Analysis of Non-invasive FBG Sensor for Monitoring Patient Vital Signs During MRI

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ABSTRACT

This article focuses on the analysis and verification of a non-invasive fiber Bragg grating (FBG) sensor used for the monitoring of a patient`s heart rate (HR) and respiratory rate (RR) in a magnetic resonance environment (MRI). Measuring heart and respiratory rate were carried out on a group of five volunteers with their written consent during MRI examinations. The type of the scanner used in the experiment was GE Signa HDxt 1.5T. The benefit of this article lies in the design of a sensor in the form of a sensor pad. The sensor is placed beneath a patient`s body lying supine. The purpose is to increase and improve the patient`s safety as well as to help doctors to predict panic and hyperventilation attacks of patients during MRI examinations. Provided Bland-Altman statistical analysis demonstrates the heart and respiratory rate detection with a satisfactory accuracy for all five volunteers.

Keywords: Fiber Bragg grating, vital sign, monitoring, heart rate, magnetic resonance environment (MRI)

1. INTRODUCTION

This article builds on the demand for medical devices and describes the use of fiber-optic technology in biomedical applications. A major and costly problem is the monitoring of human body's vital functions in magnetic resonance imaging (MRI). Conventional sensors cannot be used in this environment, and special sensors need to be used that are financially demanding. Although the scanner itself is equipped with basic sensors that are capable of monitoring the essential vital functions of patients, it is only a guide for the doctor, and in the case of any health problems, the patient needs to use additional special sensors. One of the classic problems during the examination is hyperventilation and panic attacks of patients. The proposed fiber-based fiber Bragg grating (FBG) fiber optic is immune to electromagnetic interference (EMI) and can be used directly in MRI. Fiber-optic sensors are increasingly evolving in the field of doctoral practice as described in articles [1-16]. A flexible polydimethylsiloxane (PDMS) material that is inherent to human skin and immune to EMI has been chosen to encapsulate the sensor and provide additional protection [17]. The article describes the FBG sensor itself, its implementation on the patient and the practical measurements made directly in the MRI on 5 volunteers with their written consent. The Signa HDxt 1.5T Scanner was used as a reference [18]. The obtained data were analyzed using an objective method using the Bland-Altman analysis [19].

2. METHODS

Fiber Bragg grating is special structure formed by periodic change of refractive index in core of optical fiber. If the light from the LED radiation sources falls on this structure, the narrow spectral part is reflected and the other wavelengths are transmitted without attenuation (Fig. 1). The reflected spectral part is called Bragg wavelength and its spectral position is given by the equation:

$$\lambda_B = 2n_{eff}\Lambda, \quad (1)$$

where n_{eff} is the effective refractive index of the optical fiber and Λ is the periodic change of the refractive index.

Optical Materials and Biomaterials in Security and Defence Systems Technology XIV, edited by Roberto Zamboni, François Kajzar, Attila A. Szep, Katarzyna Matczyszyn, Proc. of SPIE Vol. 10440, 104400H

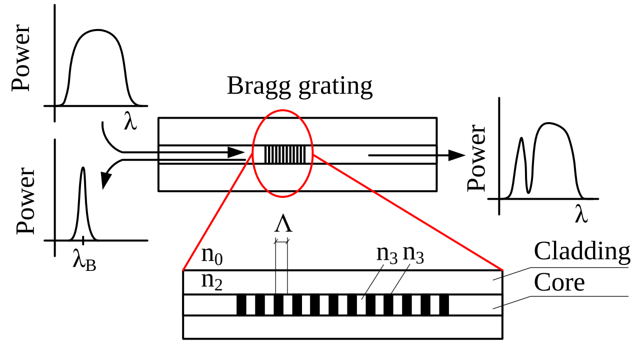

Figure 1. The principle of the Bragg grating and the detail of fiber Bragg grating in the core of optical fiber.

Bragg grating are single point measurement sensor, which are using for measurement a lot of physical, chemical or biomedical parameters. Bragg grating sensitivity to external strain and temperature is given by the equation:

$$\frac{\Delta\lambda_B}{\lambda_B} = k\Delta\varepsilon + (\alpha_\Lambda + \alpha_n)\Delta T \tag{2}$$

where λ_B is the Bragg wavelength, $\Delta\lambda_B$ is Bragg wavelength shift, k is deformation coefficient, $\Delta\varepsilon$ is strain change, α_Λ is coefficient of thermal expansion, α_n is thermo-optic coefficient and ΔT is temperature change [20].

For quasi-distributed measurement we can use more FBG sensor in one optical fiber. In this case is important to use some of multiplex division multiplex. The simplest method is wavelength division multiplex. In this case, individual Bragg gratings have to have different Bragg wavelength. Then, individual Bragg grating we can to distinguish by optical spectral analyzer [21]. For determining the number of Bragg grating in one optical fiber and parameters of these gratings, there we can use mathematical model recently published [22].

