Non-invasive vital signs monitoring system based on smart sensor mat embedded with optical fiber interferometer

Changyuan Yu*
Department of Electronic and Information Engineering
The Hong Kong Polytechnic University
Kowloon, Hong Kong
*changyuan.yu@polyu.edu.hk

Wei Xu
Anlight Optoelectronic Technology Inc.
Suzhou, China

Ying Shen
[1]*School of Electronic & Information Engineering*
Soochow University
Suzhou, China
[2]*National University of Singapore (Suzhou) Research Institute*
Suzhou, China

Shihang Bian
[1]*School of Electronic & Information Engineering*
Soochow University
Suzhou, China
[2]*National University of Singapore (Suzhou) Research Institute*
Suzhou, China

Cheungchuen Yu
Anlight Optoelectronic Technology Inc.
Suzhou, China

Shanhong You
School of Electronic & Information Engineering
Soochow University
Suzhou, China

***Abstract*—A non-invasive vital signs monitoring system based on fiber-optic interferometer is presented, where human being's heart beat and respiration signals can be precisely extracted and monitored in an unobtrusive way. The fiber sensing system is wholly embedded in a thin mat placed on the mattress.**

Keywords—vital sign, non-invasive, fiber-optic, Mach-Zehnder

I. Introduction

Vital Signs monitoring, including heart beat and breath, play a significant role both in home care and hospital care, and it is even much more important to track the users' heart beat and breath signal during sleeping in case that any sudden disease or sleep apnea could occur.[1] Traditionally, cardiac impulse signal is monitored through using electrical heart rate senor directly attached to the body skin, which is known as Electrocardiograph (ECG). As for breath, usually it can be measured from airflow around nasal cavity, movement of the chest or abdomen.[2] However, these conventional methods have some drawbacks such as uncomfortableness, need to be worn, invasive monitoring, etc.

Fiber-optic sensor has been extensively studied owing to its intrinsic advantages, including small size, light weight, immune to electromagnetic interference, remote and real-time sensing[3]. In addition, fiber can be used to transmit light signal in a very low loss and itself can be acted as sensing element. Therefore, it can be considered to be spread on the mattress to sense the micro strain induced by vital signs.

In this paper, we present an non-invasive fiber-optic vital signs monitoring based on in-line Mach-Zehnder interferometer (MZI). The MZI is constructed by sandwiching a section of few mode fiber (FMF) or multimode fiber (MMF) into two sections of single mode fibers (SMFs) acting as lead in and lead out function, respectively. High order modes can be effectively excited and interference with the core mode. It is cost-effective, non-wearable, comfortable and high sensitive.

II. Principle

The proposed vital signs monitoring system mainly based on in-line modal MZI, which is depicted in Fig. 1. It can be seen that a lead-in SMF is used to direct the LP_{01} core mode into FMF or MMF in order to stimulate high order LP_{mn} transmission modes. After that, all of the modes recouple back into the lead-out SMF to be collected by the photodetector. The output light intensity I_{out} can be written as [4]

$$I_{out} = I_{LP01} + I_{LPmn} + 2\sqrt{I_{LP01} I_{LPmn}} \cos(\Delta\varphi), \qquad (1)$$

where I_{LP01} denotes the intensity of the LP_{01} mode, I_{LPmn} denotes the intensity of the LP_{mn} mode, and $\Delta\varphi$ denotes the optical path difference between the two inference modes. The normalized extinction ratio (ER) is defined as [5]

$$\mathrm{ER} = \frac{2\sqrt{I_{LP01} I_{LPmn}}}{I_{LP01} + I_{LPmn}}. \qquad (2)$$

One can see that only if the intensity of I_{LP01} equals to I_{LPmn}, the ER could reach the maximum. As shown in the Fig. 1, a core-offset is introduced to get an optimal ER in the experiment.

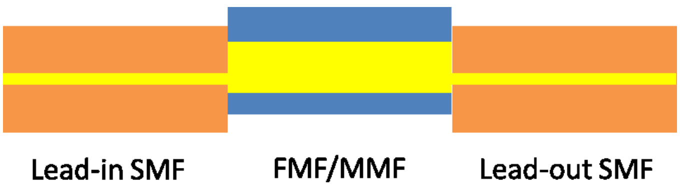

Fig. 1 Fiber Modal MZI structure.

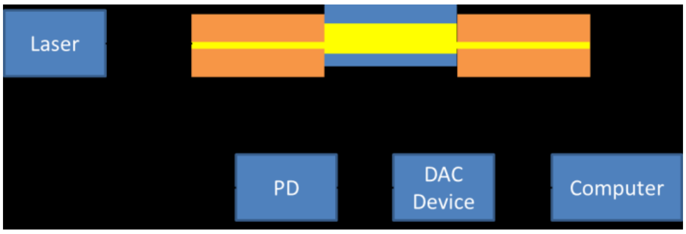

Fig. 2 Experiment setup of the SMF-FMF/MMF-SMF sensing system.

