical image processing allows us to quantify this rate in order to establish the relation with the external action on the fiber. Discrimination between temperature and vibration action is also possible through spectral analysis.

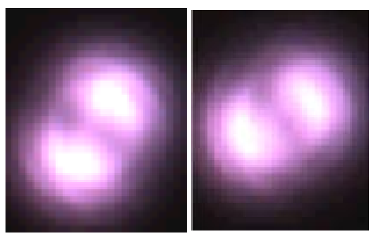

Figure 3: speckle patterns obtained with experimental setup described before (left : stable pattern before temperature change, right : during 2 K/minute temperature change applied on a 5 m long section of the fiber)

Another setup presented in figure 4 is under consideration in order to explore combined transmission, reflection and Rayleigh back-scattering techniques for perturbation point localization with low spatial resolution.

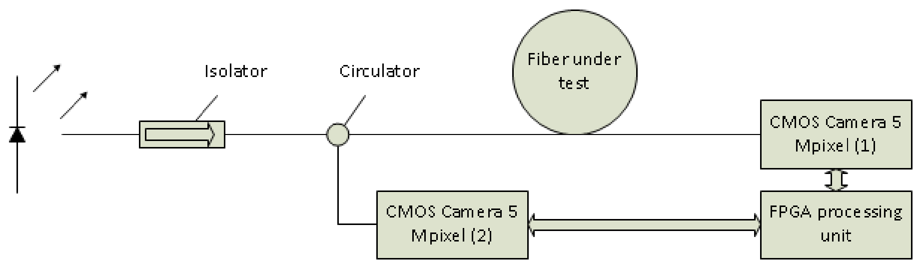


Figure 4: combined transmission, reflection and back-scattering setup

## Experimental field in Leuze-en-Hainaut

A new cable link has been installed by ORES in 2011 between the future Leuze-en-Hainaut distribution substation and Ligne transport substation. This cable is intended to give access to the power network for industrial consumers and two wind farms for a total apparent power of 30 kVA. Fiber optic will be blown in a tube attached to one of the three-phase cable trefoil (see black tube pointed in figure 5). An access to the IEC 61850 substation network is provided in order to collect operational cable data like current and transferred power. An embedded platform will sample conventional temperature and acoustic pressure together with IEC 61850 data collection. In the end, this equipment will allow us to correlate and calibrate fiber optic measurements.

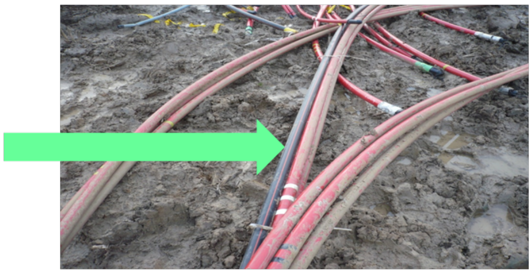

Figure 5: underground power cable trench

## Conclusion

In order to detect severe environmental conditions in the vicinity of mid-voltage power cable, a fiber optic interferometric experimental setup using a coherent source and transmitted speckle is presented. Temperature change and vibration due to mechanical damage can both be detected. Real-time signal processing is provided by a 5 Mpixel CMOS camera and an FPGA architecture. Another setup exploring combined transmission, reflection and back-scattering techniques for perturbation point localization is under consideration. In-situ validation and sensor calibration are also scheduled.

## References


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