3. EXPERIMENTAL SETUP

Experimental measurements were carried out in the private hospital of Prostejov on a group of 5 volunteers with their written consent. The FBG Interrogator with a sampling frequency of 800 Hz and a light-emitting diode (LED) with a power output of 3 mW was used to evaluate the data. The working wavelength was set to 1550 nm. The FBG sensor used is shown in Figure 2, including a description of the individual parts. As mentioned above, PDMS polymer was used for encapsulation. This material does not affect the sensor function, see articles [23-24]. For data analysis, applications developed in the LabVIEW development environment were used. Based on the known filtering techniques [25-30], the heart rate of the human body was expressed as beat per minute (bmp).

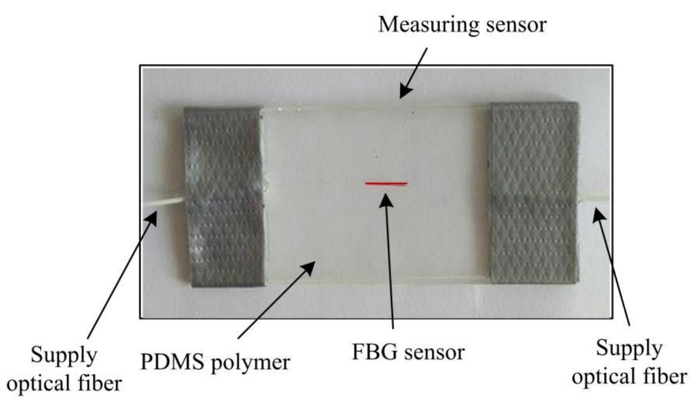

Figure 2. A prototype of the sensor for monitoring the respiratory and heart rate of the human body during MRI.

Figure 3 shows an MRI scanner and a patient bed. The FBG sensor was placed in the red marked part. The probe was placed on a solid support in the area of the heart. Attached to the patient's body was a clamping contact strip. Each patient was asked about the measure of comfort. None of the respondents did not state any discomfort during the actual readings.

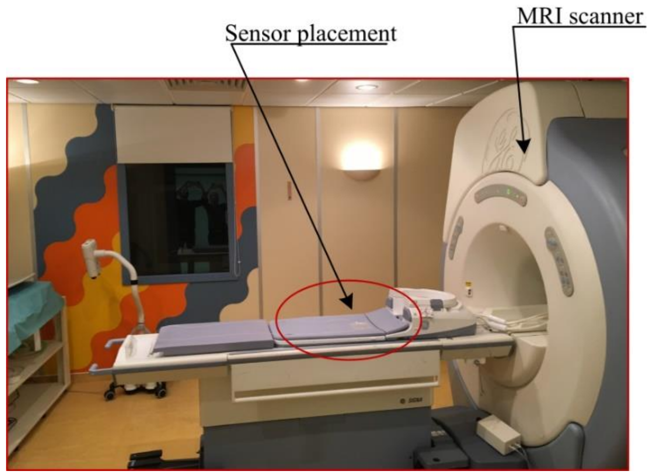

Figure 3. Implementation of the sensor on the patient part during the MRI examination.

Figure 4 shows a direct measurement scheme that was performed during the experimental measurements. To compare the differences between signals estimated from the FBG sensor and the reference signals from the scanner Signa HDxt 1.5T the Bland-Altman plot was utilized.

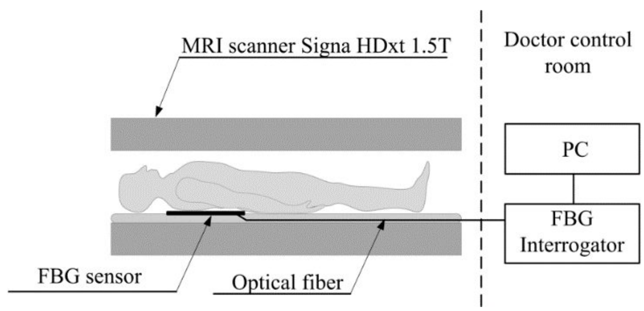

Figure 4. Experimental setup.

Figure 5 shows a recording of the respiration activity of the human body measured using the FBG sensor and figure 6 shows a recording of the heart activity. Shown are the typical waveforms representing the measured signals. For better clarity, a 60-second time signals are displayed. Two approaches can be used to analyze respiratory and heart rate. The first one (time access) is the sum of the local repeating maxima and based on it calculating the respiratory or heart rate per minutes. The second approach is based on the analysis the dominant frequency by the Fourier transform.

