

Detection of Apnea Signal using UWB Radar based on Short-Time-Fourier-Transform

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국소 푸리에 변환 기반 레이더 신호를 활용한 무호흡 검출

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Abstract Recently, monitoring respiration of people has been of interest using non-invasive method. Among the vital signals usually used for indicating health status, non-invasive and portable device based monitoring respiratory status is practically useful and enable one to promptly deal with abnormal physical status. This paper proposes the approach to real-time detection of apnea signal based on Short-Time-Fourier-Transform(STFT). Contrary to the analysis of a signal in frequency domain using Fast-Fourier Transform, this paper employs Short-time-Fourier-Transform so that frequency response can be analyzed in short time interval. The respiratory signal is acquired using UWB radar sensor that enables one to obtain respiration signal in contactless way. Detection of respiratory status is carried out by analyzing frequency response, and classification of respiratory status can be provided. In particular, STFT is employed to analyze respiratory signal in real-time, leading to effective analysis of the respiratory status in practice. In the case of existence of noise in the signal, appropriate filtering process is employed as well. The proposed method is straightforward and is workable in practice to analyze the respiratory status of people. To evaluate the proposed method, experimental results are provided.

요약 최근 비침투 또는 비접촉 방식을 활용한 호흡상태 관찰에 대한 관심이 높아지고 있다. 여러 가지 많은 생체신호들 중 호흡신호를 활용하여 건강상태를 점검하는 것은 비정상적인 건강 상태에 대한 신속한 대응을 가능하게 해 준다. 본 논문에서는 국소 푸리에 변환을 활용한 실시간 무호흡 상태 검출에 대한 방법을 제시한다. 기존의 고속 푸리에 변환을 활용한 신호해석과 달리, 본 논문에서는 국소 푸리에 변환을 사용하여 짧은 신호 구간에서의 주파수 응답을 분석한다. 본 연구에서 호흡 신호는 비접촉 방식을 활용하였으며, 초광대역 레이더 모듈을 활용하여 신호를 획득하였다. 국소 푸리에 변환을 활용하여 호흡 상태를 검출한 후, 검출 결과에 따라 호흡 상태에 대한 분류가 가능하다. 특히 국소 푸리에 변환은 실시간으로 호흡 상태에 대한 주파수 분석이 가능하도록 하였다. 호흡신호에 잡음이 존재할 경우를 대비하여 적절한 필터링 알고리즘이 적용되었다. 본 논문에서 제안하는 방법은 직관적으로 구현이 가능하고, 실질적으로 사람의 호흡상태에 대한 분석이 가능하도록 해준다. 제안한 방법을 검증하기 위해 호흡신호를 활용한 실험결과를 제시한다.

Keywords : Respiration, Apnea, Short-Time-Fourier-Transform, UWB Radar Sensor, Respiratory Status

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1. Introduction

For successful monitoring patients on hospital wards, recording vital signals is considered one of the most important tasks. In general, vital signals are composed of respiratory rate, pulse rate, blood pressure and body temperature. However, there has been reported that respiratory rate has not been paid attention compared to other three vital signals [1]. Abnormal respiration, in case of apnea, can lead to abnormal lung condition, heart disease, lack of oxygen in blood circulation, etc. As stated above, abnormal respiration can cause severe health problem. Thus, numerous work has been carried out for prevention or treatment of apnea. If apnea can be detected quantitatively, it can be possible to reduce probability of severe health problem. To detect abnormal respiratory status, monitoring system is desired. Unfortunately, monitoring system is usually very expensive, so it is difficult to apply the system to people who are not in hospital wards. Among the vital signs stated above, measurement of respiration is simpler and straightforward compared to measurement of other vital signals. To analyze respiratory status, there has been extensive research activities [2]. Respiration signal can be acquired using two primary methods, the one is contact-based one and the other one is contactless-based one. The former and the latter one are also called invasive and non-invasive method, respectively. In this paper, to avoid confusion, we will use contact and contactless based method. In general, in hospital wards, temperature, blood pressure, electrocardiogram, heart rate and respiratory rate are measured on daily basis [3]. In the past a few years, apnea has been considered one of the most dangerous respiratory disorders because it can lead to cardiovascular problem and other severe illnesses. Therefore, real time monitoring respiratory status of people is one of the solutions to prevent the severe health problem.

