This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JSEN.2018.2847333, IEEE Sensors Journal

Smart textile using hetero-core optical fiber for heartbeat and respiration monitoring

Yuya Koyama, Michiko Nishiyama, and Kazuhiro Watanabe

***Abstract*—This study aims to describe a novel smart textile that uses a single-mode hetero-core optical fiber sensor for monitoring heartbeat and respiration. The smart textile was designed by weaving hetero-core optical fibers together with the wool fabric. This novel textile that can detect variations in shapes can be incorporated into clothes. Such clothes can offer comfort to the wearer. To simultaneously monitor heartbeat and respiration, the proposed textile is sewn on to the clothes to be able to sense minute load changes produced by chest movements. The vital signs, which were calculated from the heartbeat and respiration frequency of a healthy adult, while sitting, were in agreement with those verified using commercial monitoring devices. In addition, to confirm the capability of monitoring vital signs, seven monitoring trials were performed in which the subjects were asked to wear and take off the smart cloth. The vital signs rates were successfully extracted within the 4 bpm error by the fiber optic sensor system. The proposed smart textile in clothes can monitor vital signs in daily life activities, such as sitting and standing.**

***Index Terms*—Smart textile, fiber optic sensor, hetero-core fiber optics, plain weave structure, vital signs monitoring.**

I. Introduction

WEARABLE sensor devices to monitor heartbeat and respiration are being developed worldwide for the continuous monitoring of vital signs in daily activities. Cardiac and lung diseases such as heart failure, heart attack, and respiratory failure can be identified by attaching the sensor devices to the wearers' body. However, the attached sensor devices may cause skin irritation and discomfort.

Smart textiles [1]-[3] that can sense the shape variations can contribute to the wearers' comfort when integrated with the clothing. In this context, optical fiber sensors are promising candidates for inclusion in smart textiles [4] owing to their light weight, flexibility, thinness, and electromagnetic immunity. In addition, optical fiber sensors do not generate heat and are not susceptible to electrical discharges in comparison with the existing electrical sensors.

Several applications based on optical fiber sensors in smart textiles have been proposed for the heartbeat and respiration monitoring. The suggested approaches mainly use specific fabricated carriers, such as elastic belts [5]-[6], polymer sheets [7]-[8] or adhesive material [9]-[10] that are sensitive to deformation. Comfort achieved by directly weaving optical fiber sensors into the textile fabric is more than that achieved using the suggested approaches based on combining with carriers.

Yuya Koyama is with the Department of Information Systems Science, Faculty of Science and Engineering, SOKA University, 1-236, Tangi-cho, Hachioji-shi, Tokyo 192-8577, Japan (e-mail: koyama@soka.ac.jp

Michiko Nishiyama and Kazuhiro Watanabe are with Soka University.

Smart textiles with weaved optical fiber sensors into the textile fabric have been previously fabricated using plastic optical fibers (POF) [11]-[13], microbend fibers [14], and macrobend hetero-core optical fibers [15] with multimode fiber transmission. The optical fiber sensors measure the transmitted optical intensity loss, which can be then used to develop a simple and cost-effective sensing system. However, the transmitted light in multi-mode optical fiber is easily leaked by the curvature given to the fiber line. With weaving the multi-mode optical fiber into the textile, the initial transmission loss may seem to increase and cause a decrease of signal-to-noise ratio. Therefore, the drift for the repeated applied force (20N) is 0.6±0.2% [13] corresponding to 0.12±0.04N which could be insufficient for detecting a small heartbeat movement.

Comparing to their existing multimode fiber optic sensors, hetero-core optical fiber sensors [16] based on single mode transmission have a merit of robustness to the curvature of fiber transmission line and could be improved in reliability. The transmitted light is stable against physical disturbance of the fiber line because of the single-mode transmission. In our previous research, we verified the sensor performances of hetero-core optical ber bending sensors which are highly sensitive to the curvature changes on the sensor portion [17]. The proposed sensors were applied to monitor vital body signs [18]-[19] and motion [20]. The hetero-core optical fiber sensors are incorporated into textiles [21] to fabricate smart clothes with stable single-mode fiber line in which the transmitted light endures physical disturbance. Smart clothes can monitor the vital body signs by incorporating such stable single-mode optical fiber sensors into the textile fabrics.

