ANALYSIS OF SEISMOACOUSTIC ACTIVITY BASED ON USING OPTICAL FIBER CLASSIFIER

Valery V. Korotaev; Victor M. Denisov*; Andrey V. Timofeev
ITMO University, Department of Optical and Electronic Devices and Systems, Russia, 197101, St. Petersburg, Kronverkskiy pr, 49.
**070255@gmail.com*

Abstract: This paper presents results of development of the method of seismoacoustic activity based on use of vibrosensitive properties of optical fiber. Analysis of changes of parameters of radiation of reflected signals, which take place due to microscopic seismoacoustic impacts on the optical fiber, allows to determine position of the source and to identify the its class.
OCIS codes: (060.0060) Fiber optics and optical communications; (060.2370) Fiber optics sensors, (060.2390) Fiber optics, infrared

1. Introduction

At present the interest has greatly increased in efficient solutions allowing to carry out remote monitoring of superextended objects (oil-and-gas pipelines, railway tracks, national boundary sections, perimeters of strategic objects, etc.). Traditionally, monitoring systems for extended objects are built using distributed networks of seismic sensors and systems of remote video surveillance, when both stationary video systems and mobile platforms are used as carriers. All these technological complexes, as practice has shown, demonstrate high efficiency at solving many monitoring problems.

The optimal alternative to the above approaches is the approach based on the use of the highest vibrosensitivity of the infrared energy stream injected into the ordinary optical fiber (buried in the ground near the monitoring object) with the help of a semiconductor laser of low power. In the systems of this class, all relevant information is transferred to Processing Center (PC) by the optical fiber which is not only a sensor but at the same time an effective and reliable channel for data transmission. We will call the systems of this class as optical fiber classifiers of optical pulses (OCOP), which by the principle of operation, belong to the multitude of so-called C-OTDR systems.

2. Method Idea

The basis of the described method underlying OCOP is the use of the vibrosensitive infrared stream injected into a standard monomode fiber by means of a coherent semiconductor laser at the wavelength of 1550 nm. Probing is carried out in the pulsed mode, with the frequency of 8-15 kHz at the pulse length of 20-100 ns. The optical fiber is put into the ground, at the depth of 30-50 cm, at the distance of 5-10 m from the monitoring object and, as a matter of fact, it is an optical fiber sensor. When a pulse is moving along the optical fiber, the Rayleigh elastic backscattering is realized on its natural irregularities, which due to high coherence of the used laser of 3B class leads to formation of the so-called stable interference structures of chaotic type, otherwise called speckles or speckle images. A sequence of speckles is received in the point of emanation using an ordinary welded coupler or a circulator.

Reflection of the Fresnel type is not used because the sensor end opposite to the laser is equipped with a special terminal cap. The central moment of the concept is the phenomenon that any seismic vibration arising on the surface of the optical fiber due to propagation of seismoacoustic waves from the sources of elastic oscillations, changes its local refractive index. Changes of the local refractive index are reflected in the time-and-frequency structure (TFS) of the respective speckle. Knowing the pulse duration and the velocity of wave propagation in the optical fiber, it is easy to determine the section where the TFS speckle deviation took place. Analysis of the sequence of speckle structures using wavelet conversion apparatuses (the phase of singling out of primary signs of target signals) and Lipschitz classifiers (the phase of classification of target signals) makes it possible not only to reliably detect the target source of seismoacoustic radiation, but also to determine its type and area of occurrence. In particular, location of the target source of seismoacoustic radiation is determined with the accuracy of up to 5..10 m at the distance of up 40 km from the laser location. Actually, as a result of logical processing, several thousands of the so-called C-OTDR channels are formed on the monitoring distance, each of which transfers information on seismoacoustic activity at the well-defined point of the space. It is obvious that the width of the typical C-OTDR channel is 5..10 m.

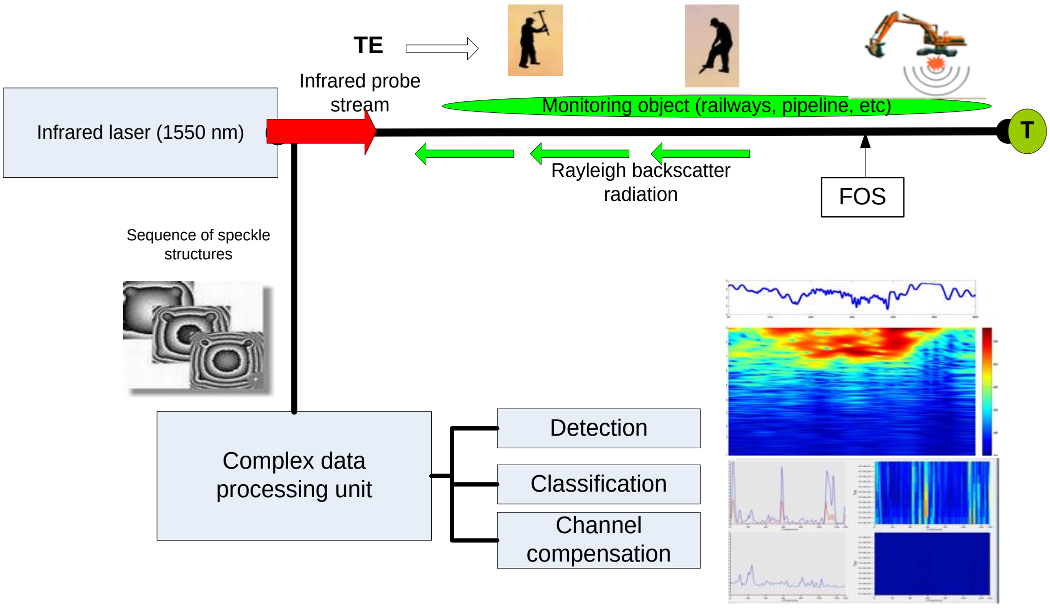

Fig.1. Method realization scheme

3. Overview of Data Processing Methods Used

The following problems are solved in the process of analysis of seismic activity:

- TSAE detection;
- TSAE location assessment;
- TSAE type classification.

