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Single-Tone Doppler Radar System for Human Respiratory Monitoring

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***Abstract*— Human respiration activities can be identified from the chest wall movement. In developing a non-contacting sensor for human respiration, the chest wall movement can be detected as a Doppler shift. Therefore, the Doppler radar is potential to be implemented for the non-contacting sensor previously mention. In this paper, the Single-Tone Doppler radar which operates at 10 GHz has been studied and proposed for detecting human respiration. The simulation experimental is performed for investigating the capability of the proposed method in detecting the human respiration parameter such as respiration rate and respiration amplitude. The results show that the proposed method is capable to extract the human respiration parameter.**

Keywords—Doppler radar, continuous wave, small displacement, respiration

I. INTRODUCTION

Respiration is one of a sign for monitoring human activities. In the medical field, rate and pattern monitoring of human respiration can be used to help in diagnosing pulmonary illness. In the hospital, respiration is mostly detected by a medical device equipment. For example, a silica-nanoparticle thin film is used for developing a sensor chip for respiration. Electrical sensors are widely used also [1].

The pulmonary volumes and capacities of human respiration vary which depends on the size of the lungs, the power of breathing, and the way of breathing. The longer activities, the higher breathing frequency are caused by the strong body movements which are using a lot of oxygen in the muscles which energize the activity [2]. The human respiration model has been studied related to the factors above. Therefore, rate and pattern of human respiration can be used to observe the condition of human health.

There are several concerns in choosing medical measurement devices. In addition to the accuracy of the measurement result, patient comfort in the use of such device, minimal distress, and hygienic measurement are also several matters of the concern, especially for long-term monitoring [3], [4]. Respiratory monitoring can be categorized as a contact or non-contact method. A non-contact method is potentially satisfied all the mention concerns above. This paper analyses the development of a non-contact method for human respiratory monitoring which is based on the radar system.

Radio and detection ranging (Radar) with the high resolution is needed for detecting human respiration. Inspired by an Ultra-Wide Band (UWB) system which can to obtains the high-resolution measurement, several types of research of a UWB radar for detecting human vital signs have been conducted [5], [6]. The experiment results in [5] show that the detection of heart-beat has a very suitable with an Electrocardiograph (ECG) measurement. Meanwhile, the large bandwidth is used, it gives several disadvantages, such as the complexity of its hardware and the problems of its interference. Frequency Modulation Continuous Wave (FMCW) radar system has been investigated for detecting human respiration also [7].

A radar consists of the transmitter and receiver parts. The transmitter output is a radio-frequency wave with a certain frequency which propagates to the target. The receiver is designed to detects the Doppler shift in echoes reflected from moving targets. For example, speedometers, Air Traffic Control (ATC), and detecting small displacement [8]. The Doppler radar is potential to be implemented by using a single-frequency signal which has an advantage for a low bandwidth usage and simple circuit. This paper is focused on the development of a Single-Tone Doppler radar system for human respiratory monitoring. A Single-Tone means that the radar transmits the single-frequency signal by extracting Doppler feature from the target only.

Human respiration activities can be identified by the chest wall movement which is related to the inhale and exhale activities. In the radar system point of view, human chest wall movement which is caused by respiration activities is such a small displacement movement which generates a Doppler shift in a reflected wave. Therefore, a Doppler radar is a great approach for detecting a human respiration monitoring [9], [10].

The radar system which has the capability for measuring a small displacement or vibration of a chest wall movement which relates to the human respiration needs to be studied and developed. An HB100 is a Doppler radar module which operates at a X-Band and developed by AgileSense$^{\text{TM}}$. This radar has the frequency of 10 GHz with the wavelength of 33 mm. It consists of a dielectric resonator oscillator, mixer, and a patch antenna. Considering the wavelength of HB100, the phase shift which is caused by the chest wall movement is potential to be detected by using its radar system. However, the capability of Single-Tone Doppler radar at 10 GHz for detecting human respiration needs to be studied first.

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Furthermore, the objective of this paper is to study the capability of Single-Tone Doppler radar at 10 GHz for detecting human respiration parameters such as its amplitude and rate.