In this study, we describe the fabrication of a novel smart textile that incorporates a stable single-mode transmission hetero-core optical fiber sensor into the textile fabric. The hetero-core optical fiber was woven together with wool fibers. This allows sensing the shape variations of the textile structure. The proposed smart textile equipped with sensors was sewn on the chest and vital body signs were obtained while the subject was sitting. Apparently, smart clothes can be used to simultaneously monitor respiratory and cardiac frequencies with a single hetero-core optical fiber sensor operating in two frequencies.

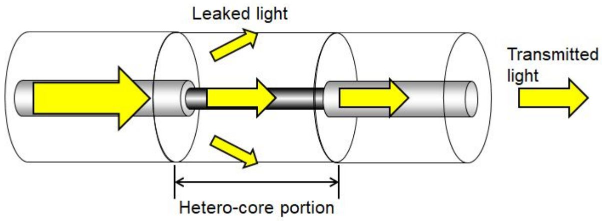
II. Design and fabrication of smart textile using hetero-core optical fiber

A. Hetero-core optical fiber

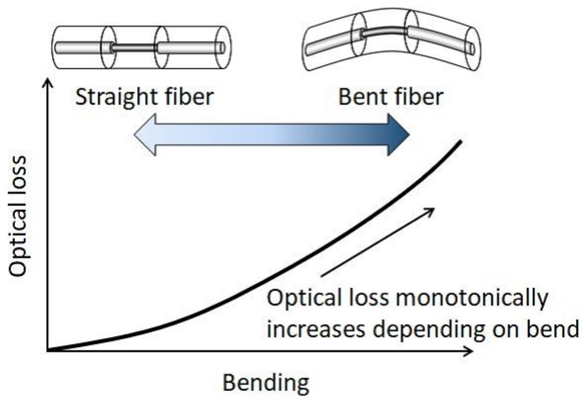
Fig. 1 shows the structure of the hetero-core optical fiber sensor and the principle for macrobending detection. As shown

1558-1748 (c) 2018 IEEE. Translations and content mining are permitted for academic research only. Personal use is also permitted, but republication/redistribution requires IEEE permission. See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JSEN.2018.2847333, IEEE Sensors Journal



(a)



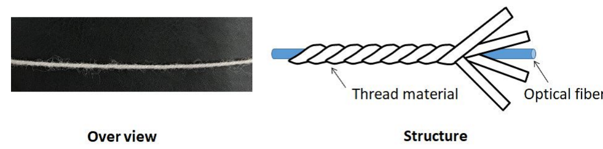
(b)

Fig. 1. Hetero-core optical fiber: (a) structure and (b) working principle.

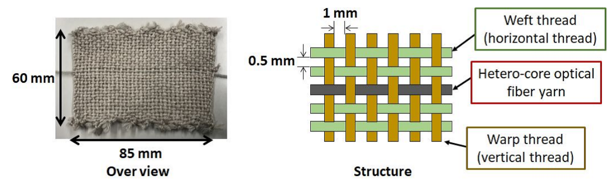
in Fig. 1(a), the hetero-core optical fiber sensor comprise of a standard single-mode fibers (9/125 μm) and short fiber segment (5/125 μm) that is called the hetero-core portion. Transmitted light partially leaks into the cladding at the interface of the hetero-core portion and the variations in the leakage depend on the soft bending of the hetero-core fiber. The hetero-core optical fibers can be operated without compensating for temperature changes. As shown in Fig. 1(b), the optical loss owing to the light leakage monotonically increases when the hetero-core optical fiber is bent [17]. Therefore, the hetero-core optical fiber can detect macrobending by measuring the light intensity. Optical loss characteristics of the hetero-core bent fiber for hetero-core insertion length were verified through experimentation [18]. The linearity of optical loss characteristics with curvature is affected by the insertion length of the hetero-core portion because of the mode coupling at the hetero-core portion. To achieve a linear property of the optical loss characteristics with curvature, the hetero-core fiber sensor needs to have the insertion length less than 2.0 mm. Therefore, we fabricated the hetero-core optical fiber whose insertion length was 1.6 mm in our experiment. In addition, the transmitted light in the hetero-core optical fiber is stable against physical disturbance of the fiber line owing to the single-mode transmission. In our previous work, the body movement caused by pulses [18] and sleep respiration [19] were monitored by monitoring the light intensity in the hetero-core bent fiber.