Contact based measurement of respiration can be conducted in environments of hospital, and the measurement can be carried out with high accuracy with stable result of the measurement. However, it sometimes suffer from the measurement itself because the health status of patients. Patients usually have difficulty in measuring respiratory rate because of lack of knowledge of measuring conditions. In addition, if patients have difficulties in generating respiration signal, acquisition of the signal can provided unreliable results that lead to wrong diagnosis or prescription. To alleviate the limitations of contact based measurement, contactless based measurement has been of interest in a few years. According to the trend of miniaturization of health-care device, portable and contactless device to measure respiration signal can be an appropriate alternative to the contact based one. Contrary to the contact based measurement, contactless based one can acquire sufficient information about respiratory status of people without constrained environment for the measurement. Contactless based measurement can be carried out using audio generation, temperature measurement, vision device or distance based measurement [4,5]. Portable and contactless devices are generally less expensive than the contact based ones in addition to the easiness of use [6]. In this paper, we propose the approach to detection of apnea using UWB radar. Similarly to the previous work, the respiratory signal is analyzed in frequency domain. However, in the previous work, status of apnea could be detected be analyzing after measuring whole signal that was measured during 60 seconds. In this work, once apnea appears, it is detected based on short-time-Fourier-transform (STFT). The overall flow of this work is shown in Fig. 1.

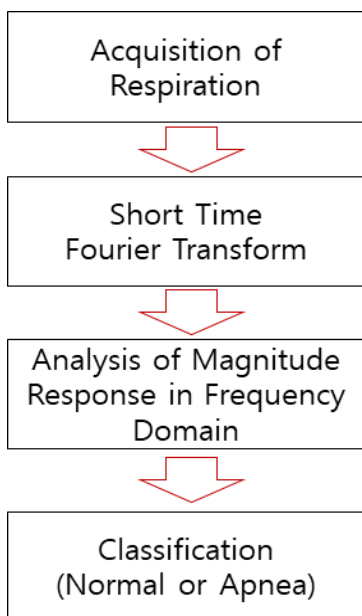


Fig. 1. Overall flow diagram of the proposed approach

Acquisition of respiration is carried out using UWB radar sensor. The sensor measures the distance from it to the chest of a target person. In particular, it measures the distance in the cases of exhalation and of inhalation. If the respiration is normal, the distance shows sinusoidal shape according to the exhalation and the inhalation. But in the case of normal respiration with some activities, it does not have sinusoidal shape any more because periodicity of the waveform may not preserved. To analyze the signal in more efficient way, analysis in frequency domain is more suitable than the analysis in time domain. Thus, in this work, respiratory signal is analyzed in frequency domain. The magnitude response is calculated in frequency domain, and the respiratory status is determined. The determination enables one to classify the respiratory status.

Rest of the paper is organized as follows. In the next section, measurement of the respiratory signal and denoising process are introduced. In section 3, the proposed approach is detailed followed by experimental results in section 4. Section 5 concludes this paper.

2. Measurement and Preprocessing

As mentioned in the previous section, respiration signal is acquired using ultra wide-band radar. The radar is able to perform monitoring respiration status by measuring distance from the radar device to the body. The UWB radar generates a signal and transmits it to measure the distance between the radar and human chest that can be in the status of exhalation and inhalation by measuring the time of reflection of radar signal. Normal breathing causes the chest to move regularly, and abnormal one generates irregular waveform. The distance is measured in both cases exhalation and inhalation. In general, normal respiration is represented as approximate sinusoidal shape. Abnormal respiration (apnea in this work) does not generate sinusoidal shape. Both signals are depicted in Fig. 2. UWB radar provides respiration signal, but the acquired signal sometimes includes noise. Thus preprocessing of the signal is also desired in practice. In Fig. 2, the signals are already denoised. To reduce or remove noise obtained in the obtained respiration signal, combined filter are applied. Combined filter is composed of Savitzky-Golay filter and Median filter [7].

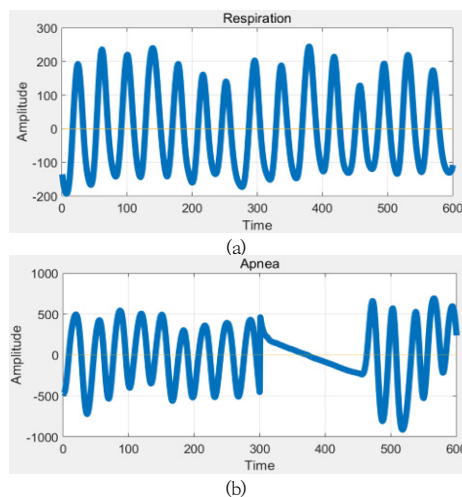


Fig. 2. Respiration signal obtained using UWB radar (a) Normal respiration (b) Respiration contains apnea status.