This paper is organized as follows; Section I describes the background and problem which addressed in this paper, Section II discusses the proposed method in detecting human respiration rate caused by the chest wall movement, Section III discusses the computer simulation using Octave in investigating the proposed method and its results and the last, is Section IV, is for the conclusion.

II. PROPOSED METHOD

A. Chest Wall Movement in Human Respiration

The relationship between the human respiration and the chest wall movement can be illustrated in Fig.1. Generally, respiration has a periodic pattern which is related to the inhale and exhale activities and it can be identified by the chest wall movement. *T(t)* is an incident of the wave from a signal source, *R(t)* is the reflected waves, and $d_o + x(t)$ is the distance between human and signal source. If the chest wall movement is modeled as a time-varying function of *x(t)*, then the propagation distance of the wave as a time-varying also. The movement which is caused by a small displacement of the chest wall movement can be analysed as a certain phase shift on the reflected wave *R(t)*.

The magnitude of the phase change which is caused by the small displacement of contraction in respiration is adequately large for measuring chest wall movement in Fig. 1. Let us apply a Doppler radar as the signal source. A Doppler radar transmits a continuous-wave signal, which is reflected by a target and then received and demodulated by a receiver. The position-varying information is demodulated proportionally in the reflected signal when the net velocity is zero. Therefore, the chest wall movement which is caused by the volume change during respiration can be detected by using the Doppler radar motion-sensing system [11].

B. CW Radar System for Detecting Chest Wall Movement

A block diagram of a CW radar system for detecting a chest wall movement is shown in Fig. 2. The transmitted signal is generated by the oscillator with a certain frequency. Its signal is used for detecting the chest wall movement which is caused by the respiration activities. The transmit signals can be expressed in (1).

$$S_T = A_T \cos(2\pi f t), \qquad (1)$$

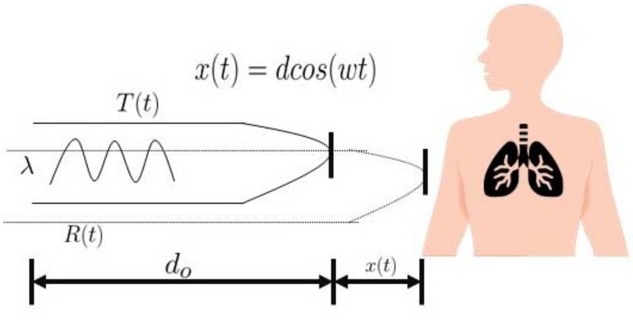

Fig. 1. A periodic chest wall movement which is caused by phase shift.

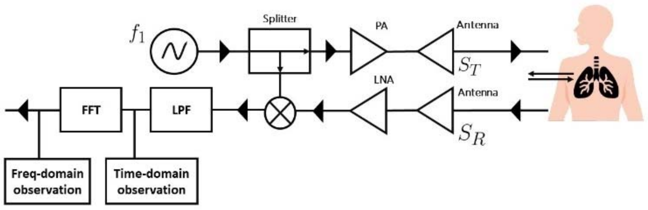

Fig. 2. A block diagram of CW radar system for detecting a chest wall movement.

where f and A_T are as a frequency of the transmitted signal and the amplitude of the transmitted signal respectively. The received signal is a reference as a human respiration which is modelled as a sinusoidal pattern. It can be expressed in (2).

$$S_R = A_R \cos\left(2\pi f t + \frac{4\pi}{\lambda} d\right), \qquad (2)$$

where d and λ are the distances between the target and the radar and wavelength of the transmitted signal respectively. If the respiration is modeled as a time-varying function which is caused by the chest wall movement and it has a periodic pattern as shown in Fig. 1, then the received signal is modified which is expressed in (3). In the (3), d and f_i refer to the amplitude and the frequency movement due to the respiration activity respectively. After it is amplified by the Low Noise Amplifier (LNA), then the received signal is mixed by the oscillator output. The output of the mixer is shown in (4).