B. Fabrication of smart textile

The optical fiber was covered with wool yarn, having a diameter of 1.3 mm, to weave hetero-core optical fibers into the textile. Fig. 2(a) shows the structure of the yarn with the hetero-core optical fiber. The loose wool yarn was twisted around the optical fibers before weaving, as shown in Fig. 2(a). The structure prevents the optical fiber from the high curvature that is produced during weaving process. Since the coating diameter of the standard single-mode optical fiber is 250 μm, the diameter of the fabricated yarn is maintained within 1.3 mm. Fig. 2(b) shows the smart textile that is woven with wool and the hetero-core optical fiber yarns on a handloom. As shown in Fig. 2(b), the plain 60 $\times$ 85 mm textile consists of warp and weft. The hetero-core optical fiber is part of the weft. The hetero-core part was centered in the woven textile whose warp has a periodicity of 1 mm.



(a)



(b)

Fig. 2. Smart textile with hetero-core optical fibers: (a) yarn and (b) woven textile.

The smart textile was designed to detect small pressure changes produced by the heartbeat and respiration. Fig. 3 shows the folding of the textile to increase the load sensitivity. As shown in Fig. 3(a), the textile is folded in an oblique direction to softly bend the hetero-core portion in the center of textile and is fixed by stitches to maintain the folded form. Fig. 3(b) shows a cross-sectional view of the folded textile. As shown in Fig. 3(b), the height of the folded textile is 15 mm, which is sufficiently thin to embed the textile in clothes that will not restrain body movements. The hetero-core portion bends when the load is applied because the textile is flexible. Therefore, the load applied to the folded textile is detected by the changes in light intensity.

III. Experimental results and discussion

A. Load characteristics

The load applied onto the proposed smart textile was measured using a digital force gauge (ZP-50N, IMADA, Japan) attached to a mechanical stage. We employed an LED light source unit with a wavelength of 1.31 μm to produce the transmitted light in a single mode fiber. Although the transmitted light from an LD source is more stable than using the LED, we used the LED for a light source in order to realize a simple and cost-effective wearable system. To detect the light intensity changes, the transmitted light was coupled to a photodiode and converted to voltage, and digitalized with an A/D converter. The vertical load was linearly applied onto

1558-1748 (c) 2018 IEEE. Translations and content mining are permitted for academic research only. Personal use is also permitted, but republication/redistribution requires IEEE permission. See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JSEN.2018.2847333, IEEE Sensors Journal

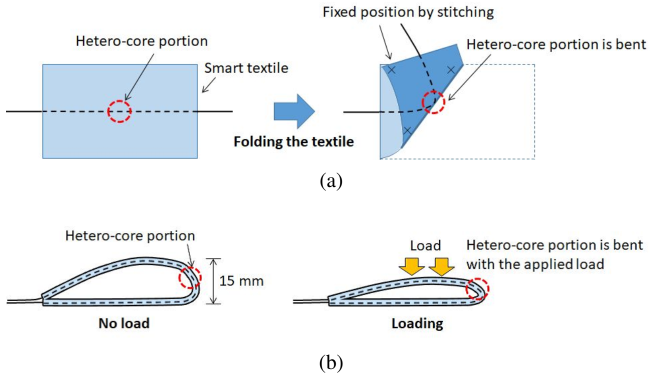


Fig. 3. Detection of small loads using the proposed smart textile: (a) folding the textile and (b) cross-sectional view of the folded textile with load.

the textile using the mechanical stage from 0 to 0.2 N in steps of 0.05 N. Fig. 4 shows the optical loss as a function of load; the optical loss increases with an increase in load. The load cycles were performed onto the textile for 20 times. As shown in Fig. 4, the hysteresis is observed in the optical loss for load and release cycles because of the weaving structure of textile. The optical loss for bending on a hetero-core optical fiber has no hysteresis as investigated in [17]. In release cycle, the optical fiber woven into the textile is more bent by the structure than the fiber in load cycle because the textile maintains the shapes. As shown in Fig. 4, the mean values of optical loss were obtained with the standard deviation as error bars. The maximum standard deviation was 0.024dB and it was 1% for the full scale of 2.3 dB, which corresponds to 0.002N. The results suggest that the smart textile with the hetero-core optical fiber is sensitive to minute load changes. When the folded textile is sewn on the inside of clothes, small distortions due to breathing and heartbeat are detected.

