Optical and Acoustical Methods in Science and Technology

Interferometric Fiber Optics Based Sensor for Monitoring of the Heart Activity

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The paper presents the concept of the interferometric fiber optic sensor system for human psycho-physical activity detection. A fiber optic sensor utilizes phase changes of propagating light to monitor patient's vital signs such as respiration cardiac activity, blood pressure and body's physical movements.

PACS: 47.63.Cb, 87.19.U−

1. Introduction

The aim of our research is to create a fiber optic sensor that utilizes optical phase interferometry to monitor patient's vital signs such as respiration, cardiac activity, blood pressure and body's physical movement [1]. The monitor, which is non-invasive, comprises of an optical fiber interferometer that includes an optical fiber situated proximately to the patient. Acousto-mechanical variations are then transferred to the optical fiber. As a result of the interference of optical signals the interferometer generates a time-varying optical intensity, which is detected at a photodetector. A signal processor coupled to the optical detector provides one or more processed output signals indicating the vital functions. The fiber optic system is of broad applicability, from routine monitoring of infants at home to detection of apnea, arrhythmia, blood pressure, and trauma.

The system can be implemented in a variety of embodiments ranging from a low cost monitor for infants to a high end product for hospital use. When integrated and combined with ECG information, the monitor provides ballisto-mechanical information regarding the heart for early diagnosis of cardiac conditions or prediction of events or for correcting ECG signals corrupted due to time varying magnetic and electric fields. In some of the embodiments of the sensor, the system can be made remotely and portable.

In this article a fiber optic sensor technology is developed. Emphasis is placed on the problem of feature extraction to reduce all spectral responses to several features allowing simple classification of different perturbation from the human body for continuous monitoring of human activity [2]. The identification of specific signals is investigated in the interferometer fiber optic sensor responses. The field of signal processing techniques for interferometric fiber optic systems is relatively explored. However, research was conducted to find optimal techniques of demodulation, denoising of perturbance and identification type of perturbation for specific different configuration of fiber optic systems.

2. The concept of using interferometric fiber sensors for the measurement of human activity

The measuring system includes an optical fiber-based interferometer sensor situated proximately to a patient. The interferometer detects vital function signals such as the acoustomechanical signals generated by the patient. Specifically, vital functions such as cardiac activity, respiration, and movement generate characteristic acoustomechanical waves that are transmitted through the patient's body to the optical fiber situated proximately to the patient. Advantageously, the fiber optic-based vital sign monitoring system measures, non-invasively and non-intrusively, the "ballisto-mechanical" response of the patient's cardiac system, the pulmonary system, and physical movement.

Fiber optic technology is widely used for many purposes such as communications and remote sensing of physical processes. Fiber optic-based sensors have many advantages. For example, they are lightweight, rugged and corrosion-resistant. Furthermore, optical signals transmitted through optical fibers are immune to electrical or magnetic interference. Moreover, due to their corrosion-resistance, the sensors can be sterilized easily which is important in case of medical use. What is more, since optical fibers are passive the threats of patient electrocution and data corruption that exit with other monitors are eliminated. These advantages make fiber optic-based sensors useful in a variety of environments, such as monitoring the vital signs of infants and adults in home, confined care facilities in-hospital and for military purposes.

The presented research is carried out at the laboratory bench of the Military Academy of Technology. The block

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diagram, presented in Fig. 1, illustrates an interferometric fiber optic sensor in three configurations. Every interferometer includes an optical source, an optical fiber and a photodetector. A portion of the optical fiber is incorporated into a sensor pad that receives acoustomechanical signals generated by a human body. In the interferometer, light from an optical source is launched into an optical fiber, and is modulated within the optical fiber by the acoustomechanical signals. In response, the interferometer generates a time-varying signal which is detected by the photodetector producing an electrical signal responsive thereto. The electrical signals generated by the photodetector are supplied to a signal processor, such as a digital signal processor (DSP).

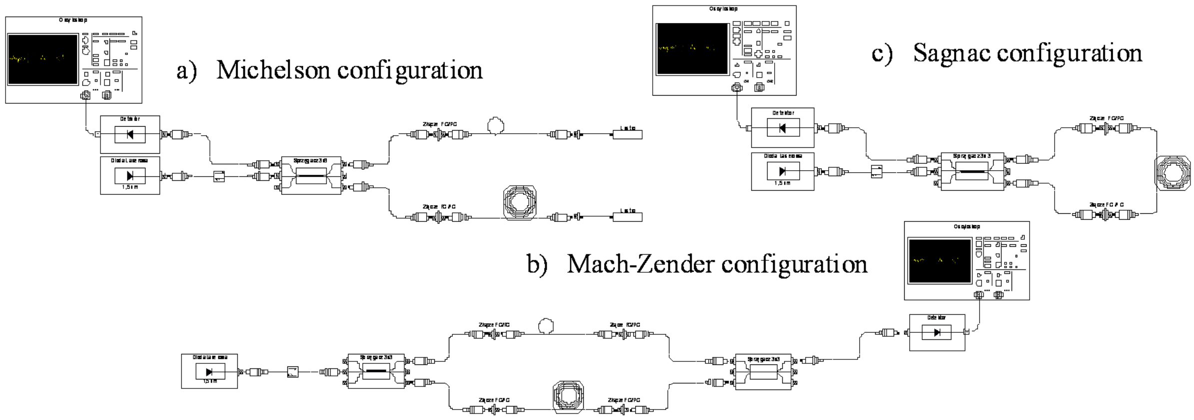

Fig. 1. The scheme of interferometric fiber optic sensor.

