Microbend Fiber Optic Sensor for Perioperative Pediatric Vital Signs Monitoring

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ABSTRACT

We have demonstrated a highly sensitive microbend fiber optic sensor for perioperative pediatric vital signs monitoring that is free from direct contact with skin, cableless, electromagnetic interference free and low cost. The feasibility of our device was studied on infants undergoing surgery and 10 participants ranging from one month to 12 months were enrolled. The sensor was placed under a barrier sheet on the operating table. All patients received standard intraoperative monitoring. The results showed good agreement in heart rate and respiratory rate between our device and the standard physiological monitoring when signals are clean.

Keywords: Vital signs monitoring, Pediatric patient monitoring, Fiber optic sensor

1. INTRODUCTION

Monitoring of physiological parameters is essential in ill and perioperative patients to detect deterioration in condition and facilitate appropriate medical intervention. Limitations in current technology include the need for direct skin contact, restriction of patient's movement by cables and sensors and poor compliance. Infants, in particular tolerate placement of multiple monitors poorly. An ideal technology is one that gives real time, noninvasive, contactless, cableless, accurate monitoring for rapid response. In recent years, there has been a rapid emergence of such new technologies operating on a nonintrusive and cableless platform without body skin direct contact. The new technologies offers greater comfort and ease of use. More importantly these new technologies enable the automatic measurement of heart rate and respiratory

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rate, without constraint to the person's activities. Electronic sensors are used for such applications [1-3]. Nevertheless, they are prone to electromagnetic interference and radiofrequency (RF) heating if they are used in magnetic resonance imaging (MRI), particularly in high-field MRI environment. The use of optical fiber sensors as vital signs monitors is an attractive option in high-field MRI environment and many of such sensors have been proposed for monitoring of respiratory rate and heart rate in the past [4-12] but few were tested for operating patients, especially for pediatric patients whose ages are ranged from one month to 12 months old. These pediatric patients' body weight is significantly lighter compared to adult patients. The normal physiological heart rate and respiratory rate for infants are also higher than adults. To meet the challenge of small body weight in infants (one month to 12 month old), a highly sensitive sensor may be required. We developed a microbend fiber optic sensor for vital signs monitoring that is free from direct contact with skin. It is cableless, electromagnetic interference free and low cost. The feasibility of our device was studied on infants undergoing surgery with IRB approval. 10 participants ranging from one month to 12 months were enrolled. The sensor was placed under a barrier sheet on the operating table and data was wirelessly transmitted to a notebook and saved for offline analysis. All patients received standard intraoperative monitoring. The results showed good agreement in heart rate and respiratory rate between our device and the standard physiological monitoring when signals were relatively clean. Our new microbend fiber optic sensor is a potential solution for monitoring respiratory rate and heart rate in perioperative or ill infants and is Magnetic Resonance Imaging safe.

2. INSTRUMENTATION AND EXPERIMENT

The microbend fiber sensor consists of a section of graded multimode optical fiber clamped between a pair of microbenders as shown in Fig.1. Its technology principle is based on fiber optic microbending theory. As the displacement between two microbenders changes, the sinusoidal amplitude of the calmped multimode optical fiber changes with infant's body vibrations caused by respiration/heart beating and other vibrations, e.g., body movement. The light intensity in the microbending fiber is modulated with the body vibrations/body movement; some light is lost from the fiber core through coupling between guided modes and radiation modes. Respiration rate and heart rate could be obtained by demodulating output signals.

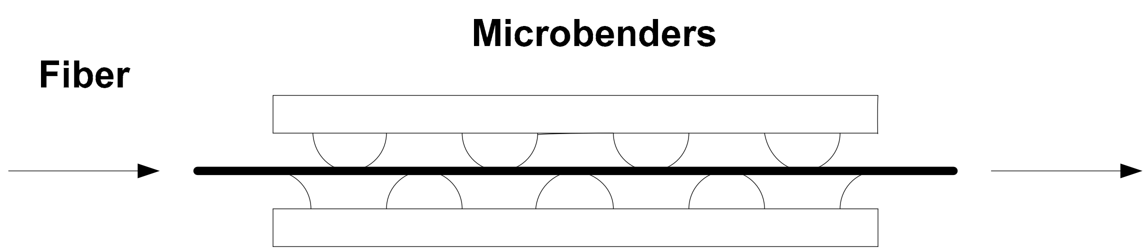


Fig. 1 Schematic of the microbend fiber sensor with dual microbenders

To achieve the best sensor sensitivity to detect body vibrations caused by respiration/heart beating, the key parameters for graded index multimode fiber should meet the following equation [11]:

$$\Lambda = \frac{\pi D n}{NA} \tag{1}$$

where Λ is the pitch of microbender, D is the diameter of the multimode fiber, n is the core refractive index and NA is the numerical aperture of the fiber. Fig.2 shows a typical microbender. It has a mesh structure. Although there are more parameters in the design, equation (1) is still useful to guide the sensor design. To obtain the best sensitivity, dual microbenders should be used as shown in Fig.1. If only one microbender was used as shown in Fig.3, sensitivity will suffer greatly. This was confirmed by our experiment.