B. Respiratory and cardiac responses

The smart textile with the hetero-core optical fiber sensor was used to measure the heartbeat and respiratory waves in a healthy adult while sitting. Fig. 5 shows the experimental setup. As shown in Fig. 5(a), we used an LED light source with a wavelength of 1.31 μm, a photodiode, and an A/D converter. The light intensity was measured with a sampling frequency of 8 Hz. The smart textile was sewn into the inner side of a wool cardigan. As shown in Fig. 5(b), the textile was positioned onto the lower side of the left chest of the clothes to allow for detecting and transmitting chest movements. The light intensity of the hetero-core optical fibers was monitored in a human subject at rest.

Fig. 6(a) shows the raw data for the optical loss response, where the wave was considered to fluctuate owing to both heartbeat and respiration. As shown in Fig. 6(a), respiration consists of inhaling and exhaling, which are shown in the optical loss wave. There are also small fluctuations presumably owing to the heartbeat. To extract these components, frequency spectrum analysis was performed using FFT. Fig. 6(b) shows the frequency spectrum, in which the main frequency peak at 0.25 Hz corresponds to the respiration component. In addition, the spectrum has a small peak in the range 0.84–1.57 Hz corresponding to a heart rate of 50–96 times per minute. The range is attributed to the distortion of the clothes owing to the heartbeat which is less in comparison to that of breathing.

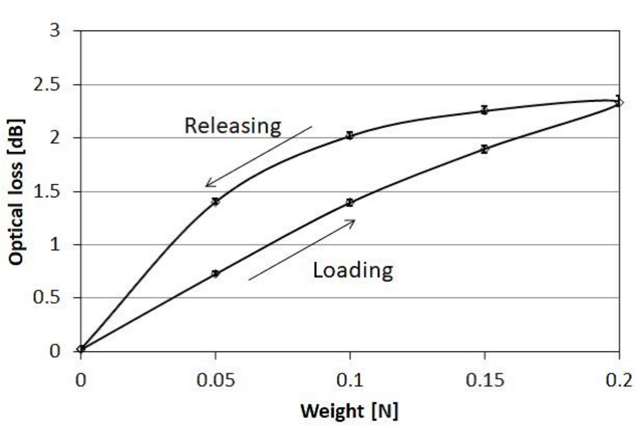


Fig. 4. Optical loss vs the load in the textile.

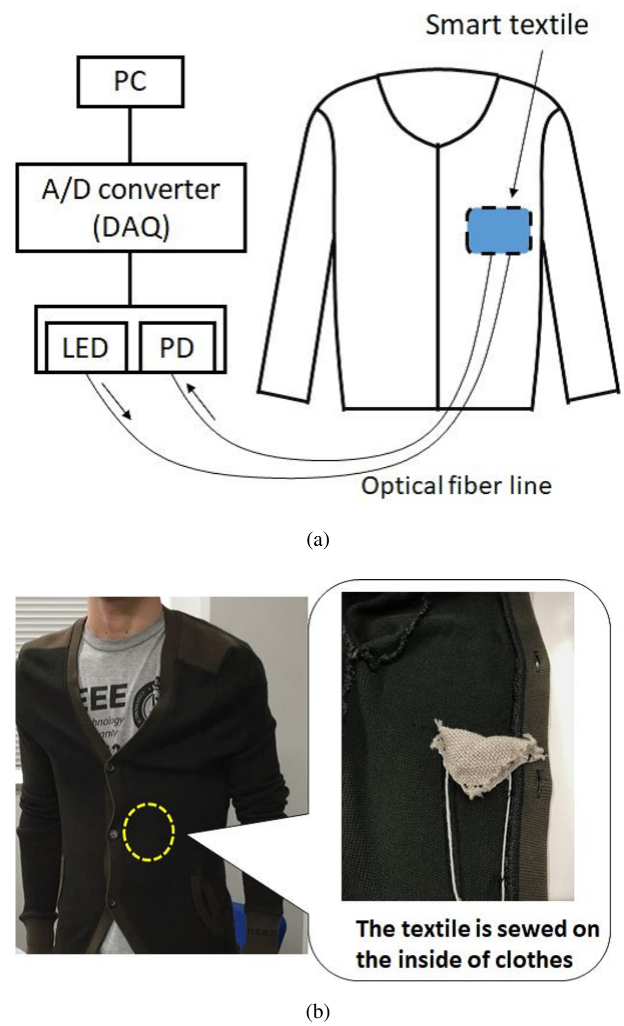
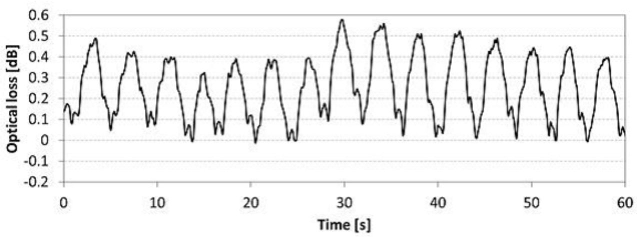


