Non-invasive smart monitoring system based on multi-core fiber optic interferometers

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***Abstract*—A smart monitoring system based on fiber-optic interferometers using multi-core fiber (MCF) is presented in this paper. Interference among cores in the seven-core fiber (SCF) was introduced by using multi-mode fiber (MMF) coupling and experimental setup was designed to collect the data of user on bed for processing. With optimized algorithm, three body activities, including on the bed, off the bed and body movement, can be identified successfully. For further processing on collected data, respiration of the user can also be obtained. The smart monitor is contactless and non-invasive which is user-friendly and secure.**

Keywords—Multi-core fiber, Smart monitoring system, fiber sensor

I. Introduction

In the modern ageing society, health problem of senior citizen has drawn an increasingly wide attention. Aged people suffer from a series of senile diseases, like Alzheimer's disease and sleep apnea hypopnea syndrome (SAHS). These old patients need real time monitoring, especially during the sleeping time. Current vital signs monitors need to be directly attached to human body [1], which may discomfort the users. Radar-based monitor [2-3] that can realize contactless to user, however, will be affected by electromagnetic interference. Compared with these, optical fiber sensor has numerous merits, such as electromagnetic immunity, low cost and light weight, which has caused a lot of concern. In this paper, a smart monitoring system based on the multi-core fiber (MCF) interferometer is proposed. The optical fiber sensor is embedded in the mattress and the user does not need to wear electronics, which is user-friendly and convenient. The smart monitoring system can judge three action statuses of user, off the bed, on the bed and body movement, respectively. Moreover, respiratory rate can be obtained timely by the system.

MCF is commonly used in the spatial division multiplexing communication system and it has also attracted much research interest in the fiber sensing domain. Seven-core fiber (SCF) is proposed replacing conventional Mach-Zehnder interferometer (MZI) structure in this paper. Compared with MZI which has been reported previously [4], SCF is more stabilized and compact since the interference occurs among different cores in a single fiber rather than two individual fibers. Experimental results show that the smart monitoring system based on SCF can realize accurate judgement of three statuses and detection of breath rate during the sleeping time.

II. Principle and Experimental Setup

The structure of optical fiber sensor is implemented by sandwiching a segment SCF between two multi-mode fibers (MMF). The sketch diagram of SMF-MMF-SCF-MMF-SMF, MSM for short, is shown as Fig. 1. In the SCF from YOFC in China, the diameter of cladding and each core are 150 μm and 7.9 μm respectively and core-to-core pitch size is 42.3 μm. The core and cladding diameter of MMF are 105/125 μm. To fabricate the interferometer, SCF is spliced to MMF by fusion splicer (Fujikura LZM-100). The length of SCF is 70 cm, and length of MMF is optimized to 1 mm to guarantee high coupling efficiency. The role of MMF is to expand and couple the light beam. As shown in the Fig. 2, modal distribution of MMF simulated by COMSOL covers all cores of SCF hence light beam can be excited into each core, which enabled the multi-beam interference in SCF. The output interference spectrum shown in the Fig. 3 is observed by optical spectrum analyzer (YOKOGAWA, AQ6370).

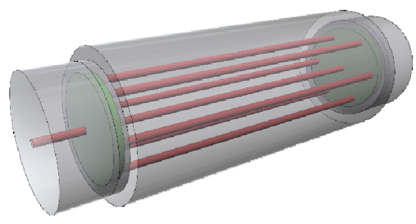

Fig. 1. Structure of interferometer based on SCF.

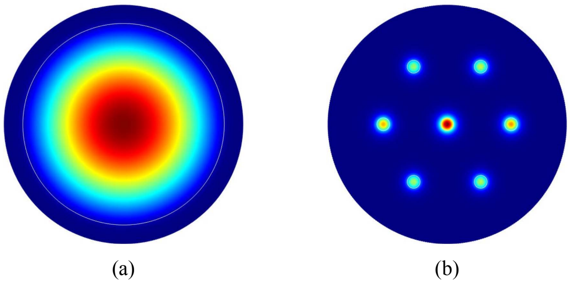

Fig. 2. Modal distribution of (a) MMF, (b) SCF.

