

Alternative fiber optic sensor based on Bragg grating for heart rate monitoring

Abstract

This paper deals on the alternative fiber optic sensor based on fiber Bragg grating (FBG) for use in biomedical applications. FBG measurement probe mounted on the human chest provides respiratory and heart activity monitoring. The big advantage of these sensors are immunity to electromagnetic interference and therefore they are able to be employed in magnetic resonance imaging (MRI) environment. The FBG encapsulation plays an important role in sensor protection against external effects and damages. This article focuses on the various types of FBG encapsulation and implementation on the human body for vital sign monitoring. Presented results of fiber optic sensors show a very interesting alternative to conventional respiratory and heart rate monitors.

Keywords: fiber Bragg grating, sensors, respiratory rate, heart rate

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Introduction

A number of research articles which used one or more FBGs have presented results of measurements of respiration rate, heart rate or both simultaneously.¹⁻³ Other reports have presented very interesting results based on the design and construction of an FBG-based sensor attached to the patient's chest that enables respiratory rate, heart rate and temperature monitoring.⁴ The experimental results reported in article describe an FBG-based sensor encapsulated into polymer polydimethylsiloxane (PDMS), which is mounted on an elastic contact strap that encircles the patient's chest.⁵ Fiber optic sensors encapsulated into smart textile are henceforth very popular for respiratory rate monitoring capable of operating in MRI environments.⁶⁻⁷

Methods

An optical fiber is a transparent cylindrical fiber made from silica glass. Optical fiber consists of an inner core, an outer cladding and acrylate protection with the outer diameter of 250 μm. Optical fibers are used to transmit light between the two ends of the fiber and find wide usage in fiber-optic communications. Specially designed fibers are also used for sensory applications. The most common types of fiber sensors are fiber Bragg gratings. Bragg grating is formed by the periodic change of refractive index in the core of the optical fiber.⁸ This structure reflects narrow part of propagation light and transmits other wavelengths (Figure 1). Central part of reflected light is called

Bragg wavelength and is given by equation:

$$\lambda_B = 2n_{eff}\Lambda$$

where n_{eff} is effective refractive index of periodic structure in core of optical fiber and Λ is period between these periodic changes. For biomedical applications, Bragg gratings are encapsulated into polymer polydimethylsiloxane (Figure 2A) and placed on the chest and fixed by a contact elastic strap. Another type of Bragg measurement probe consists of fiber Bragg grating located between two layers in process of print with 3D printer (Figure 2B). The source used for measurement is the wide spectral LED (Light Emitting Diode). Next, there is a circulator that directs light to Bragg grating, and reflected Bragg wavelength directs into OSA (Optical Spectrum Analyzer) where shifts of Bragg wavelengths are analyzed in the spectral domain.

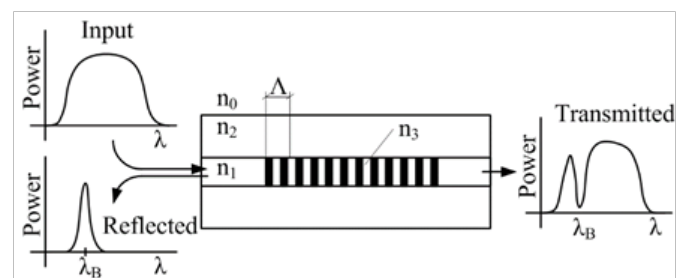


Figure 1 Operating principle of fiber Bragg grating.

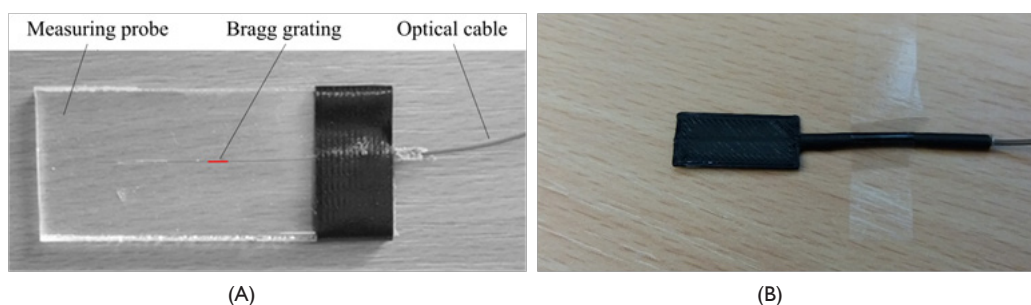


Figure 2 Measurement probe with Bragg grating encapsulated into PDMS (A); FBG measurement probe fabricated in 3D printer.