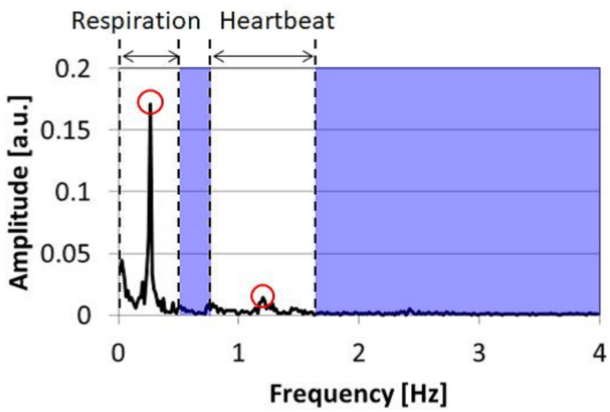
Fig. 5. Experimental setup for the simultaneous monitoring of heartbeat and respiration: (a) system configuration and (b) position of the textile.

1558-1748 (c) 2018 IEEE. Translations and content mining are permitted for academic research only. Personal use is also permitted, but republication/redistribution requires IEEE permission. See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.

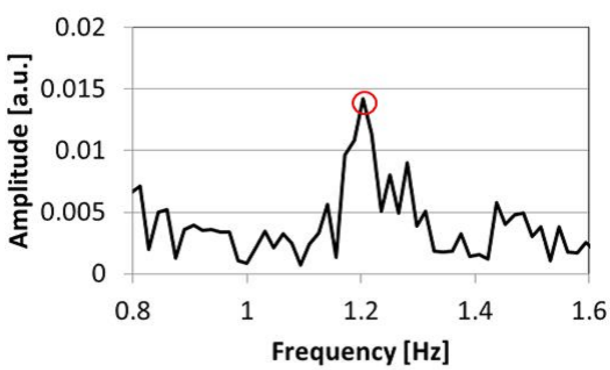
This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JSEN.2018.2847333, IEEE Sensors Journal



(a)



(b)



(c)

Fig. 6. Sensor response for (a) raw data acquired with the proposed textile, (b) respective frequency spectra, and (c) enlarged view of the heartbeat-related spectrum.

Fig. 6(c) shows an enlarged view of the spectrum including the range 0.84–1.57 Hz. As shown in Fig. 6(c), the peak at 1.2 Hz corresponds to a heartbeat rate (HR) of 72 times per minute although the amplitude was smaller than that of breathing. The results suggest that the dominant component in the optical loss wave can be extracted by picking up the maximum peak in the frequency spectrum range of interest. Bandpass filtering for the acquired optical loss signal allows extracting the individual respiratory and cardiac components.

The signals were then filtered using software developed in Python. Two bandpass filters for the frequency ranges of 0.05–0.5 Hz and 0.84–1.57 Hz were used to obtain the respiratory and cardiac components, respectively. Fig. 7(a) shows the respiratory signal after the first bandpass filtering of the raw data.