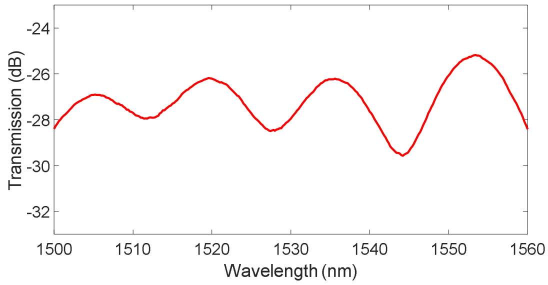

Fig. 3. Interference spectrum of MSM structure.

Theoretically, modes of center core and surrounding cores are excited in the SCF by MMF and the phase difference φ between the center core and surrounding cores can be given as

$$\varphi = \frac{2\pi L}{\lambda}(n_c - n_s), \quad (1)$$

where n_c and n_s represent refractive index of center core and surrounding cores respectively. L is the length of SCF and λ is the wavelength of light source. The transmission intensity can be described as

$$I = I_c + I_s + 2\sqrt{I_c I_s}\cos\varphi, \quad (2)$$

where I_c and I_s are the light intensity of center core and surrounding cores. When SCF segment was subject to micro-strain, n_c and n_s change respectively due to the elasto-optical effect, and φ changes simultaneously, which generates varying transmission intensity.

The setup of smart monitoring system contains a laser source (Amonics, 1550nm DFB Laser Source), an attenuator, a MSM fiber sensor, a photodetector (PD), a data acquisition (DAQ) card and a computer, which are shown in Fig. 4. With PD placed on the end of the system, the signals of light intensity oscillated with the varying phase difference can be obtained in real time.

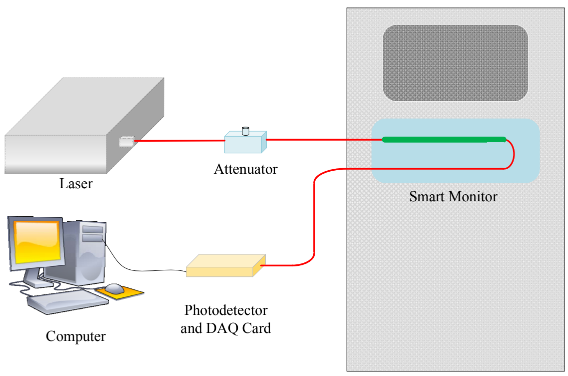

Fig. 4. Schematic diagram of the experimental setup.

III. Result and Discussions

Raw data shown in Fig. 5, which was collected by DAQ card at a sampling rate of 200 Hz, represents three body activities: off the bed, on the bed and body movement, respectively.

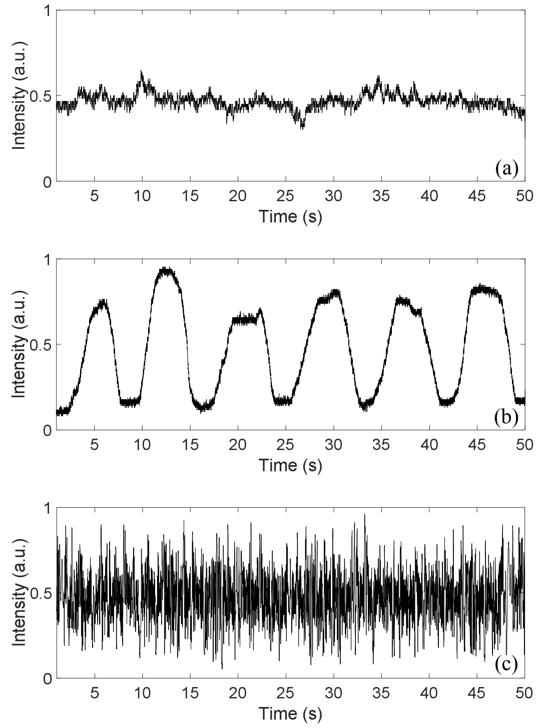

Fig. 5. Raw data of three statuses: (a) off the bed, (b) on the bed, (c) body movement.