$$S_R = A_R \cos\left(2\pi f t + \frac{4\pi}{\lambda} d\cos(2\pi f_i t)\right). \qquad (3)$$

$$S_M = S_T \,.\, S_R = \begin{matrix} A_M \cos(4\pi f t + \frac{4\pi}{\lambda} d \cos 2\pi f_i t) + \\ A_M \cos(\frac{4\pi}{\lambda} d \cos 2\pi f_i t)\,. \end{matrix} \qquad (4)$$

The mixer output S_M is similar to the narrow-band frequency modulation signal [12]. Therefore, the spectrum of S_M is influenced by the amplitude of the respiration pattern.

$$S_{LPF} = \sum_{n=0}^{\infty} A_n \cos(2\pi n f_i t) \qquad (5)$$

The Low Pass Filter (LPF) output of Doppler radar which is shown in (5) represents as a respiration which is detected by the radar system.

The index n represents the frequency of each component at the LPF output. The index A_n represents the amplitude of each component. The harmonic component which is shown in (5) will rise if the amplitude of the respiration pattern d is increased. From the LPF output, it can be identified that the respiration pattern is associated by the respiration rate with the fundamental frequency of the LPF output and the amplitude of the respiration by the number of the harmonic frequency comes out significantly. The representation of the LPF output is more convenient if it is in the frequency-domain. Therefore, the Fourier Transform is needed for processing the LPF output data. After it is converted into the digital signal, then it needs the Fast Fourier Transform (FFT) computation for obtaining the representation of frequency-domain.

TABLE I. THE NUMBER OF RESPIRATORY FREQUENCY BY AGES.

Groups	Ages	Frequency rate (times/ minute)
Newborn	Under 1 year old	44
Infants	Under 2 years old	50
Toddlers	Under 6 years old	25
Children	Under 15 years old	20
Adults	Above 15 years old	16

III. RESULT AND DISCUSSION

A computer simulation which is using Octave is performed for investigating the proposed Doppler radar in detecting human respiration. The simulation is performed for the following purpose: observing the performance of the proposed radar in detecting different respiration rate, observing the performance of the proposed radar in detecting different respiration amplitude, and observing the performance of the proposed radar in detecting several real cases of human respiration rate. The simulation refers to the specification of the HB100 module. A Single-Tone Doppler radar system generates and transmits a single-frequency electromagnetic wave with the frequency of 10 GHz.

In this paper, several respiration patterns with the different rate and amplitude are simulated and analysed both in time and frequency domain. In this experiment, the target object is located around 3 m from the CW radar system. Related to the equation of (2), the frequency of transmit signal f is set to 10 GHz. A_R and f_i are a varied rate which will be simulated. The information of the target positions data is required for detecting the small displacement on the target. Refers to the Table I, the normal respiration rate which is caused by the age, from an adult to an infant, it has ranged from 16 to 50 times per minutes. The simulation selects three-different respiration rates: 16, 20, and 30 times per minute. It represents the normal respiration rate of adult, child, and baby.

The LPF output in *time-domain* for the three-different respiration rate is shown in Fig. 3. On this figure, the simulation is performed by taking the example of the respiration rate f_i of 0.26 Hz, 0.33 Hz, and 0.5 Hz. This example is equaled to the 16, 20, and 30 times per minute of the normal respiration rate. The result in Fig. 3 indicates the LPF output for the three-different respiration rates. The rhythmic of the human respiration for the three-different respiration rates produce an LPF output with the different pattern. Furthermore, it can be analysed that the respiration condition is from the pattern of an LPF output. However, the frequency-domain representation of an LPF output is more suitable to obtains more accurate information about the rate. As shown in Fig. 2, the Fast Fourier Transform (FFT) computation is used to achieve the frequency domain representation of an LPF output.

The LPF output in *frequency-domain* for the three-different respiration rate which has the same case as a simulation in Fig. 3, is shown in Fig. 4. The spectrum of LPF output has been represented in normalized value. Normalization is done by dividing the spectrum of an LPF output with the maximum of its absolute value. The proposed of radar system can to detect the three-different pattern rates. A 0.26 Hz, 0.33 Hz, and 0.5 Hz of respiration rates which have been simulated, it has a different pattern in the frequency domain. The respiration rate can be determined from the frequency which is associated with the peak spectrum of the fundamental frequency component.

