Two frequency Radar Sensor for Non-contact Vital Signal Monitor

Joon Ho Oum[1], Dong-Wook Kim[2], Songcheol Hong[1]

[1]Dept. of EECS, Korea Advanced Institute of Science and Technology(KAIST),
373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea
[2]Dept. of Radio Science and Engineering, Chungnam National University
220 Gung-dong, Yuseong-gu, Daejeon 305-764, Republic of Korea

***Abstract* — We propose a two frequency radar sensor structure for non-contact vital signs monitor. The vital signs measured by traditional Doppler sensor are diminished if the body has a large motion. The radar structure is proposed which is strong to human motions. This utilized frequency dependent dielectric characteristics of human body tissues.**

***Index Terms* — heart, ECG, vital signs, heartbeat, ECG , Doppler radar**

I. INTRODUCTION

A microwave Doppler radar can detect human vital signs as a non-contact, non-invasive method and can have long detection range comparing to other non-contact heartbeat sensors [1]-[3]. However, it is difficult to retrieve vital signs if the body has large random motion. In this work, we propose a new radar sensor structure that the vital signs are not diminished even when the body has random motions. We will introduce the principle and experimental results of proposed radar sensor and the result will be compared to Doppler radar sensor.

II. DOPPLER RADAR VITAL SIGNS MONITOR

Fig.1 shows structure of Doppler radar sensor for non-contact vital signs detection. As shown in Fig. 1, the RF signal, $S_T(t)$ is transmitted to the chest and the reflected signal $S_R(t)$ is down converted by mixer. The transmitted and received signal can be expressed as:

$$S_T(t) = A_T \cos[2\pi f t + \phi] \tag{1}$$

$$\begin{aligned} S_R(t) &= A_R \cos[2\pi f (t - \frac{2d(t)}{c}) + \phi] \\ &= A_R \cos[2\pi f t - \frac{4\pi f}{c} d(t) + \phi] \end{aligned} \tag{2}$$

where f, c, ϕ, and d(t) is frequency of oscillator, speed of transmitted signal, phase of transmitted signal, and time dependent distance between antenna and the chest. A_T and A_R are amplitude of transmitted signal and received signal.

The distance d(t) can be expressed as :

$$\mathrm{d(t)} = \mathrm{n(t)}\lambda + \mathrm{s}mall(\mathrm{t}) \tag{3}$$

where n(t) is integer number, λ is wavelength of transmitted signal, and small(t) is length less than λ .

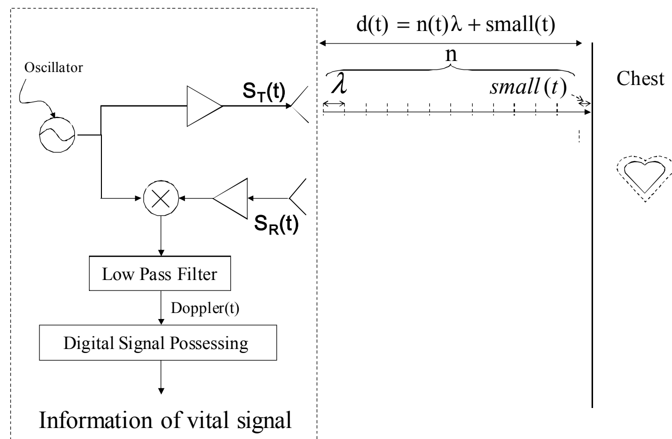

Fig. 1. Doppler radar sensor for non-contact vital signs detection

If the received signal is low pass filtered after the down conversion, the low pass filtered signal Doppler(t) can be written as :

$$\begin{aligned} Doppler(t) &= A_D \cos[\frac{4\pi f}{c} n(t)\lambda + \frac{4\pi f}{c} small(t) + \phi] \\ &= A_D \cos[\frac{4\pi f}{c} small(t) + \psi(t)] \end{aligned} \tag{4}$$

where A_D is amplitude of down converted signal. The phase term, ψ can be expressed as:

$$\psi(t) = 4\pi n(t) + \phi \tag{5}$$

The phase ψ is a function of distance between antenna and chest, and if the body is stationary or the movement of body is smaller than the wavelength, the phase $\psi(t)$ has constant value because n(t) is constant. The cardiopulmonary activity of human makes small movements on the chest. The displacement of chest wall motion due to heartbeat is reported to 0.04~1.2 mm, and small(t) has the information of cardiopulmonary activity of stationary human [4],[5].