Results

The measurement probes were placed on the chest under the elastic strap. The strap was relatively tightened to increase the sensitivity of the probes. Figure 3A shows the measured data where the breathing activity is noticeable. Each separate peak is the maximal inflation

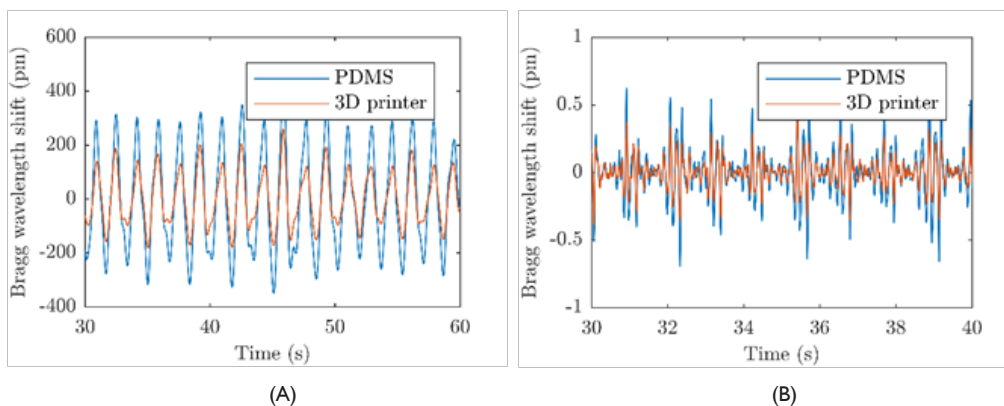


Figure 3 Respiratory activity from measurement probes without filtration (A); Heart activity signal from measurement probes after filtration by the band pass filter.

Heart rate from both measurement probes based on fiber Bragg grating and reference ECG is shown in Figure 4A & Figure 4B. To compare the differences between the reference signals from ECG and those acquired from both measurement probes, the Bland-Altman plot was utilized.⁹ The differences between the sensor and the reference

of the patient and the subsequent descent is the gradual exhalation. For further processing, a band-pass filter of the 10th order with a range from 5 to 20 Hz was used for heart activity derivation. Figure 3B shows the results of the filtration. In the first second, there is a synchronization pulse, and there are noticeable periodic repetitions that represent the pulse activity.

traces, $x_1 - x_2$, are plotted against the average, $(x_1 + x_2)/2$, where x_1 is reference heart rate from ECG and x_2 is heart rate determined from FBG measurement probes. The reproducibility is considered to be good if 95 % of the results lie within the ± 1.96 SD (Standard Deviation) range.

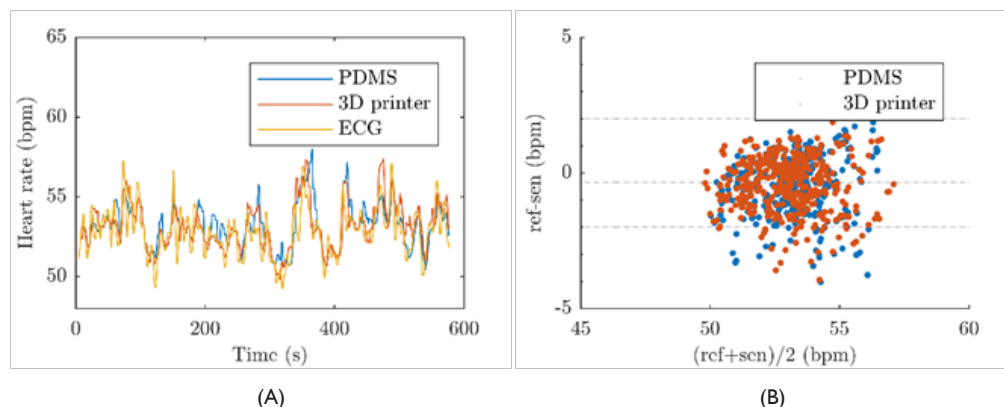


Figure 4 Heart rate calculated from both FBG measurement probes and reference ECG (a); Bland-Altman statistic for heart rate measurement with FBG measurement probes.

Conclusion

This article describes an alternative non-invasive fiber-optic sensor based on the fiber Bragg gratings for the monitoring of a patient's heart rate and respiratory rate. The Bland-Altman statistical analysis demonstrates no basic systematic errors. For the entire data set 96.49 % (for PDMS probe) and 95.4 % (for printed probe) of the values lie within the ± 1.96 SD range for the heart rate determination. The results of heart rate measurements are characterized by the maximum relative error of 4.67 %. These results can help to predict hyperventilation and panic attacks of patients during MRI examination.

Acknowledgements

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Conflict of interests

Authors declare that there is no conflict of interest.

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