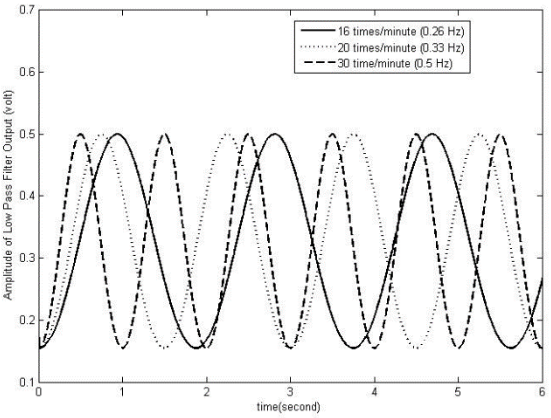

Fig. 3. An LPF output in the time-domain which represents a three-different of respiration rate.

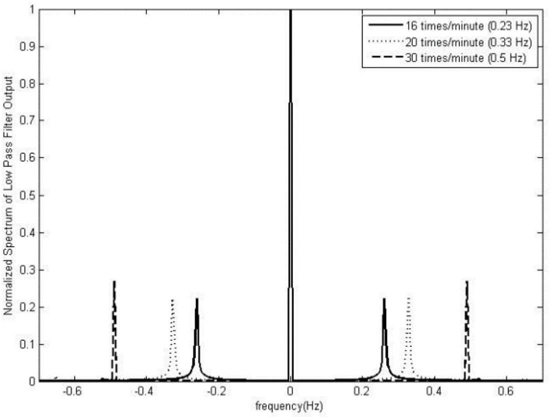

Fig. 4. An LPF output in the frequency-domain which represents a three-different of respiration rate.

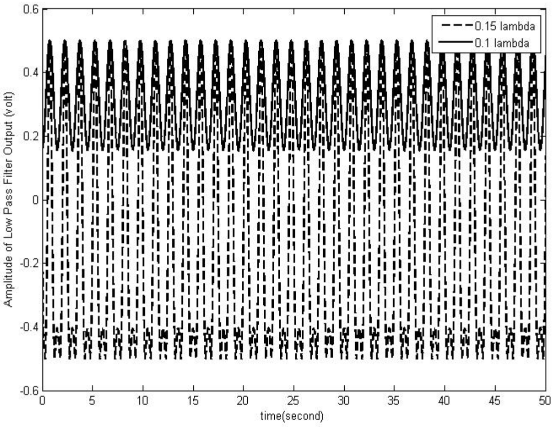

Fig. 5. An LPF output in time-domain for two-different respiration amplitude.

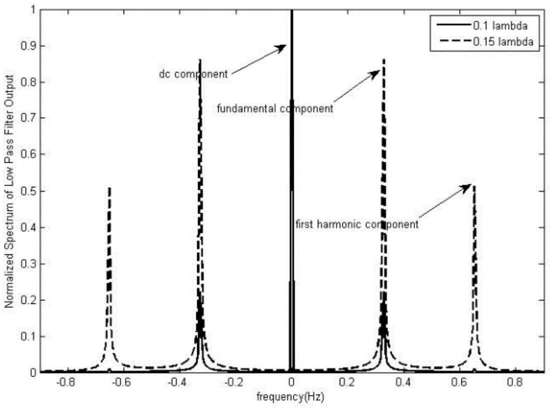

Fig. 6. An LPF output in frequency-domain for two-different respiration amplitude with the respiration rate of 0.33 Hz.