The interferometer can be implemented in many different configurations. For instance a Fabry–Perot interferometer, a Mach–Zehnder interferometer [3], a Sagnac interferometer or a Michelson interferometer may be used. Many interferometer configurations are known, some of them are used in our investigation. Generally, an interferometer requires at least two optical paths that may be established in a single fiber or two separate fibers joined by a coupler. The light from the optical source is divided between the two optical paths, and the photodetector detects intensity changes resulting from the interference of two waves with different phases traveling in the two optical paths. The acoustomechanical signals modulate one of the optical paths but not the other one (or not the same amount), thereby creating a time varying (modulated) signal responsive to the applied acoustomechanical signals [4]. Same interferometers, such as a Mach–Zehnder interferometer, utilize two optical fibers to provide the two different optical paths, whereas other interferometers such as a Sagnac interferometer utilize a continuous single optical fiber into which light from the optical source is injected simultaneously into both ends using a fiber splitter/coupler.

3. Experimental results

The simulations presented above proved correctness of the human activity monitoring method and enabled us to construct the sensor. Taking advantage of the above--mentioned conception of the sensor, the interferometric setup presented in Fig. 1 was built and tested in laboratory conditions in order to evaluate its parameters. The sensor loop had 1, 2, 5, 7, 10, 15 and 20 m length and was arranged on special coils (pad) of fibers. In order to disturb the fiber a sensor head was placed at many positions on fiber sensor configuration. The output signals were filtered by means of a RC filter and digitalized. Finally, they were registered and send to data processing unit. The signal processing was carried out by means of Lab View software.

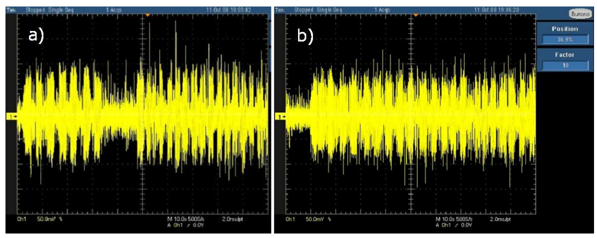

Fig. 2. The signals from the interferometric fiber optic sensor in the Michelson configuration.

The examples of the registered signals from interferometric fiber optic sensor in the Michelson configuration for two different positions of sensor head of the human body are presented in Fig. 2a and b, respectively.

Figure 3a and b, respectively present the examples of the registered signals from interferometric fiber optic sensor in the Mach–Zender configuration for two different positions of sensor head of the human body.

The examples of the registered signals from interferometric fiber optic sensor in the Sagnac configuration for two different positions of sensor head of the human body

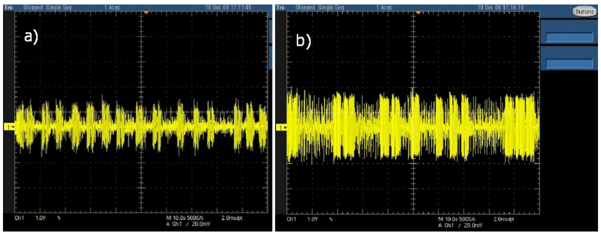

Fig. 3. The signals from the interferometric fiber optic sensor in the Mach–Zender configuration.

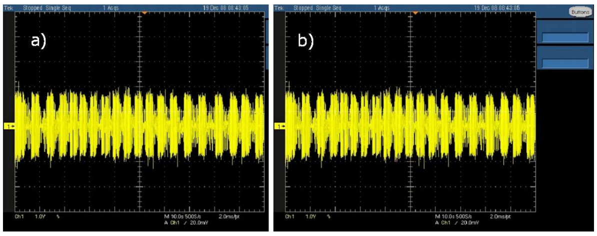

Fig. 4. The signals from the interferometric fiber optic sensor in the Sagnac configuration.

are presented in Fig. 4a and b, respectively.

The convergence of laboratory and simulation results proved that the numerical model of the sensor was correctly constructed. According to expectation, in presented configuration the environment background does not have a major influence on the test system.

4. Conclusions

We proposed the method of detecting, monitoring and identification of human body signal by means of fiber optic sensor as well as the sophisticated signal processing by utilizing interferometric technique. We tested our setup for many configurations of sensor loop (sensor head). We received results that are consistent with earlier modelling parameters. One of the major problem with using this technology is changing the state of signal caused by the body movement. Therefore, further work on the project is carried out to eliminate this obstacle.

Acknowledgments

The project is co-financed by the European Regional Development Fund within the framework of the 1. priority axis of the Innovative Economy Operational Programme, 2007–2013, submeasure 1.3.1. Development projects" contract no. UDA-POIG.01.03.01-14-136/08-00.

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