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Non-invasive smart health monitoring system based on optical fiber interferometers

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ABSTRACT

Vital signs (including breath and heartbeat) monitoring is a key tool in healthcare. Current monitors need invasive electronic sensors attached to user's body, which is inconvenient and uncomfortable. We demonstrate photonic smart health monitoring system based on phase-sensitive optical fiber interferometers. Users simply lie/sleep on a sensor mat embedded with optical fiber interferometers. Breath and heartbeat will introduce slight strain changes on the mat and affect the light propagating within the fiber. Breathing and heartbeat waveforms can be achieved by analyzing the output light with signal processing. The system can collect user's signals continuously and remotely to provide big data for health analysis. Our technique is non-invasive, highly sensitive, and immune to electromagnetic interference.

Keywords: *Non-invasive, breath monitoring, heartbeat monitoring, optical fiber interferometer*

1. INTRODUCTION

With the population ageing globally, healthcare becomes extremely important with a market of trillion dollars. Vital signs (including breath and heartbeat) monitoring is a key tool in healthcare in general, since vital signs serve as a universal communication tool for patient status and severity of illness, which is important for longitudinal monitoring, continuity of care, and improved communication between healthcare professionals. Every day, people sleep for about eight hours. Many diseases or accidents, such as sleep apnea hypopnea syndrome (SAHS) and sudden infant/adult death syndrome (SIDS/SADS) happen during that period. Therefore, real-time vital signs monitoring shows great significant in sleeping time.

Traditionally, sensing electrodes are intrusively attached directly to users' skin to for vital signs monitoring, which makes users uncomfortable and even causes cross infections. In addition, the whole monitoring setup is expensive [1].

For contactless vital signs monitoring, both radar-based and piezoelectric polyvinylidene fluoride (PVDF)-based monitors are proposed to detect heartbeat or respiration [2-5]. However, these electronic monitors may be affected by electro-magnetic interference (EMI). When these sensors are used in strong EMI environment like magnetic resonance imaging (MRI), they may not work.

Fiber-optic sensors have attracted many attentions due to their intrinsic merits of high sensitivity, remote sensing, low cost, small in size and immune to EMI [6]. They have been widely studied to monitor a variety of parameters, including temperature [6], strain [7], humidity [8], sound [9] and so on. Here we propose and investigate a non-invasive fiber-optic vital signs monitor based on Mach-Zehnder interferometer (MZI). It only consists of one laser source, two 3-dB couplers, one photo-detector (PD), and some single mode fibers (SMFs). All the fibers used are with 900um protection buffer. The user only needs to put the sensing mat embedded with SMF under the bed and sleep/lie on it. Experimental results show that our system can achieve the waveforms of heartbeat and respiration for real-time health monitoring.

2. PRINCIPLE AND EXPERIMENTAL SETUP

The sensing mechanism is very simple, which is based on Mach-Zehnder interferometer as shown in Fig. 1.

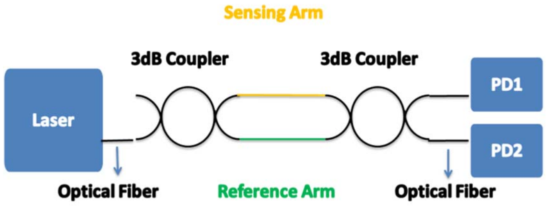


Fig. 1. The structure of the MZI

The structure contains a laser diode, two 3-dB optical couplers, two PDs and fibers. Note that only one PD is needed in actual use. All the fiber used in the setup are with 900-um protection buffer to avoid breaking. The upper branch of the fiber acts the sensing arm while the lower branch acts the reference arm. The output lights collected by PD1 and PD2, denoted by I_1 and I_2 respectively, can be written as

$$I_1 = \frac{I_{in}}{2}(1 \pm \cos\Delta\varphi)$$
$$I_2 = \frac{I_{in}}{2}(1 \mp \cos\Delta\varphi),$$

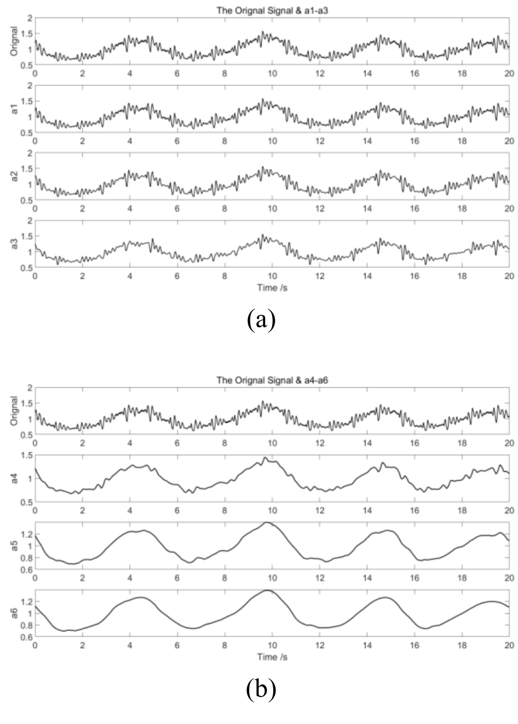
where I_{in} denotes the input light intensity, $\Delta\varphi$ denotes the accumulated phase difference between the sensing arm and the reference arm. $\Delta\varphi$ can be further rewritten as