All these problems are solved on the basis of the so-called “front-end speckle patterns processing” (FESPP). As a result of FESPP, multidimensional information invariants, otherwise called primary signs or features, are singled out from the sequence of the speckle structures corresponding to various C-ORDR channels. Naturally, this analysis is carried out not on a stationary speckle corresponding to the channel state in absence of external disturbances, but on the difference between the speckles adjacent by probing time intervals, which is substantially different from zero. It is this information that is significant for the system and will be called “C-OTDR signal”. And it is C-OTDR signals that are subjected to profound processing in order to solve a complex of problems of remote monitoring. The so-called multidimensional GMM vectors [1] built either by spectral or wavelets coefficients computed above the speckles are used as primary signs in the OCOP system. Then, in the space of primary signs, the problems of TSAE detection, location assessment and classification are solved. Use of such multilevel approach allows to significantly increase the anti-interference ability of the system, making it robust against the impact of noises of internal and external nature.

TSAE detection is carried out within the widespread concept of guaranteed detection of statistical disorder of observed processes in C-OTDR channels. Guaranteeing is understood in the sense of ensuring the a priori specified lower boundary of the confidence coefficient P_c with which the concrete time interval T contains the moment τ of discontinuous variation of statistical properties of observations. Or else, $P(\tau \in T) \geq P_c$ and $|T| \leq \pi$ for the specified $\pi > 0$. Detection problems are solved using the principle of simultaneous processing of data from all channels of the adjacent group, which allows to reduce the average time of observation needed for provision of the specified level of reliability.

TSAE location assessment is based on solving an ordinary triangulation problem using measurements of the adjacent group of channels.

The TSAE classification problem seems to be the most difficult. For solving this problem, the approach is used which is based on the ensemble of Lipschitz classifiers, namely the Support Vector Machine ensemble [2]. As a rule, a multitude of target classes has the cardinal number of m > 20. Thus, the classification problem has to be solved in the multiclass formulation. In practice, the “one-against-all” approach has turned out to be efficient, within the framework of which the m-class problem is replaced by a series of m binary classification problems, each of which is solved efficiently with the help of the SVM ideology. The Bhattacharyya kernel [3] having good smoothing characteristics was used as the SVM kernel function. To assess reliability of the classification solution, the confidence set approach [4] was used. Use of the phenomenon of multichanneling, consisting of registration of data from channels of the adjacent group, made it possible to significantly increase reliability of solution of the classification problem, at the same time minimizing the impact of the medium of propagation of seismoacoustic waves. This approach is detailed in [5].

4. System Accuracy Characteristics

Table 1 contains results of numerical simulation which to a certain extent characterize the quality of functioning of the algorithmic complex of the system. Real data obtained from C-OTDR systems became the initial data for numerical experiments. In the experiment, the control unit of C-OTDR system was located 20 km from the TSAE realization place, i.e. the seismoacoustic situation was undergoing detailed monitoring at the distance of 20 km. The information which came from these sensors was also used in the numerical research of quality of work of algorithmic support of the system. The symbol α denotes the value of the type 1 errors (target missing), and the symbol β denotes the value of the type 2 errors (false alarm). Values α, β were obtained experimentally for various types of TSAE. The findings demonstrate the acceptable accuracy of TSAE classification. It must be noted, that energetically weak events generated by small objects and taking place at a significant distance from the sensor are classified expectedly worse.

Table 1. Monitoring System Accuracy Characteristics

TSAE Type	Distance	α	B
Manual ground digging	12	0.1	0.12
Group of pedestrians	10	0.13	0.11
Pedestrian	5	0.16	0.1
Passenger car	10	0.09	0.1
Truck	20	0.07	0.08
"Ground digging by heavy excavator"		0.06	0.09

5. Conclusion

Complex monitoring of state of hazardous extended objects, such as oil-pipelines and gas-pipelines, railway tracks, national boundary sections, become a more and more topical task which needs application of modern methods of taking and processing of information. High efficiency of solution of the problem of monitoring of such objects was proven in the course of pilot operation of the OCOP system based on the C-OTDR principle of data processing.

To obtain seismoacoustic data, vibrosensitive properties of infrared stream injected into the optical fiber by semiconductor laser are used. The fiber is put near the monitoring object at the depth of 50-100 cm. Analysis of the back reflected stream allows to identify and localize a fact of threat with high accuracy.

This work was partially financially supported by Government of Russian Federation, Grant 074-U01.

References

[1] Chang Huai You, Kong Aik Lee, Haizhou Li, A GMM supervector Kernel with the Bhattacharyya distance for SVM based speaker recognition, ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing: 4221-4224 (2009).

[2] Hearst M.A, Dumais S.T., Osman E., Platt J., and Scholkopf B. Support Vector Machines, IEEE Intelligent Systems, vol. 13(4):18-28 (1998).

[3] Kailath T. The Divergence and Bhattacharyya Distance Measures in Signal Selection, IEEE Transactions on Communication Technology 15 (1):52-60 (1967).

[4] Timofeev A.V., The guaranteed estimation of the Lipschitz classifier accuracy: Confidence set approach. Journal Korean Stat. Soc. 41(1).P.105-114 (2012).

[5] Timofeev A.V., Egorov D.V., Multichannel classification of target signals by means of an SVM ensemble in C-OTDR systems for remote monitoring of extended objects, MVML-2014 Conference Proceedings V.1, Prague, (2014).