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Therefore, the sensitivity of Doppler radar sensor for small movement detection can be expressed as:

$$S[\psi(t)] = \frac{\partial\,\text{Doppler}(t)}{\partial\,\text{small}(t)} = -A_D \frac{4\pi f}{c}\sin[\frac{4\pi f}{c}\text{small}(t) + \psi(t)] \tag{6}$$

As shown in Eq. (6), the sensitivity of Doppler radar sensor is diminished at a particular distance between antenna and the chest wall. This is known as 'null point problem' [6].

If the chest motion amplitude due to the cardiopulmonary and respiratory activity of human are A_R and A_H, respiration signal to heartbeat signal power ratio with Doppler radar sensor can be expressed as:

$$\frac{H}{R} = \left(\frac{H_{\text{Doppler}}}{R_{\text{Doppler}}}\right)^2 \approx \left(\frac{S[\psi(t)]A_H}{S[\psi(t)]A_R}\right)^2 = \left(\frac{A_H}{A_R}\right)^2 \tag{7}$$

where H_{Doppler} and R_{Doppler} are heartbeat and respiration signal amplitude detected by Doppler radar sensor. The H and R are heartbeat and respiratory signal power of Doppler sensor output. As shown in (7), H/R ratios of Doppler radar sensor are not dependent on the oscillation frequency but only on the chest wall movement characteristics of human under measurement. Moreover, if the body has random motion larger than the wavelength or moves with the similar frequency to cardiopulmonary activity, the information of small movement can not be retrieved from Doppler(t) in Eq. (4). This is because the cosine function doesn't have unique inverse function value and is a nonlinear function. However if the frequency of motion is different to that of cardiopulmonary activity or is not random, cardiopulmonary activity signal can be retrieved as long as the signal to noise ratio (SNR) of the sensor is large enough to be detected .

III. Non-contact Vital Signs Monitor using Two Frequency Radar

Fig. 2 shows the frequecy depedent dielectric property and penetration depth of biological tissues [7, 8]. If a high frequency (over 10GHz) wave is incident on the body, because the penetration depth is few mm, most of incident wave is reflected by the skin. However, if the freqeucny of incident wave is low, the wave can penetrate the body and reflection is occurred at tissue inside the body. For example, penetration depth of muscle tissue is 2.2 cm at 2.4 GHz and 4.4 cm at 800 MHz.

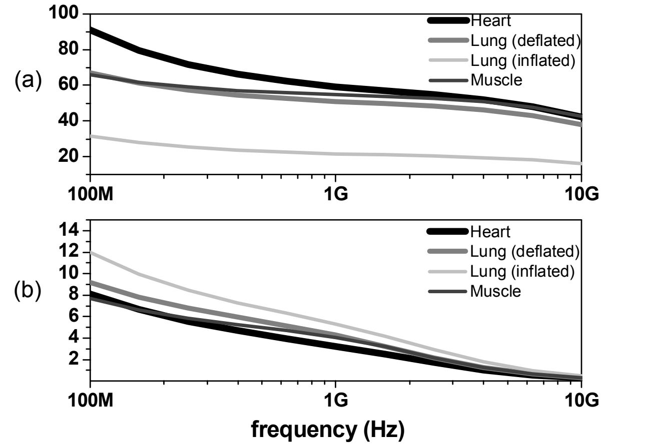

Fig. 2. The frequency dependent dielectric properties of human tissue. (a) Relative dielectric constant, (b) Penetration depth (cm). after [8]

Fig. 3 shows the principle of proposed radar sensor. If we transmit low frequency signal , $S_{1T}(t)$, to the chest wall then the wave is reflected by tissues inside of the chest. And if we transmit high frequency signal, $S_{2T}(t)$, to the chest wall then the wave is reflected on the surface of the chest. If the frequency of $S_{1T}(t)$ and $S_{2T}(t)$ is f_1 and f_2 , the distance between antenna and the reflection plane can be written as :

$$\begin{aligned} d_2(t) &= n_2(t)\lambda_2 + \text{small}_2(t) \\ d_1(t) &= n_1(t)\lambda_1 + \text{small}_1(t) = d_2(t) + \text{depth}(t) \end{aligned} \tag{8}$$

where $n_1(t)$ and $n_2(t)$ are integer number, λ_1 and λ_2 are wavelength of transmitting wave, and depth(t) is the difference between $d_1(t)$ and $d_2(t)$. The depth(t) is the distance between two different reflection plane P1 and P2 as shown in Fig. 3. And the depth(t) is not affected by the distance between antenna and the chest wall.