III. EXPERIMENT SETUP

The experiment setup is shown in Fig. 2, which is mainly consisted of a laser source, a section of lead-in SMF, a length of FMF or MMF, a section of lead-out SMF followed by a photodetector (PD), data acquisition card (DAC) device and an personal computer used to further process the collected raw data. All the splicing points is fused by a commercial splicer Fujikura FSM-80S. MMF is step-indexed with core/cladding diameter of 62.5/125um, while FMF is two mode fiber (TMF) with core/cladding diameter of 20/125um.

IV. RESULTS AND DISCUSSIONS

Experiments are carried out on SMF-MMF-SMF (SMS) and SMF-TMF-SMF (STS) structure, respectively to investigate the performance of vial sign monitoring.

Firstly, SMS-based sensing system is addressed. Fig. 3 shows the results of the sensing system, where the length of the MMF is eight meters and the core-offset is 3um. Fig. 3(a) gives the raw collected data by the PD. Fig. 3(b) and Fig. 3(c) respectively show the extracted respiratory signal and heat beat signal within ten seconds. One can see that there are 3 breathing cycles and 11 cardiac cycles. The signal processing mainly includes wavelet analysis because the frequency band of the cardiac signal is quite different from the band of the breath signal.

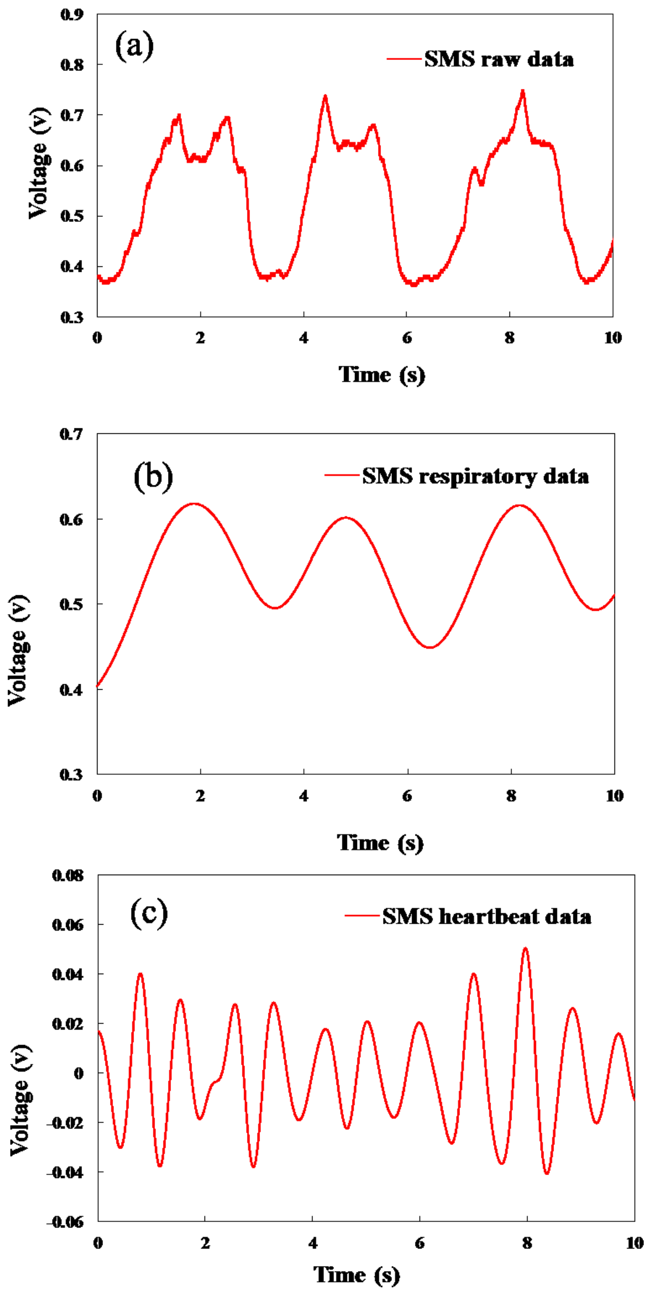

Fig. 3 SMS based vital signs within 10 seconds (a) raw data; (b) extracted respiratory signal (c) extracted heart beat signal.

