Non-wearable Respiration Monitoring Based on Mach–Zehnder Interferometer

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***Abstract*—A novel non-wearable respiration monitoring smart mat structure embedded with optical fiber sensor is proposed and experimentally investigated, which can effectively detect the breathing rate (BR) of human subjects in sleeping position. The sensing principle is mainly based on the Mach–Zehnder interferometer (MZI), and the fibers used are all common single mode fibers (SMFs) with 900-micron buffer jacket avoiding fragility in practical use. The monitoring system has the advantages of non-invasion, non-fragility, simple structure, high sensitivity, low cost, and anti-electromagnetic interference.**

Keywords—Mach–Zehnder interferometer (MZI); respiration; non-wearable; optical fiber sensor

I. Introduction

As a key vital sign, respiration rhythm can provide some details of the health condition of a person. Many diseases or accidents, such as sleep apnea hypopnea syndrome (SAHS) and sudden infant/adult death syndrome (SIDS/SADS) happen during sleep. Therefore, real-time respiration monitoring during sleep shows great significant.

The most reliable way of respiration monitoring during sleep is polysomnography (PSG) [1]. However, it is time-consuming, complex, intrusive and uncomfortable. Fiber optic sensors based on Mach–Zehnder interferometer (MZI) have attracted many interests due to the intrinsic merits, including high sensitivity, immune to electromagnetic field, etc. [2]-[4].

However, MZI simply based on single mode fibers (SMFs) with 900-micron buffer jacket has barely been studied in vital signs monitoring due to its extremely high sensitivity and susceptibility to environments. In this paper, to our best knowledge, it is for the first time that the above mentioned MZI structure is set up and investigated experimentally to monitor breathing rate (BR) while resting. All the fibers used are SMFs with 900-micron protection buffer. It is simple, low cost and non-intrusive.

II. Principle and Experimental Setup

The sensing principle is mainly based on the MZI. The structure of MZI is simple and the schematic diagram is illustrated as Fig. 1.

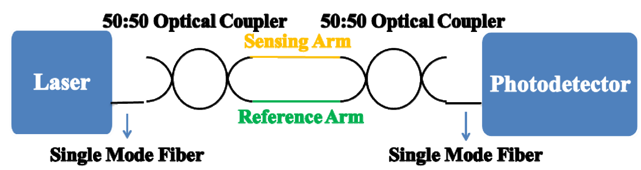

Fig. 1. The structure of MZI.

The whole system consists only of one distributed feedback (DFB) laser source, two 50:50 optical couplers, one photodetector, several SMFs and one mat. As shown in Fig. 1, the output light is collected by the photodetector, and can be expressed as

$$I = \frac{I_{in}}{2}(1 \pm \cos\Delta\varphi). \qquad (1)$$

where I is the intensity of the output light detected by the photodetector, I_{in} is the intensity of the input light, $\Delta\varphi$ is the phase difference between the two arms. The BR can affect $\Delta\varphi$, and thus change I.

The overall sensing platform and the picture of a subject under test are shown in Fig. 2 (a) and Fig. 2 (b) respectively. The sensing mat is put on a bed and a subject should be lying on it when under test.

(a) (b)

Fig. 2. (a) The mat placing on a bed. (b) A subject on the mat.

III. Result and Discussion

A. Results

The data are collected at a sample rate of 2040 Hz and imported into MATLAB for further processing.

A bandpass filter is used to preprocess the raw data. As shown in Fig. 3, the Fast Fourier Transform (FFT) is also applied to observe the frequency domain ranging from 0.1 to 0.5 Hz, corresponding to BR from 6 to 30 breaths per minute.

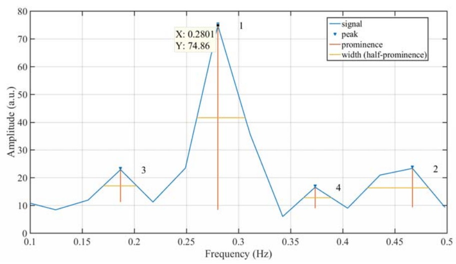

Fig. 3. Frequency domain of the reconstructed signal.