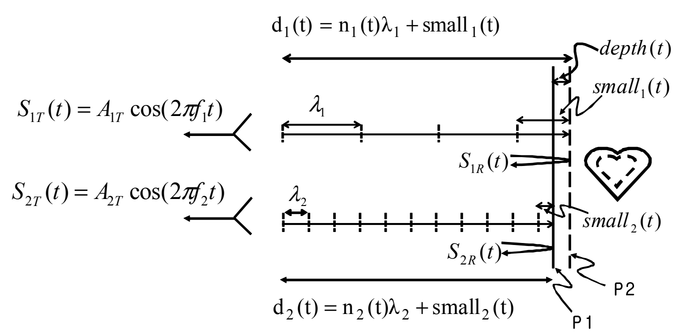

Fig. 3 Principle of the proposed radar sensor for vital signs detection

Fig. 4 is simplified cut view of human chest. We assumed the body is cylinder and the heart is in the center of body and the lung is close to the surface of chest. If we assume the high and low frequency wave is reflected at the point p1 and p2 then we can define depth(t) as R1-R2. We separate the heart and lung motion as shown in Fig. 4 for the simplicity. If the heart is in center of the cylinder and the displacement motion of cardio activity is M_H, the change of depth(t) due to cardio activity can be expressed as :

$$\Delta \text{depth}_H(t) = \Delta R1 - \Delta R2 = \alpha M_H \tag{9}$$

where Δ depth$_H$(t) is change of depth(t) due to heartbeat and α is proportional coefficient for heartbeat. Because the location of lung and heart is different, the change of depth(t) due to respiration can be expressed as:

$$\Delta \text{depth}_R(t) = \beta M_R \qquad (\beta \neq \alpha) \tag{10}$$

where Δ depth$_H$(t) is changes of depth(t) due to respiration, M_R is displacement of lung motion, and β is proportional coefficient for respiratory activity. Therefore, the total change of depth(t) can be written as:

$$\Delta \text{depth}(t) = \Delta \text{depth}_H(t) + \Delta \text{depth}_R(t) \tag{11}$$

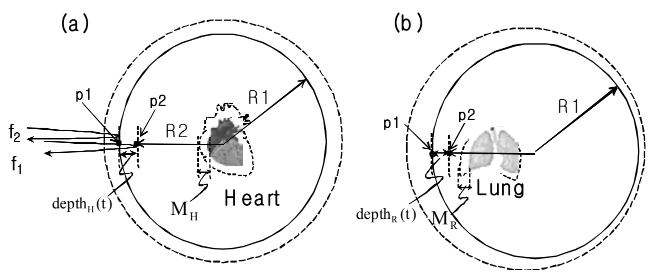

Fig. 4 Simplified cut view of human body

As shown in Fig. 3, If we transmit two different signal $S_{1T}(t)$ and $S_{2T}(t)$ to the chest, the received signal can be expressed as:

$$\begin{aligned} S_{1R}(t) &= A_{R1}\cos[2\pi f_1 t - \frac{4\pi f_1}{c} d_1(t)] \\ S_{2R}(t) &= A_{R2}\cos[2\pi f_2 t - \frac{4\pi f_2}{c} d_2(t)] \end{aligned} \tag{12}$$

If we multiply $S_{1R}(t)$ and $S_{2R}(t)$ and the output signal is pass through a band pass filter (BPF) whose center frequency is f_2-f_1, the filtered signal can be expressed as;

$$\begin{aligned} &\text{BPF}[S_{1R}(t)\times S_{2R}(t)]_{f_2-f_1} \\ &\approx A\cos[2\pi(f_2-f_1)t + \frac{4\pi f_2}{c}(d_2(t)-d_1(t))] \end{aligned} \tag{13}$$

where A is amplitude of band pass filtered signal. The band pass filtered signal is down converted with mixer and low pass filtered. The low pass filtered signal can be written as:

$$\begin{aligned} &\text{LPF}[\text{BPF}[S_{1R}(t)\times S_{2R}(t)]_{f_2-f_1} \times \cos[2\pi(f_2-f_1)t+\theta]] \\ &= A_o \cos[\frac{4\pi f_2}{c}\text{depth}(t)] \end{aligned} \tag{14}$$

where A_o is ouput amplitude of proposed radar sensor. If the frequency f_1 is near to f_2 the depth(t) is not function of distance between antenna and the chest. Although the term depth(t) is inside cosine function in (14), the signal is not diminished by the random position to antenna. Because the radom motion increase noise level, it is important to increase signal to noise ratio to detect the vital signs of human with motion in proposed radar structure.