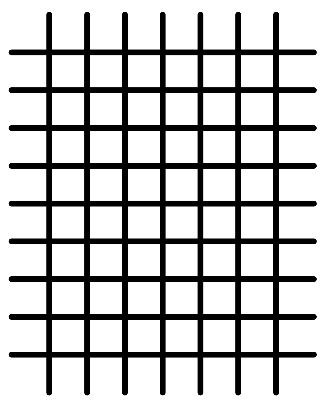


Fig. 2 Schematic of the microbender with a mesh structure

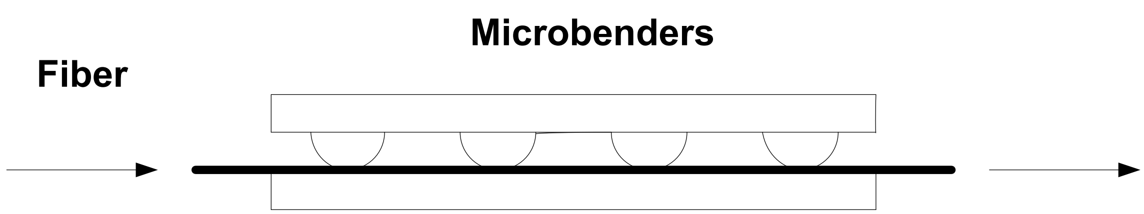


Fig. 3 Schematic of the microbend fiber sensor with single microbender

Fig.4 shows our instrumentation which consists of measurement mat, transceiver, and notebook. About A3 size highly sensitive microbend fiber sensors were made with a thickness of about 2mm. Transceiver consists of light source at 1310nm, detector, microprocessor and other circuits. The output signal of transceiver is wirelessly transmitted to a notebook which is sampled at 50Hz. The raw data were collected for offline signal processing. Fig.5 shows the prototype of the sensor used for the trial and the position in the operating table. It should be noted that the sensor mat was put under the barrier sheet.

This study was a prospective cross sectional study of 10 infants for surgery in KK Women's and Children's Hospital, Singapore conducted from June 2016 to September 2016. Approval from SingHealth Institutional Review Board (IRB

2016/2094) and parental consent were obtained. Clinical data acquisition was performed by the clinical investigator. In this clinical study, observations were performed on 9 anesthetized patients intraoperatively and 1 awake patient post-surgery in recovery. For the 9 patients under anesthesia, standard intraoperative physiological monitoring applied. Heart rate was monitored using electrocardiography (ECG) with Philips Physiological monitoring (Philips Corporation, MA, US) and respiratory rate monitored using airway spirometry monitoring with Draeger Ventilator (Draeger Inc, Houston, US). For single awake patient (patient # 6), heart rate was monitored with pulse oximetry (Masimo Corporation, Irvine, US) and respiratory monitoring was monitored by the investigating investigator. .