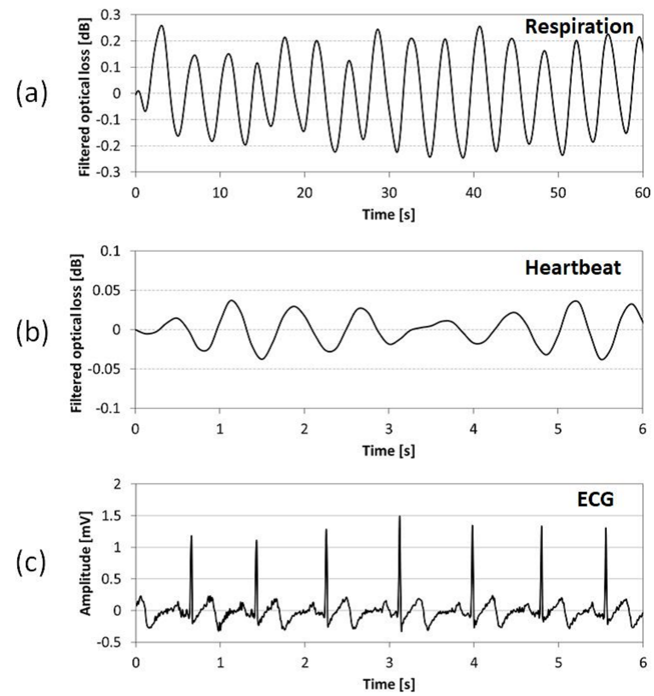


Fig. 7. Filtered (a) respiratory, (b) heartbeat, and (c) ECG signals; the latter is for reference.

To verify the respiratory rate, the number of breaths per minute was manually counted by observing how many times the chest rises in a recorded video. The respiration waveform in Fig. 7(a) agrees with the number of respiration times. Fig. 7(b) shows the cardiac wave obtained after the second bandpass filtering of the raw data. To evaluate the cardiac frequency, the electrocardiogram signal was simultaneously obtained by a commercially available monitoring device (BItalino revolution board kit, PLUX Co., Portugal), as shown in Fig. 7(c). The cardiac rate was counted by using the optical loss variation because the two waves are in good agreement in terms of phase. In contrast, the amplitude is low and is approximately 3 s in Fig.7 (b). The relative amplitude is considered smaller when compared with respiration because the small pressure by the garment at the chest area decreases during exhalation. These small variations are detected by the time differentiation of the optical loss variation.

To confirm the capability of monitoring vital signs, seven monitoring trials were performed in which the subject put on and off the smart clothes. The respiration rate (RR) and HR were estimated using the maximum peak in the frequency range of interest; they are expressed in beats per minute (bpm). The reference values were obtained with the above mentioned procedure. Fig. 8 shows the errors obtained from the difference between the calculated rate and reference values. The RR and HR were successfully extracted within the 4 bpm error by the fiber optic sensor system. The existing belt type sensor based on microbend technique detects a heartbeat rate within the accuracy of ± 2 bpm[14]. The performance of proposed textile as shown in Fig. 8 is almost comparable to that of the belt sensor. Clearly, the textile has the capability to simultaneously

1558-1748 (c) 2018 IEEE. Translations and content mining are permitted for academic research only. Personal use is also permitted, but republication/redistribution requires IEEE permission. See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JSEN.2018.2847333, IEEE Sensors Journal

monitor vital signs. The results suggest that the clothes with the novel textile can monitor the vital signs of the user.

We focused on the capability of the proposed textile to simultaneously monitor heartbeat and respiration, while it is being worn. The RR and HR of the subject were calculated by the maximum frequency components that were obtained by filtering the raw data. The heartbeat detection system crucially relies on the sensor textile's position on the clothes. When the sensor textile placement is changed, it is difficult to detect heartbeat because the chest movement due to the heartbeat is so small. Thus, the sensor textile needs to be placed on the chest close to heart in order for the textile to be sensitive to the chest movements occurred by the heartbeat. In practical use, when different users wear the clothes, the textile will be unable to monitor the vital signs because of the misalignment of the textile in the clothes. Currently, the best place on the cloth for the textile to monitor vital signs, especially heartbeat, depends on body size.

In addition, the amplitude of heartbeat component in the optical intensity waves depends on the preload which is applied to the sensor textile fixed to the clothes. The user's performing activities such as talking and moving his limb cause the decrease in the preload and some artifact waves which appear as spurious frequencies for heartbeat component in the spectrum. They could prevent the system from finding the correct peak corresponding to a heartbeat rate in the frequency spectrum range of measured waves. Therefore, in order not to change the preload, the proposed system should be used with the user sitting or standing.

The maximum curvature limit of hetero-core optical fiber was verified in the previous work [18]. The hetero-core optical fiber can be used in the radius of curvature of 6 mm without the fiber failure. The structure of proposed textile is possibly bent over the limit, as shown in Fig. 3. In practical terms, the hetero-core optical fiber is broken when the load applied to the textile exceeds 25 N. Therefore, the textile sensor has to be used in the range of loads.