Fig. 5 shows proposed radar structure to detect depth(t) of stationary person. We use two different frequency signal source with the frequency of f_1=800 MHz (0 dBm), f_2=2.4 GHz (-10 dBm). A broadband vivaldi antenna is used to transmit the two signals, HMC286, HMC373LP3 (Hittite) is used for LNA, AD8353 (Analog Device) is used for gain block, and AD8343 (Analog Device) is used for mixer block. The high frequency power combiner, band pass filters, low pass filters are made by microstrip lines and hybrid couplers (XC0900L, 1P603, Anaren Microwave) are used. The sensor output is band pass filtered and amplified by SR560 LNA (pass band: 0.01~10Hz, 34dB gain) and is recorded by data acquisition board to the PC.

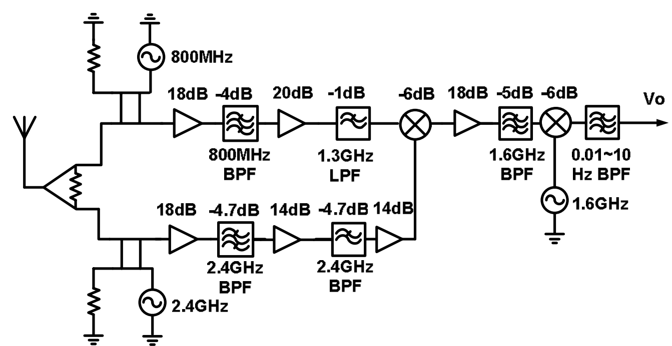

Fig. 5 The proposed radar sensor structure

IV. Experimental Results

For the comparison, we used Doppler radar sensors using three different frequencies (2.4GHz, 10.525GHz, 24 GHz) whose structure is as shown in Fig. 1 The distance between chest and antenna is 15 cm and the measurement is performed on a same person.

Fig. 6 shows the measurement results of the sensors. The output of 2.4 GHz Doppler sensor is noisy because of the clutter signals (ex. WLAN). The heartbeat to respiration signal power ratio (H/R) of Doppler radar sensors are in the range of -17~-20 dB and don't have significant difference with the frequency. The measurement results of H/R are summarized in

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Table 1. This result can be explained by (7). However, the proposed radar sensor has much lower H/R, -31.7dB. The proposed sensor detect the change of the depth(t), and the signal power due to lung's motion is higher than that of heart because the lung is near to the surface (skin). Therefore the proposed radar sensor's H/R is much smaller (>10 dB) than that of the Doppler radar sensor which detects only the movement of surface or inner tissue. This can be understood that the proposed sensor detects the change of two different reflect position of human body.

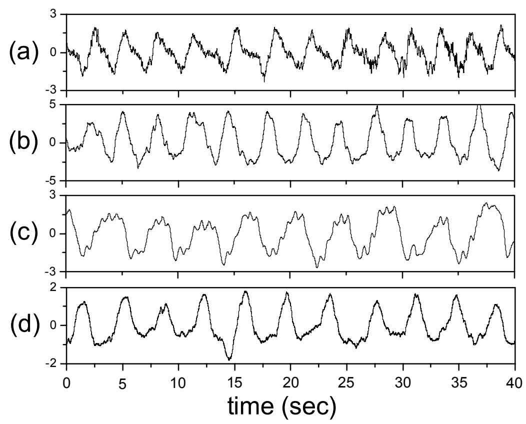

Fig. 6 Signals of Doppler radar vital signs monitors with different frequency and the proposed radar as shown in Fig. 5. (a) 2.4GHz, (b) 10.525 GHz, (c) 24 GHz (d) The proposed radar as shown in Fig. 5 (f_1= 800 MHz, f_2= 2.4 GHz)

Frequency	2.4 GHz	10.525 GHz	24 GHz	800MHz, 2.4GHz
Type	Doppler Radar	Doppler radar	Doppler radar	Proposed radar sensor
H/R	- 19.8dB	-17.8dB	-19dB	-31.7dB

Table 1 Summary of H/R measurement results

V. CONCLUSION

We proposed two frequency radar sensor to detect vital signs that is independent on the distance between the antenna and human body. The proposed sensor is compared to Doppler radar sensors with different frequencies. However, it is important to find a way to increase the SNR of the proposed sensor to detect vital signs of human in random motions.

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