These filters can alleviate limitations of each filter, and the work showed better performance of noise reduction. Denising process can be represented as follows.

$$r(t) = r_f(t) + n(t) \quad (1)$$

$$\hat{r}(t) = r(t) \otimes h(t) \quad (2)$$

where $r(t)$, $r_f(t)$ and $n(t)$ are defined as obtained signal, original signal and noise signal, respectively. Denoised signal $\hat{r}(t)$ can be achieved by applying combined filter $h(t)$ to $r(t)$. $h(t)$ is a filter that combines the Savitzky-Golay filter and Median filter. Once preprocessing is complete, the respiration signals are analyzed in frequency domain. However, in the previous work [8], respiratory status could be analyzed once the whole signal is obtained. In practice, it is sometimes late to prevent or diagnose the severe illness resulted from apnea. In the next section, analysis and detection of abnormal respiration is carried out using STFT.

3. Proposed Approach

As mentioned in the previous section, respiration signal is acquired using UWB radar. Once acquisition starts, frequency response is recorded in real-time using STFT. If we use Fast Fourier Transform (FFT), in frequency domain, we cannot analyze any information related to time. However, in practice, we need to detect apnea in real time. STFT enable one to analyze frequency response that changes over time [9]. Whole signal is segmented using window whose size can be determined according to the applications. Fourier transform is carried out for the segment of the signal, and the result of STFT can be represented as follows.

$$R(\omega, k) = \int_{-\infty}^{\infty} r(t)w(t-k)e^{j\omega t} dt \quad (3)$$

where $r(t)$ is a respiration signal and $w(t)$ is a window (rectangular shaped window). $w(t)$ moves over the signal and the size of it determines the size of segment of a signal. In other words, the result of STFT is Fourier transform of the segment of a signal $r(t)w(t)$. There exists trade-off between large size and small size of window. The size of window affects capability of analysis of localization details of a signal in frequency domain. Since the present work chiefly deals with discrete signal, Discrete STFT (DSTFT) is used as written as

$$R[n, \omega] = \sum_{k=-\infty}^{\infty} r[n]w[n-k]e^{-j\omega n} \quad (4)$$

where $r[n]$ and $w[n]$ are discretized signal of $r[t]$ and $w[t]$, respectively. STFT enables us to detect apnea status when using UWB radar. There are many types of window that can be used to localize the signal that is to be transformed to frequency domain. In this work, Hamming window is employed. The type of window is important to achieve accurate analysis result, however, this paper does not discuss about the window because it is beyond the main topic of this paper. Next section provides experimental results that substantiate the proposed approach.

4. Experimental Results

Concerning all above, this section provides the experimental results to substantiate the proposed approach. As shown in Fig. 2, respiration signal is obtained using UWB radar sensor (manufactured by NOVELDA X4). Since the present work is conducted for practical applications, respiration is categorized as only two groups, the one is normal and the other is abnormal one. In particular, normal signals are composed of two subgroups, the one is respiration without activity and the other one is respiration during speech activity. Abnormal respiration is apnea in this

work. Since it is difficult to obtain apnea signal from real patients, testee people emulates apnea in normal environment. Normal signal with speech activity is totally different from the one without activity from visual perspective. As shown in Fig. 3, normal respiration during speech activity shows the plot in time domain.

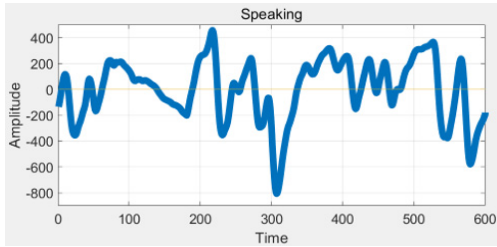


Fig. 3. Normal respiration during speech activity

Since it is difficult to classify normal and abnormal signals in time domain, transformation of a signal is desired. In the previous work [7], FFT is employed. However, FFT can provide frequency response once whole signal data is obtained. In other words, frequency response of short time interval is difficult to be obtained only using FFT. In addition, the limitation is existed in that status of respiration can not be detected in real time. Therefore, this paper suggests employing STFT to detect apnea in real time. The number of collected respiration signals is about 700. Respiration is obtained for 60seconds, and 600 samples are obtained. In other words, sampling rate is 10Hz. Overall flow of the experiment is shown in Fig. 4. Once the signals are transformed using STFT, detection of apnea is appropriately carried out. Once apnea starts, frequency response (magnitude response) shows high variation as shown in Figs 4, 5 and 6.

