OPTICAL FIBER INFRASTRUCTURE PROTECTION DEMONSTRATION SYSTEM USING DISTRIBUTED OPTICAL SENSING

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Abstract: The paper deals with optical fiber distributed sensing based on Mach-Zehnder interferometry for infrastructure protection. The system is used in the landscape model, where digging can be simulated. The developed system measures vibrations close to the optical fiber and evaluates the exceeding of the limit value of the signal deviation, on the basis of which the alarm is triggered. This demonstration model is used to demonstrate the possibility of protecting the optical fiber infrastructure from mechanical damage, such as optical cable cuts caused by digging activity. The paper describes both the design of the demonstration system and the GUI for setting and evaluating alarms.

Keywords: data acquisition, GUI, interferometry, optical fiber, photodetector, sensor

1 INTRODUCTION

With the growing need for increased transmission speeds in data networks, optical fibers are being used more frequently. With the growing number of optical cable installations, new possibilities offer the use of this medium for non-data applications, such as the transmission of ultrastable quantities or the sensing of acoustic/mechanical vibrations and temperature in the immediate vicinity of optical cables. Optical fiber sensors are now mainly used with new installations, but in special cases, these can also be used on existing infrastructures, in some cases also on fibers with active data transmission. Reduce of the costs for the installation of new optical cables thus decrease overall costs. Optical fiber sensors can be used in places with unsuitable conditions for electronic and other sensors, such as, high temperature, humidity, strong electromagnetic interference, etc [1]. In addition, due to their size, accuracy, and wide range of measurement options, such as temperature, pressure, refractive index, or vibration [1] [2], these sensors are increasingly used in non-standard conditions, such as aircraft and space shuttle sensors [3], or for measuring the properties of high voltage transformers [4].

There are many types of optical sensors. One important group are distributed optical sensors. These sensors can measure quantities along the entire length of the fiber and basically can be divided into two basic categories. The first category uses backscattering. The Rayleigh, Brillouin, and Raman scatterings are the most suitable. Each type of scattering is used for a different application. Circulators are used for signal analyzes which is reflected back from the measured optical fiber [5]. The second category uses interferometers. The most commonly used interferometer is the Mach-Zehnder interferometer. However, there are many others, such as Michelson, Sagnac, or Fabry-Perot interferometer [6], which is suitable for point measurements. Distributed sensors are more suitable for more sophisticated measuring systems, for example for measuring acoustic vibrations or for measuring the magnetic field.

2 OPTICAL FIBER SENSING SYSTEM

Vibration sensors are a key part of interferometric sensors. The Mach-Zehnder interferometer is shown in the Figure 1. Due to its simplicity, this interferometer is used in affordable sensor systems. A simple Mach-Zehnder interferometer can be used together with operational amplifiers and other components for vibration detection, when the limit is exceeded, the alarm is triggered [7]. Which is essentially a primitive but effective security feature. A Mach-Zehnder interferometer is also suitable for low-cost vibration detection of infrastructures such as buildings or bridges [8].

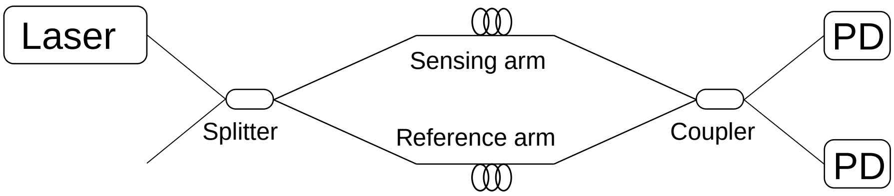

Figure 1: Scheme of Mach-Zehnder interferometer.

2.1 LASER

The basis of the interferometer that was used a was low-noise, 1550 nm laser Koheron LD100, shown in the Figure 2. The current is set by a precision trimmer from 0 to 55 mA and operates at a voltage from 3.3 V to 5 V. The LD100 is equipped with a modulation input connected to alternating current for current modulation from 1 kHz to 200 MHz. The LD100 typically has a spectral bandwidth of 3 MHz. The signal from the laser is not modulated in any way in the interferometer connection and light into the fiber is coupled with a constant wavelength [9].