As depicted in Fig. 3, the highest peak point represents the average breathing frequency. And for this subject, denoted as Subject 1, the average breathing frequency is 0.2801 Hz, i.e., the BR is breaths 16.806 per minute accordingly. The time domains of the original signal and reconstructed signal are shown in Fig. 4 (a) and Fig. 4 (b) respectively.

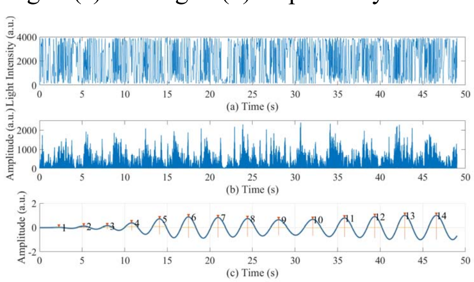

Fig. 4. Time domain of (a) the original signal, (b) the reconstructed signal, (c) the output signal.

Other sets of data from four other subjects (Subject 2 – 5) of different BR, ranging from 6 to 30 breaths per minute, are also processed. The results are shown in Fig. 5.

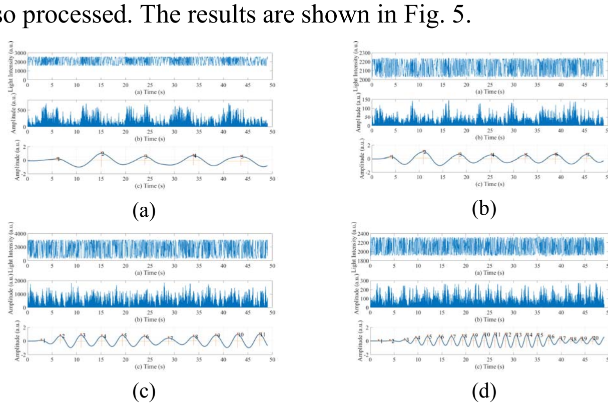

Fig. 5. (a) Subject 2. (b) Subject 3. (c) Subject 4. (d) Subject 5.

As depicted in Fig. 5, respectively, 5, 7, 11 and 20 breaths are detected during the testing period (approximately 49 seconds). The average breathing frequencies of the four subjects are 0.1156, 0.1401, 0.2179 and 0.4358 Hz, thus the BR are 6.936, 8.406, 13.074 and 26.148 breaths per minute respectively. As illustrated in Fig. 4 and Fig. 5, the system can detect the BR from 6 to 30 breaths per minute perfectly.

B. Subject and Body Movements Detection

Subject existence and body movements can also be detected. An example is shown in Fig. 6. The time domain of the original signal is shown in Fig. 6 (a). While no subject is under test, the subject detection signal automatically gives amplitude of zero while displaying, as shown in Fig. 6 (b). When a body movement of the subject occurs, the movement detection signal automatically gives amplitude of the maximum value to mark the body movement, as shown in Fig. 6 (c).

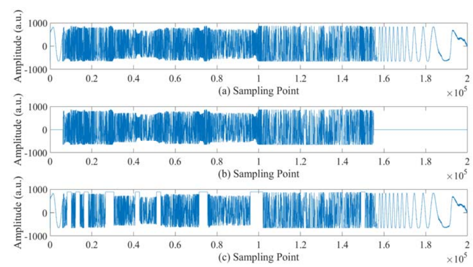

Fig. 6. Time domain of (a) the original signal, (b) the subject detection signal, (c) the movement detection signal.

IV. Conclusions

In conclusion, a non-wearable respiration monitoring smart mat structure based on MZI is proposed and experimentally demonstrated to realize the BR detection, subject existence and body movements. The proposed monitoring system has the advantages of non-invasion, non-fragility, simple structure, high sensitivity, low cost, and anti-electromagnetic interference.

Acknowledgment

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