It can be seen that the signal jitter of body movement is much larger than that of the other two sets while signal of off the bed status is relatively stable. Therefore, we designed an algorithm to extract the jitter level of signal.

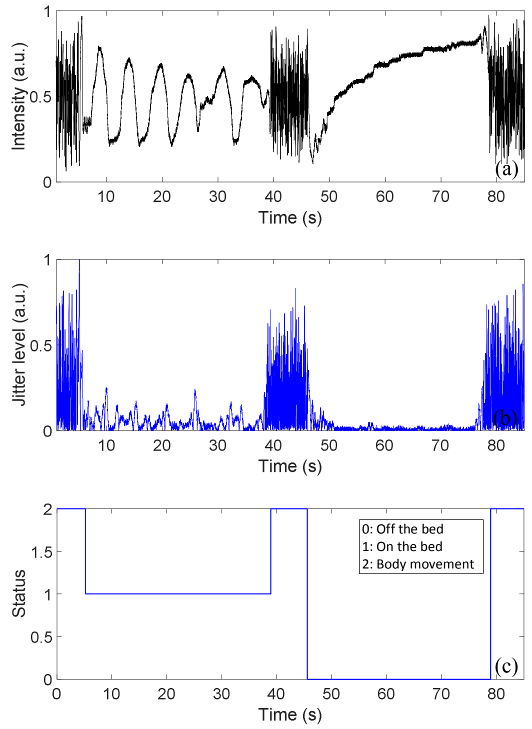

Fig. 6. (a) Raw data lasting for 85s, (b) result obtained, (c) outcome of three statuses decision.

Fig. 6(a) shows original data lasting for 85s which includes three statuses and Fig. 6(b) is the corresponding result obtained. In Fig. 6(c), judgement of three statuses can be obtained through a decision algorithm and the result agrees well with the original signal.

Applying Fast Fourier transform (FFT) to the raw data, respiration frequency of user can be obtained. The Fig. 7(a) and (b) show original data and individual FFT result. It can be clearly seen from the FFT result that the peak frequency is 0.13, thus the breath rate can be calculated to 8 bpm, which is consistent with the common situation.

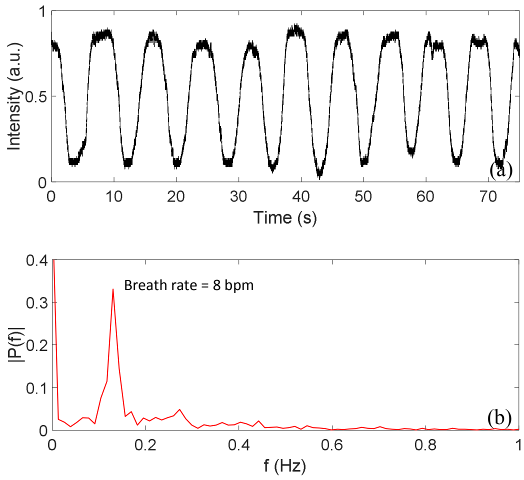

Fig. 7. (a) Original breath data, (b) FFT result.

IV. Conclusion

In conclusion, a smart monitoring system based on multi-core fiber-optic interferometers is presented in this paper. The optical fiber sensor has various advantages of light weight, compact construction and electromagnetic immunity. In addition, it is contactless, convenient and user-friendly. The experiment results show that the monitoring system can detect three statuses of body activities and breath ratio of 8 bpm can also be calculated.

Acknowledgment

This work is supported by Hong Kong Polytechnic University (1-ZVHA, 1-ZVGB, 1-BBYE, and 1-BBYS); National Natural Science Foundation of China (NSFC) (61501027); Fundamental Research Funds for the Central Universities (FRF-TP-17-019A2).

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