In Fig. 4, apnea occurs during 15seconds (from 45second to 60second). In Fig 5 and in Fig. 6, apnea occurs during 15seconds as well. Apnea in Fig. 5 starts at 30second and in Fig. 6 starts at 40second. Frequency response is exactly matched to the moment of apnea in time domain.

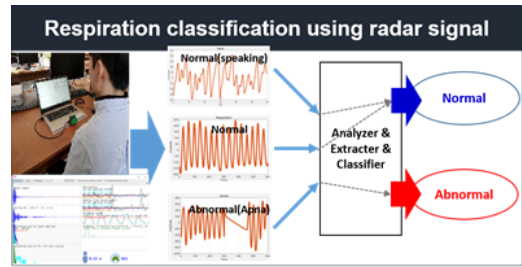


Fig. 4. Overall flow of the experiment.

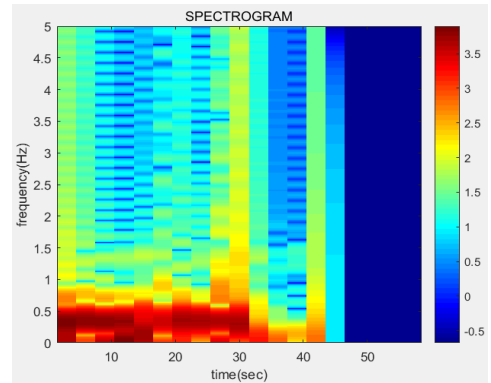


Fig. 5. STFT of apnea signal. Apnea occurs at 45second and persists for 15seconds.

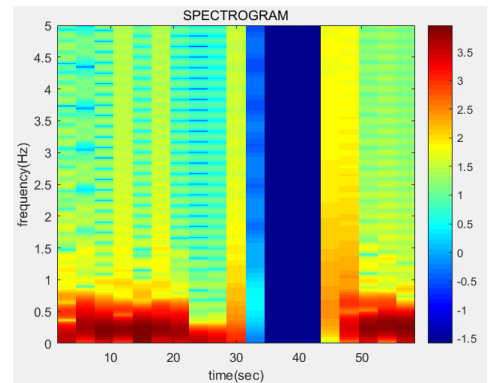


Fig. 6. STFT of apnea signal. Apnea occurs at 30second and persists for 15seconds.

The experiments verifies that the result of STFT exactly detects the moment of apnea. In the case of normal respiration, STFT shows low variation compared to the one shown in Figs 5, 6 and 7. Fig. 8 shows the result of normal respiration.

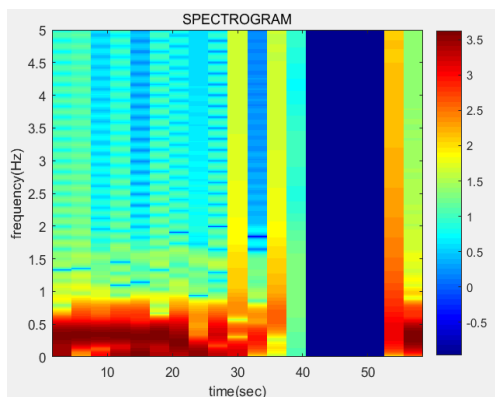


Fig. 7. STFT of apnea signal. Apnea occurs at 40second and persists for 15seconds.

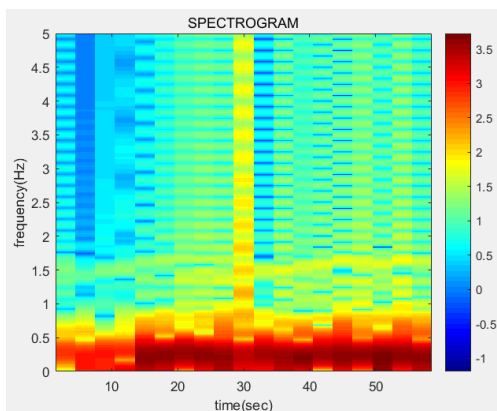


Fig. 8. STFT of normal respiration.

As shown in the experiments, classification of the respiratory status can be successfully performed in practice. To evaluate performance and accuracy of the present work, comparison needs to be carried out. However, to the best knowledge of the authors, there has been few work related to respiratory signal analysis. In particular, detection of the moment of apnea has not been performed compared to the work of measurement of the number of respiration or other vital signals[10, 11]. As shown in Table 1, the estimated duration of apnea and the real duration are compared. Accuracy is simply calculated based on the difference between the estimated duration and the real duration.