$$\Delta\varphi = (n_{sen}L_{sen} - n_{ref}L_{ref})2\pi/\lambda,$$

where n_{sen}, L_{sen}, n_{ref}, L_{ref} represent the refractive index and the length of the sensing arm and the reference arm respectively, λ is the wavelength of the incident light source in vacuum. When people lie on the bed, the heartbeat and respiration cause micro-strain variations transferred to the MZI under the bed, which changes the $\Delta\varphi$. Then the output light intensity I_1 or I_2 changes accordingly. The data are collected with data acquisition device and further processed with MATLAB.

3. RESULTS AND DISCUSSIONS

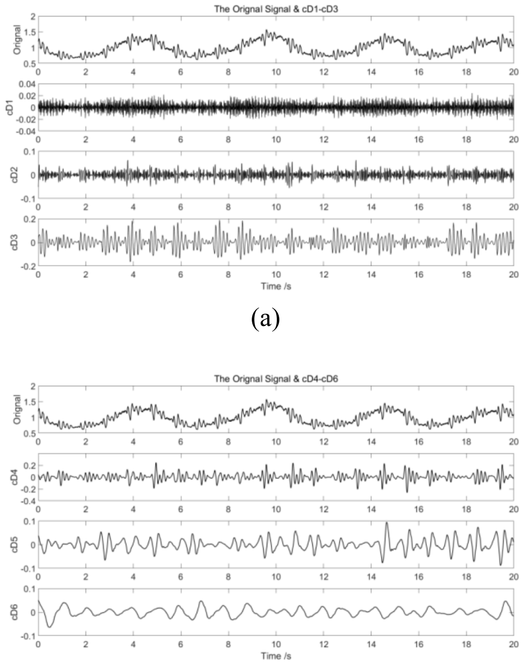
The data are collected by data acquisition device (National Instruments, NI USB-6000) with a sample rate of 100 Hz. Wavelet transform based on Daubechies-4 is used to analyze the original raw signal and extract the breath and heartbeat signal, which is shown in Fig. 2. For the signal over 20 seconds, Fig. 2(a) shows the approximation coefficients a1-a3 and Fig. 2(b) shows the approximation coefficients a4-a6. Fig. 3 (a) shows the detail coefficients cD1-cD3 and Fig. 3(b) shows the detail coefficients cD4-cD6.



(a)

(b)

Fig. 2. (a) The original signal and approximation coefficients of a1-a3. (b) The original signal and approximation coefficients of a4-a6.



(a)

(b)

Fig. 3. (a) The original signal and detail coefficients of cD1-cD3. (b) The original signal and detail coefficients of cD4-cD6.

The details in level 3 and 4 are used to reconstruct the heartbeat signal, while the approximation in level 6 is used to reconstruct the respiration signal, which is shown in Fig. 4. It can be seen that the subject under test has 21 heartbeats and 4 breaths in 20 seconds. Fig. 5 shows another dataset over 60 seconds, where we can see that one has 52 heartbeats and 15 breaths.

All these vital signs data can be collected continuously and transmitted to data center for further health analysis.

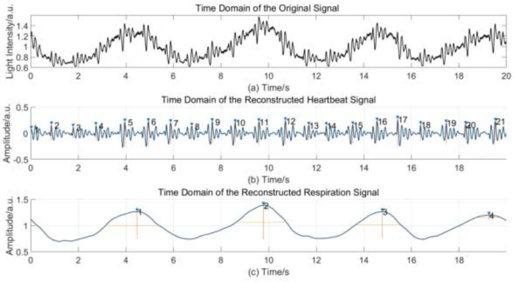


Fig. 4. Time domain of (a) the original signal of 20 seconds, (b) the reconstructed heartbeat signal, (c) the reconstructed respiration signal.

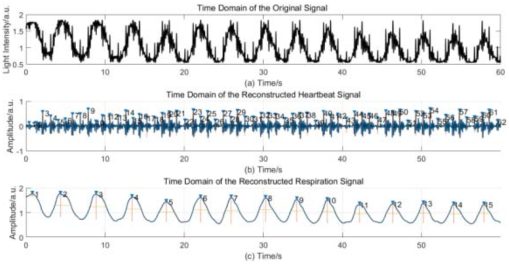


Fig. 5. Time domain of (a) the original signal of 60 seconds. (b) the reconstructed heartbeat signal. (c) the reconstructed respiration signal.

4. CONCLUSION

In conclusion, a SMF-MZI-based non-invasive vital signs monitor is presented and experimentally validated. It shows the ability to monitor the heartbeat and respiration without direct attachment to the user's body. The proposed monitoring structure is simple, cost-effective and non-invasive.

5. ACKNOWLEDGMENT

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