2.2 PHOTODETECTOR

A Koheron PD100 photodetector is used to convert the light signal into an electrical, shown in the Figure 2. PD100 photodetectors are amplified photodetectors with a bandwidth of about 100 MHz. The photodetector contains an InGaAs photodiode with a wavelength range of 900–1700 nm and its power supply from 6 to 15 V. Small signal bandwidth is 1.6 kHz – 105 MHz at 3 dB and input current noise density is 9 pA/$\sqrt{\text{Hz}}$ at 10 MHz [10]. A special single-mode optical fiber with a 900 νm buffer, which is thinner than conventional fibers, was used to construct the interferometer. The cladding of the fiber has diameter of 900 μm. These fibers were used as measuring and reference fibers. In this case, the measuring fiber is passed over the upper part of the model, and the reference fiber is placed in the lower part of the model so that these fibers do not interact with each other.

2.3 DATA ACQUISITION UNIT

Analog Discovery 2 (AD2) was used to evaluate data from a Mach-Zehnder interferometer. The selected connection corresponds to the basic diagram of this interferometer, which is shown in Figure 1. LabVIEW for GUI programming was used, where a library supplied by the software manufacturer is provided.

AD2 is a multifunctional USB device combining a two-channel oscilloscope, a functional analog waveform generator, a 16-channel logic analyzer, a pattern generator, including a programmable power supply. This USB-powered device allows you to create and test analog and digital circuits in any environment [11].

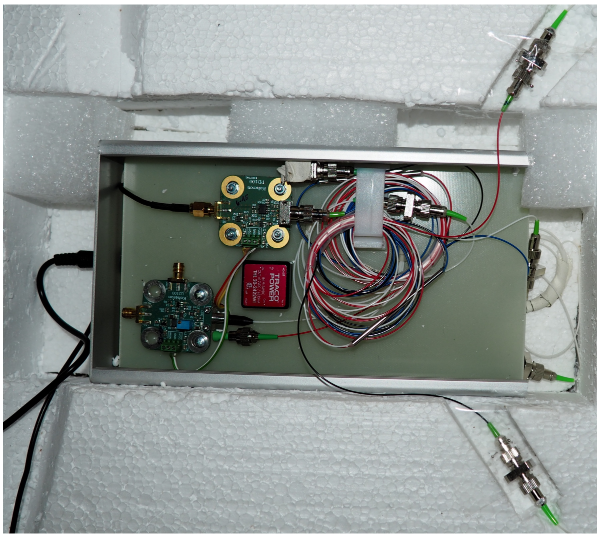

Figure 2: Connection of Mach-Zehnder interferometer.

3 MODEL FOR DEMONSTRATION

A landscape model for optical fiber guidance was made, as can be seen in Figure 3. The model consists of a wooden vessel into which an interferometer has been implemented. The interferometer is surrounded by a damping material so that it is not affected by any external influence and is stored in the model. The upper part of the model presents a landscape where one half is a meadow/field and the other is sand, representing the soil. The sensing arm of the interferometer is guided under this sandbox. The two halves are shielded from each other by different materials, under the "meadow" there is damping cotton wool, and therefore this part serves as a resting zone. When the model of digger travels through the rest zone, the sensor system does not react, and when the digger travels from the rest zone to the other half of the sand, the sensor system reports that there is increased movement in the area, it detects this movement due to increased vibrations. The final feature is that when initiating digger work in the fiber area, the sensor system evaluates it as a dangerous movement and sends a warning to the graphical user interface (GUI) in Figure 4.

Figure 3: Model of the landscape for demonstration of sensing vibrations.

4 GUI FOR THE MODEL

A program in LabVIEW was created for this model, which is used for processing measured data, including analysis of data. This program ensures that the entire sensor system works in real-time. Within this program, the following parts were solved. Communication and settings of Analog Discovery 2. Sensing and control of the signal in real-time. Detection of the signal threshold level and subsequent analysis. Acquiring and saving measured data to a file and converting the signal to audio signal.