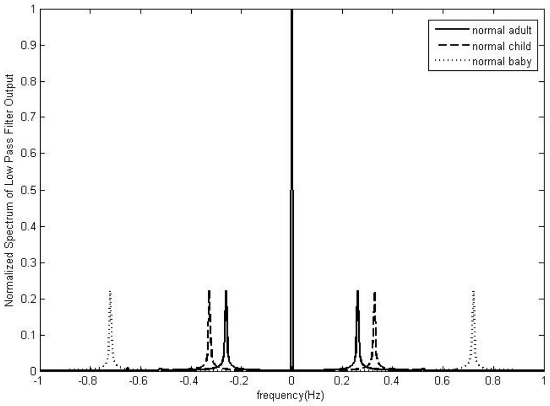

Fig. 7. The normalized spectrum of LPF output for several human respiration cases.

The LPF output for two-different amplitude respiration rate in *time-domain* is shown in Fig 5. The amplitude of 0.1 λ and 0.3 λ are simulated at the same respiration rate of 0.33 Hz. The result shows that the respiration amplitude has influenced the peak-to-peak value of the LPF output. The high amplitude will cause the high peak-to-peak value and vice versa.

The LPF output for two-different amplitude respiration in *frequency-domain* is shown in Fig. 6. The result is taking from the same simulation case within Fig. 5. In the spectrum of 0.3 λ, the first harmonic component (0.66 Hz) appears either the fundamental component (0.33 Hz) also. However, the harmonic components are not for the low amplitude (0.1 λ) significantly. By increasing the respiration amplitude, it has been affected by increasing the appearance of the harmonic component. The appearance of the frequency harmonic in high respiration amplitude causes the increase of the bandwidth of the power spectrum. By increasing the respiration amplitude, it may be caused by the high activity or illness. Therefore, the appearance of the harmonic component can be used to identify it.

The speed of human respiratory rate is caused by the several factors; age, gender, and activities [2]. The simulation has been performed for detecting the respiration pattern for several different ages group. As shown in Fig. 7, the simulation takes a sample by a baby, child, and adult rate respiration. By the normalized spectrum of an LPF output, the frequency of the baby case is around 0.72 Hz, while for the child is around 0.32 Hz, and for the adult is around 0.26 Hz. By the time age is changing, the rate of respiration is changing [13]. For the grouping of human rate respiration rate by ages at times per minute is shown in Table I [2].

The effect of the respiration amplitude to the LPF output has been analysed from the power spectrum's perspective. The effect of the respiration amplitude to the power spectrum of the LPF output is shown in Fig. 8. The higher respiration amplitude which is caused by the LPF output has the higher power spectrum level than the lower amplitude. In the previous result, it has been discussed that the higher respiration amplitude increases the harmonic component existence at the spectrum of the LPF output. Furthermore, it affects the increase of the bandwidth and power spectrum of the LPF also.

IV. CONCLUSION

The first stage on developing proposed Single-Tone Doppler Radar for the human respiration monitoring has been conducted by the performing Octave simulation which is used for investigating the capability of the proposed Single-Tone Doppler Radar in detecting rate and magnitude of human respiration. The time-domain and the frequency-domain analysis have been conducted in this study. The simulation is performed by taking several cases with the different respiration parameters. The simulation results on Single-Tone Doppler Radar at 10 GHz show that the proposed radar system has the capability to detect the human respiration parameter, such as respiration rate and the amplitude of the chest wall movement. Due to its function to detect the respiration rate and amplitude, the *frequency-domain* observation is more suitable than *time-domain*. The respiration rate can be determined from the fundamental frequency component of the LPF output. The respiration amplitude can be determined from the total power spectrum of the normalized output of the LPF.

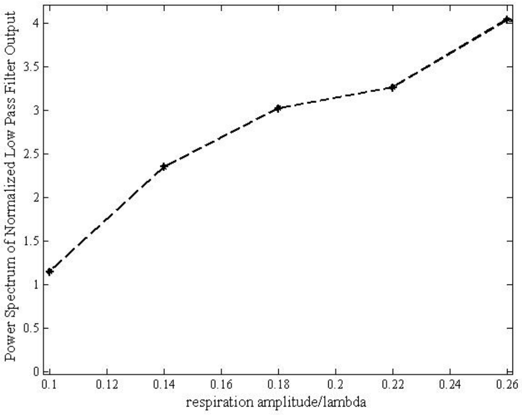

Fig. 8. A power spectrum of normalized LPF output.

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