The proposed smart textile could be combined with wearable systems for long-term vital signs monitoring. A wireless system with a Bluetooth device and low power consumption of 100 mW per channel is commercially available [22], whereas the LED/PD device used in this study had a power consumption of 1 W.

IV. Conclusion

In this study, we proposed a novel smart textile for monitoring heartbeat and respiration, which was designed by incorporating a hetero-core optical fiber sensor into textile fabrics. The hetero-core optical fiber sensor was woven together with the wool fibers to monitor the shape variations in the textile structure. The fabricated smart textile is useful to develop a simple and cost-effective system. The textile was tested to ensure sensitivity to minute load changes. A standard deviation of 1% was obtained at the full scale of 2.3 dB that corresponds to 0.2 N. The textile was sewn on the chest to simultaneously monitor heartbeat and respiration of a human subject while sitting. The heartbeat and respiratory frequency were measured by a hetero-core fiber sensor. The calculated vital signs from the peak frequency agreed with those from a commercial physiologic monitoring device and video recordings. In addition, seven monitoring trials were performed where the subjects were asked to put on and off the smart cloth to confirm the capability of monitoring vital signs. The rates were successfully extracted within the error of 4 bpm using a fiber optic sensor system. In conclusion, the smart textile can monitor vital signs of humans while sitting and standing.

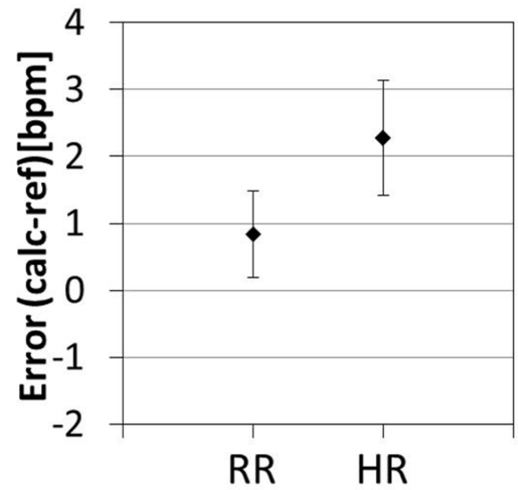


Fig. 8. Error of vital signs rate monitored by the fiber optic sensor system and reference rates.

V. Acknowledgment

This work was supported by JSPS KAKENHI Grant Number JP 17K18185.

References

[1] R. Paradiso, G. Loriga and N. Taccini, "A wearable health care system based on knitted integrated sensors," *IEEE Transactions on Information Technology in Biomedicine*, vol. 9, no. 3, pp 337–344, Sept. 2005.

[2] G. Cho, K. Jeong, M. J. Paik, Y. Kwun and M. Sung, "Performance Evaluation of Textile-Based Electrodes and Motion Sensors for Smart Clothing," *IEEE Sensors Journal* vol. 11, no. 12, pp. 3183–3193, Dec. 2011.

[3] M. A. Yokus, R. Foote and J. S. Jur, "Printed Stretchable Interconnects for Smart Garments : Design, Fabrication, and Characterization," *IEEE Sensors Journal*, vol. 16, no. 22, pp. 7967–7976, Nov. 2016.

[4] A. Grillet et al., "Optical Fiber Sensors Embedded Into Medical Textiles for Healthcare Monitoring," *IEEE Sensors*, vol. 8, no. 7, pp. 1215–1222, Jul. 2008.

[5] J. Witt et al., "Medical Textiles With Embedded Fiber Optic Sensors for Monitoring of Respiratory Movement," *IEEE Sensors Journal*, vol. 12, no. 1, pp. 246–254, Jan. 2012.

[6] Fajkus M, Nedoma J, Martinek R, Vasinek V, Nazeran H, Siska P. , "A Non-Invasive Multichannel Hybrid Fiber-Optic Sensor System for Vital Sign Monitoring," *Sensors*, vol. 17, no. 1, pp. 1–17, 2017.

[7] A. Silva, F. Gonalves, P. Mendes, J. H. Correia, "PVC formulation study for the manufacturing of a skin smart structure based in optical fiber elements," *J. Polymers Adv. Technol.*, vol. 23, no. 2, pp. 220–227, 2010.