The front panel is divided into several parts. Dominant is the display of measured data, where it is possible to see how vibrations cause signal deviation. The threshold for motion detection is used to detect the digger approaching the sand, and the Threshold for vibration detection is used to detect possible fiber disturbance. These thresholds can be set in case the digger model would replace another machine or a digger with a different weight. To the left of the graph are the scale and color settings of the graph. There are also a STOP button to end the program and a button to save the signal to a file and an audio file. At the bottom of the GUI is a top view of the model, where the colors of the sand and fiber change (in Figure 4 yellow sand, and red fiber) depending on whether a motion is detected in the fiber area. There is also a hazard statement with date and time. Based on the intensity of the vibrations, the Optical fiber in danger window also pops up, which can be canceled using the Continue or Call operator button if there is an immediate threat to the fiber. The front panel also contains FEEC and Optolab logos, because the model is primarily intended for the presentation of research, as can be seen in Figure 4.

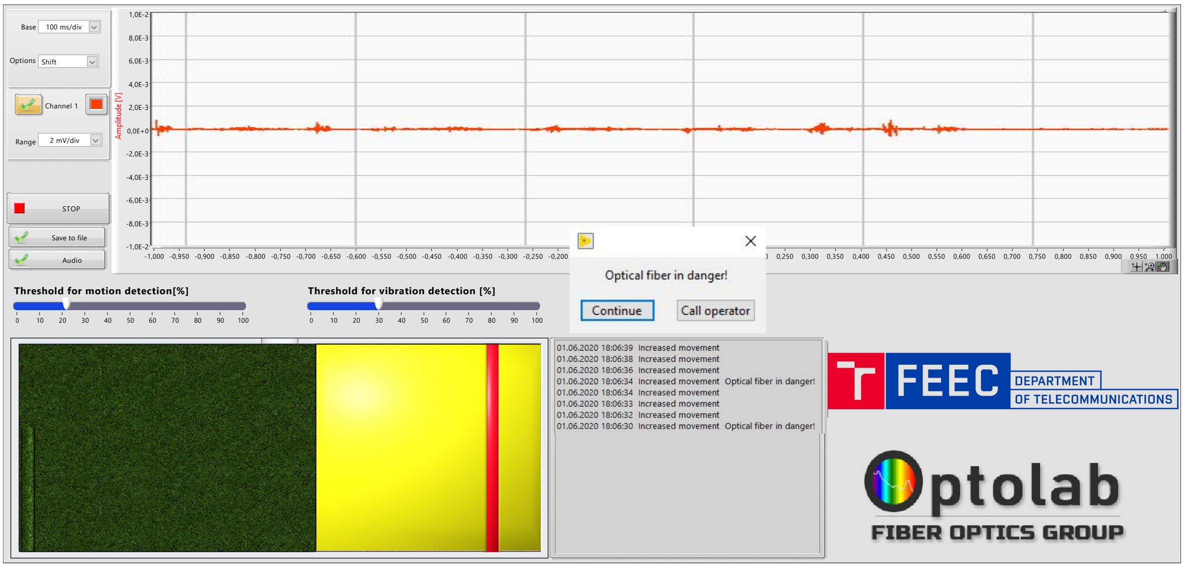

Figure 4: Front panel of graphical user interface.

5 CONCLUSION

Interferometric distributed fiber optic sensing systems have been described in the paper. A Mach-Zender interferometer was chosen to demonstrate the use of the interferometer as a vibration detector. The next part of the paper describes the individual components of the sensor system and the board for data acquisition and preprocessing. The landscape model demonstrating the excavation work is described below. The last part describes a graphical user interface for evaluating the exceeding of the threshold value and thus triggering an alarm. The GUI is also able to export data or possibly convert data to a wav audio file. The model was tested and will be used to demonstrate the use of optical distributed sensors at promotional events organized by BUT. This model was included in the video for Open Days BUT FEEC. This model has reliably demonstrated the possibility of securing optical fibers using an optical fiber interferometer and is the basis for the application of interferometers in practice as security devices to increase the security of optical fibers or use to secure objects and perimeter.

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