Table 1. Accuracy of estimation of apnea

Actual apnea duration (sec)	Estimated apnea duration (sec)	Accuracy(%)
45 ~ 60	45.21 ~ 60.19	99.6
30 ~ 45	30.17 ~ 45.34	92.5
40 ~ 55	40.65 ~ 55.69	98.8

5. Conclusion

In this paper, we proposed the approach to detection of apnea that is one of the most severe obstructive breathing. Proposed method can be applied to prevention of health problems that is resulted from breathing problem. Contrary to using FFT to classify respiratory status, STFT is more suitable to detect and classify respiratory status in real time. In the future, we plan to propose the approach to classification of abnormal respiration with more specific categories. In addition future work will include classification of various types of respiration using deep learning algorithm.

References

- [1] M. A. Cretikos, R. Bellomo, K. Hillman, J. Chen, S. Finfer and A. Flabouris, "Respiratory rate: the neglected vital sign", *Medical Journal of Australia*, Vol. 188, No. 11, pp. 657-659, June. 2008. DOI : <https://doi.org/10.5694/j.1326-5377.2008.tb01825.x>
- [2] F. Q. AL-Khalidi, R. Saatchi, D. Burke, (2011) H. Elphick and S. Tan, "Respiration rate monitoring methods: A review", *Pediatric Pulmonology*, Vol. 46, No. 6, pp. 523-529, June. 2011. DOI : <https://doi.org/10.1002/ppul.21416>
- [3] Y. Khan, A. E. Ostfeld, C. M. Lochner, A. Pierre and A. C. Arias, "Monitoring of vital signs with flexible and wearable medical devices", *Advanced Materials*, Vol. 28, No. 22, pp. 4373-4395, Feb. 2016. DOI : <https://dx.doi.org/10.1002/adma.201504366>
- [4] G. Ossberger, T. Buchegger, E. Schimback, A. Stelzer and R. Weigel, "Non-invasive respiratory movement detection and monitoring of hidden humans using ultra wideband pulse radar", *Proceedings of International Workshop on Ultra Wide band Systems Joint with Conference on Ultra Wideband Systems and Technologies*,

IEEE, Kyoto, Japan, pp. 395-399, Aug. 2004.

DOI : <https://dx.doi.org/10.1109/UWBST.2004.1321003>

- [5] K. S. Tan, R. Saatchi, H. Elphick and D. Burke, "Real-time vision based respiration monitoring system", *Proceedings of 7th International Symposium on Communication Systems, Networks & Digital Signal Processing*, IEEE, Newcastle upon Tyne, UK, pp. 770-774, 2010.
- [6] W. Daw, R. Kingshott, R. Saatchi, D. Burke, A. Holloway, J. Travis, R. Evans, A. Jones, B. Hughes and H. Elphick, "Medical Devices for Measuring Respiratory Rate in Children : a Review", *Journal of Advances in Biomedical Engineering and Technology*, Vol. 3, No. 1, pp. 21-27, Mar. 2016.
DOI : <http://dx.doi.org/10.15379/2409-3394.2016.03.01.04>
- [7] J. Chen, P. Jönsson, M. Tamura, Z. Gu, B. Matsushita and L. Eklundh, "A simple method for reconstructing a high-quality NDVI time-series data set based on the Savitzky-Golay filter", *Remote Sensing Environment*, Vol. 91, No. 3-4, pp. 332-344, June. 2004.
DOI : <https://doi.org/10.1016/j.rse.2004.03.014>
- [8] S. Kim, C. Hwang, J. Kim, C. Park and D. Lee, "Similarity based classification and detection of Respiratory Status in Frequency Domain", *Proceedings of 7th International Conference on Signal Image Processing and Multimedia*, SIPM, Sydney, Australia, pp. 1-9, Mar. 2019.
- [9] N-G. Jung, C-M. Park, J-B. Lee and Y. Park, "A study on the application of TEO and STFT signal processing techniques for detection of electric railway contact loss", *Transactions of the Korean Institute of Electrical Engineers*, Vol. 67, No. 11, pp. 1530-1535, Nov. 2018.
DOI : <http://doi.org/10.5370/KIEE.2018.67.11.1530>
- [10] Y-C. Kim, M-T. Cho, C-S. Lee, K-S. Kim, M-G. Choi and H-J. Joo, "Acceleration sensor processing algorithms for monitoring sleep patterns", *Proceedings of Annual Conference of Korea Academia-Industrial Corporation Society (KAIS)*, KAIS, Gangwon, South Korea, pp. 373-375, May. 2015.

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