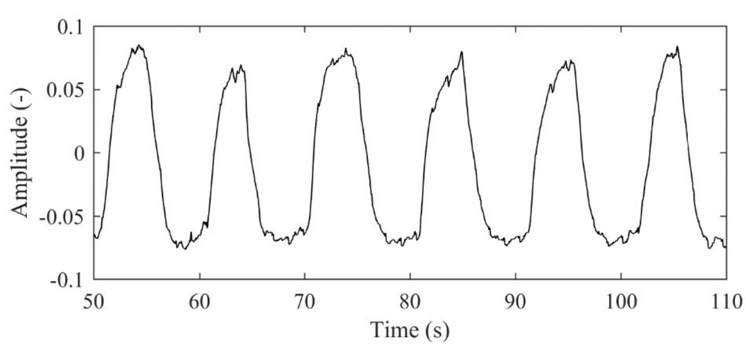

Figure 5. 60-second signal of respiratory activity of the tested subject.

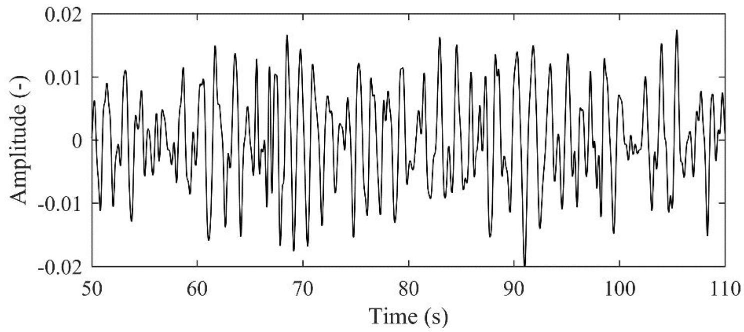

Figure 6. 60-second signal of heart activity of the tested subject.

Figure 7a shows Bland-Altman plots for all respiratory measurements performed. A detailed analysis is described in Table 1. For the all entire set of data (all test subjects) we can state all values (95.44 %) lie within the ± 1.96 SD (Standard Deviation) range for the heart and respiratory rate determination. Figure 7b shows Bland-Altman plots for all heart rate measurements. A detailed analysis is described in Table 2. For the all entire set of data (all test subjects) we can state all values (95.20 %) lie within the ± 1.96 SD (Standard Deviation) range for the heart and respiratory rate determination.

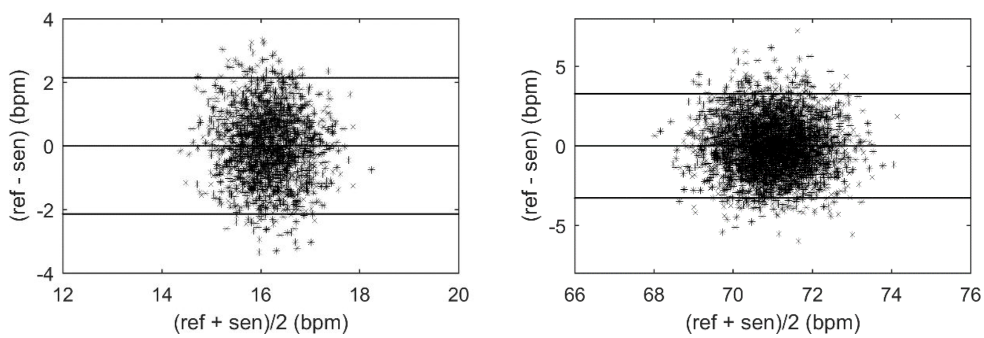

Figure 7. (a) Bland-Altman plots for all respiratory measurements; (b) Bland-Altman plots for all heart measurements.

Table 1. Summary of the respiratory rate measurements.

Test subject	**Rec. time (s)**	**Respiratory Rate**	
		NoS sensor	**Samples in ± 1.96 SD (%)**
1	600	182	95.43
2	600	194	95.44
3	600	174	95.42
4	600	167	95.46
5	600	171	95.44

Table 2. Summary of the heart rate measurements.

Test subject	**Rec. time (s)**	**Heart Rate**	
		NoS sensor	**Samples in ± 1.96 SD (%)**
1	600	721	95.09
2	600	784	95.31
3	600	747	95.05
4	600	684	95.20
5	600	647	95.35

4. CONCLUSION

This article describes a created prototype of the sensor based on the FBG for the monitoring of a patient`s respiratory and heart rate in the magnetic resonance environment. The functionality of sensor was verified by a real measurement in the clinical conditions (thanks to the private clinic Prostejov). All measurements were performed with five test subjects with their written consent. The Bland-Altman statistical analysis demonstrates no basic systematic errors. Presented results can be used for the future research study. Also, authors hope so these presented results can help to better increase in fiber-optic technology in biomedical applications because these types of sensors can help to predict hyperventilation and panic attacks of patients during magnetic resonance examination.

ACKNOWLEDGEMENTS

This article was supported by the Ministry of Education of the Czech Republic (Projects Nos. SP2017/128 and SP2017/79). This research was partially supported by the Ministry of Education, Youth and Sports of the Czech Republic through Grant Project no. CZ. 1.07/2.3.00/20.0217 within the framework of the Operation Programme Education for Competitiveness financed by the European Structural Funds and from the state budget of the Czech Republic.

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