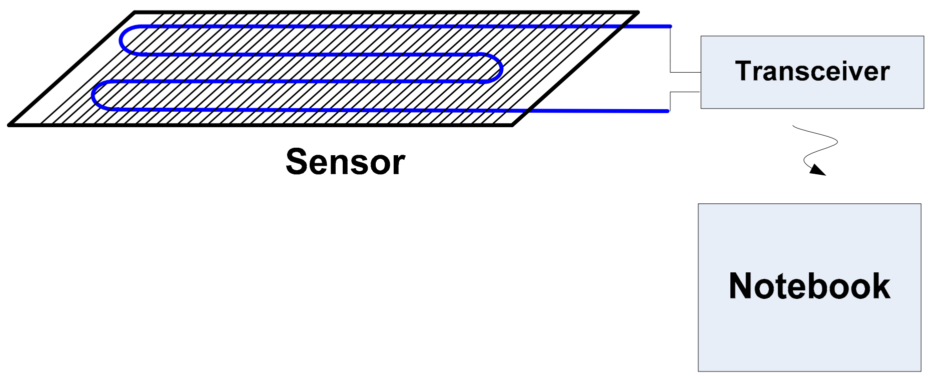


Fig. 4 instrumentation system

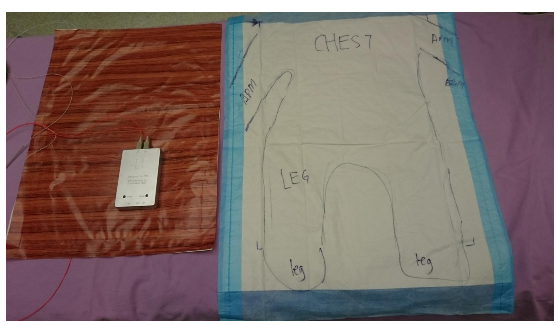


Fig. 5 Sensor mat and position in the operating bed

Fig.6(a) shows a typical raw data measured from our sensor from a patient (#3) whose age was one month old and his body weight was 3.78kg as the patient was under anesthesia and not moving in the bed. The respiratory signal and heart beating signal is clearly seen. Fig.6 (b) and (c) shows the FFT spectra of respiratory signal and heart beating signal.

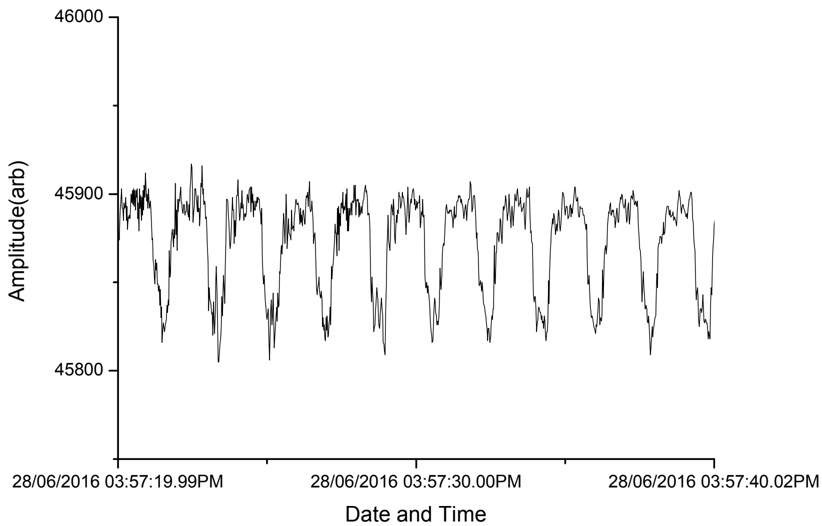
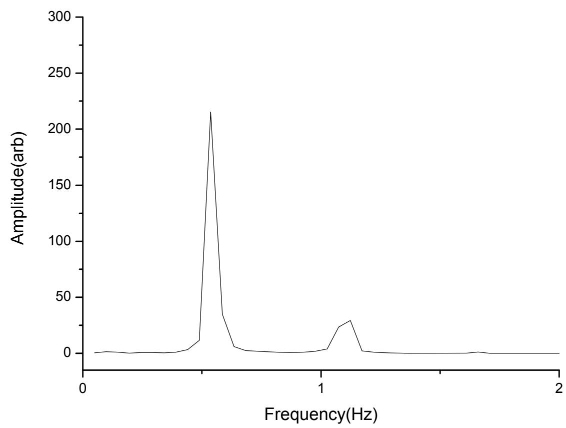
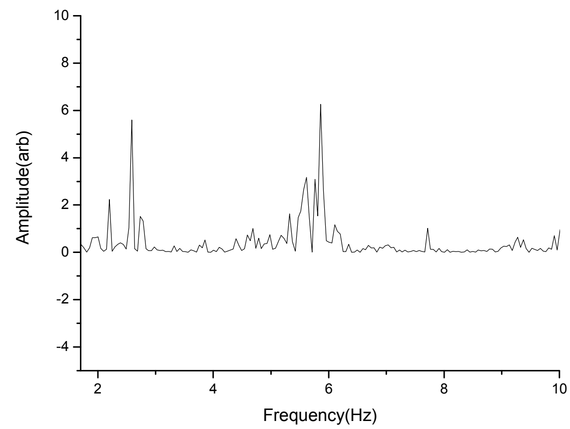


Fig.6 (a) Raw data from patient #3



(b)