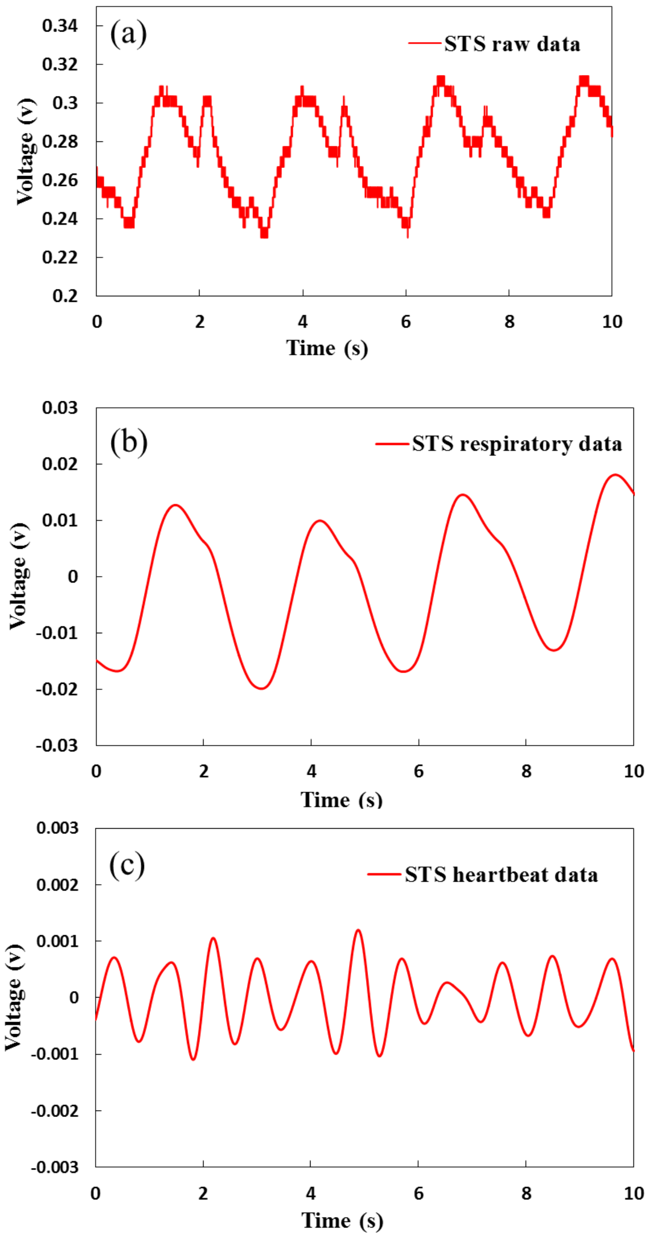

Fig. 4 STS based vital signs within 10 seconds (a) raw data; (b) extracted respiratory signal (c) extracted heart beat signal.

Secondly, STS-based vital sign monitoring experiment is carried out and Fig. 4 shows the results of such vital signs monitoring system with duration of 10 seconds where the TMF's length is 70cm and the core-offset is 5.6um. Fig. 4(a) shows the collected original data by PD and DAC device. Fig. 4(b) and Fig. 4 (c) explicit show the wavelet transform processed respiratory signal and heat beat signal. Obviously, it can be seen that there exist 3 breathing cycles and 11 cardiac cycles.

Therefore, both the proposed SMS and STS structure can realize vital signs monitoring in a non-invasive and unobtrusive way, which may have a great potential in future industrialization..

V. Conclusion

A non-invasive high sensitive vital signs monitoring system based on fiber-optic Mach-Zehnder modal interferometer is presented and investigated experimentally. Both the proposed SMS and STS structure can achieve heart beat and respiration monitoring. The whole fiber sensing system is embedded in a thin mat placed on the mattress, which gives good user experience.

Acknowledgment

This work is supported by National Natural Science Foundation of China (Grant No. 61501313 and 61471253) and the support of HKPU 1-ZVHA and 1-ZVGB.

References

[1] C. Yu, W. Xu, N. Zhang, and C.C. Yu, "Non-invasive smart health monitoring system based on optical fiber interferometers," 16th International Conference on Optical Communications and Networks (ICOCN) 2017, pp. 1-3, Wuzhen, China, August 7-10, 2017.

[2] F. Q. Alkhalidi, R. Saatchi, D. Burke, et al, "Respiration rate monitoring methods: a review," Pediatric Pulmonology, vol. 46, pp. 523-529, 2011.

[3] A. Grillet, D. Kinet, J. Witt, et al, "Optical fiber sensors embedded into medical textiles for healthcare monitoring," IEEE Sensors Journal, vol. 8, pp. 1215-1222, 2008.

[4] K. Wang, W. Xu, N. Zhang, K. Li, C.C. Yu, and C. Yu, "Fiber-optic in-line Mach-Zehnder modal interferometer for breathing monitoring application," OptoElectronics and Communications Conference (OECC) 2017, Paper Oral 2-1S-4, pp. 1-3, Singapore, July 31-August 4, 2017.

[5] H. Kim, and H. G. Alan, "Chirp characteristics of dual-drive. Mach-Zehnder modulator with a finite DC extinction ratio," IEEE Photonics Technology Letters, vol. 14, no. 3, pp. 298-300, 2002.