[8] J. P. Carmo, A. M. F. da Silva, R. P. Rocha and J. H. Correia, "Application of Fiber Bragg Gratings to Wearable Garments," *IEEE Sensors Journal*, vol. 12, no. 1, pp. 261–266, Jan. 2012.

[9] C. Massaroni et al., "Design and Feasibility Assessment of a Magnetic Resonance-Compatible Smart Textile Based on Fiber Bragg Grating Sensors for Respiratory Monitoring," *IEEE Sensors Journal*, vol. 16, no. 22, pp. 8103–8110, Nov. 2016.

1558-1748 (c) 2018 IEEE. Translations and content mining are permitted for academic research only. Personal use is also permitted, but republication/redistribution requires IEEE permission. See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JSEN.2018.2847333, IEEE Sensors Journal

[10] M. Ciocchetti et al., "Smart textile based on fiber Bragg grating sensors for respiratory monitoring: Design and preliminary trials," *Biosensors*, vol. 5, no. 3, pp. 602–615, Sep. 2015
[11] A. Masuda, T. Murakami, K. Honda, and S. Yamaguchi, "Optical Properties of Woven Fabrics by Plastic Optical Fiber," *J. Text. Eng.*, vol. 52, pp. 93–97, 2006.
[12] M. Rothmaier, B. Selm, S. Spichtig, D. Haensse, M. Wolf, "Photonic textiles for pulse oximetry," in *Opt. Exp.*,vol. 16, no. 17, pp. 12973-12986, Aug. 2008.
[13] M. Rothmaier, M. P. Luong, F. Clemens, "Textile pressure sensor made of flexible plastic optical fibers," *Sensors*, vol. 8, pp. 4318–4329, 2008.
[14] X. Yang, Z. Chen, C. S. M. Elvin, L. H. Y. Janice, S. H. Ng, J. T. Teo, R. Wu, "Textile Fiber Optic Microbend Sensor Used for Heartbeat and Respiration Monitoring," *IEEE Sensors Journal*, vol. 15, no. 2, pp. 757–761, Feb. 2015.
[15] K. Alemdar, S. Likoglu, K. Fidanboylu and O. Toker, "A novel periodic macrobending hetero-core fiber optic sensor embedded in textiles," *2013 8th International Conference on Electrical and Electronics Engineering (ELECO)*, Bursa, 2013, pp. 467-471.
[16] K. Watanabe, K. Tajima and Y. Kubota, "Macrobending characteristics of a hetero-core splice fiber optic sensor for displacement and liquid detection," *IEICE Trans. Electron.*, vol. E83-C, no. 3, pp. 309–314, 2000.
[17] H. Sasaki, Y. Kubota and K. Watanabe, "A hetero-core splice fiber optic displacement sensor and the accuracy evaluation," *Transactions of the Society of Instrument and Control Engineers*, vol. 40, no.10, pp.981–987, 2004.
[18] M. Nishiyama, M. Sonobe and K. Watanabe, "Unconstrained pulse pressure monitoring for health management using hetero-core fiber optic sensor," *Appl. Opt.*, vol. 52, no. 16, pp. 3876–83, 2013.
[19] M. Nishiyama, M. Miyamoto and K. Watanabe, "Respiration and body movement analysis during sleep in bed using hetero-core fiber optic pressure sensors without constraint to human activity," *J. Biomedical Opt.*, vol. 16, no. 1, pp. 1–7, 2011.
[20] Y. Koyama, M. Nishiyama and K. Watanabe, "A Motion Monitor Using Hetero-Core Optical Fiber Sensors Sewed in Sportswear to Trace Trunk Motion," *IEEE Transactions on Instrumentation and Measurement*, vol. 62, no. 4, pp. 828–836, 2013.
[21] Y. Koyama, M. Nishiyama and K. Watanabe, "Smart Textile with Plain Weave Structure Using Hetero-Core Optical Fiber Sensor and Wool Threads," *2018 International Conference on Intelligent Autonomous Systems (ICoIAS' 2018)* , Singapore, 2018.
[22] [Online]. Available: http://www.core-system.jp/doc/catalog/i-Line_BOX8B.pdf

1558-1748 (c) 2018 IEEE. Translations and content mining are permitted for academic research only. Personal use is also permitted, but republication/redistribution requires IEEE permission. See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.