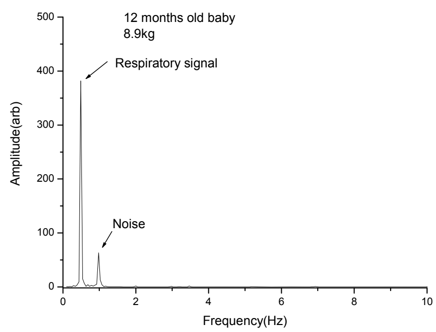
(c)

Fig.6 (b) and (c) FFT spectra of respiratory signal and heart beating signal of patient #3

The frequencies of respiratory signal and heart beating signal can be easily identified. The respiratory rate is 0.54*60=32.4bpm and heart rate is 2.59*60=155.4bpm. We also can see the second harmonics of the heart beating signal. The use of the harmonic signals is very useful because it provides more information for development of algorithm for noise removal. .

Fig.7 shows typical FFT spectra of signals from patient #5 whose age is 12 months old and his body weight is 8.9kg. We can see that the respiratory signal is located at 0.5Hz and its signal is quite strong with good signal to noise ratio.

However, in the spectrum of heart beating signal, it is quite noisy around fundamental heart beating frequency. Only the second, third and fourth harmonics can be identified clearly for the calculation of heart rate. The noises around the fundamental frequency of heart beating signals are mainly due to the body movement during the operation. Use of higher harmonics is one of effective methods for the removal of noises in the algorithm development.



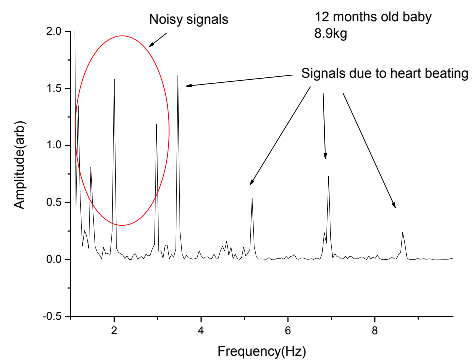


Fig.7 FFT spectra of respiratory signal and heart beating signal of patient #5

Table 1 below shows the measurement results on respiratory rate and heart rate from patient #2 (4 months old, 5.2kg). It can be seen from the Table 1 that the maximum error is 3.8bpm for respiratory rate and 4bpm for heart rate. The errors are acceptable for clinical applications.

Respiratory rate measurement

Time	Microbend sensor	Equipment	Error
12:16	55.8	57	1.2
12:23	54.9	55	0.1
12:28	52.8	53	0.2
12:32	52.7	50	2.7
12:37	52.8	49	3.8

Heart rate measurement

Time	Microbend sensor	Equipment	Error
12:16	136	135	1
12:23	135	136	1
12:28	137	138	1
12:32	132	128	4
12:37	126	123	3

Table 1 An experimental result on respiratory rate and heart rate for patient #2

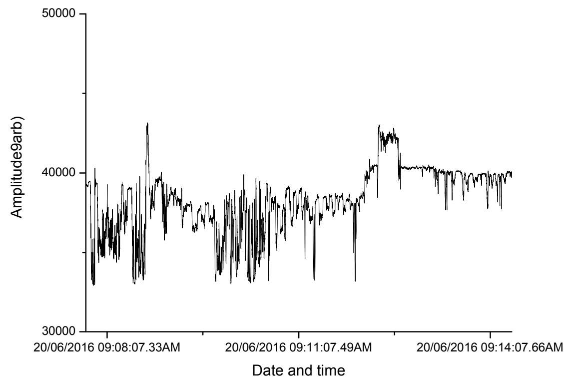


Fig.8 Raw data from patient #1

During operation, gross movement of patients occurred as a result of surgical manipulation as well as positioning for surgical access. In this case, the respiratory signal and heart beating signal was crumpled and was very difficult for an algorithm to extract correct signals, especially for heart beating signal extraction, as shown Fig.8. However, if the patients were not moved and laid down quietly, the signals were relatively clean and vital signs might be measured correctly. This work has showed that the microbend fiber sensor may be used for baby monitoring even the body weight is as low as 2.4kg.

3. CONCLUSION

We have demonstrated a microbend fiber sensor to measure respiratory rate and heart rate for infants during operation. When the patients were still the respiratory signal and heart beating signal obtained were clean with accurate measurement of respiratory rate and heart rate. The measurement of respiratory rate is comparatively easier than heart rate measurement. This work has showed that the microbend fiber sensor may be used for baby monitoring even the body weight is as low as 2.4kg. This microbend fiber sensor may be useful for periodic health monitoring in a home environment.

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