Mohd Azlishah Othman, Mohan Sinnappa, Hazwani Azman, Mohamad Zoinol Abidin Abd Aziz, Mohd Nor Hussein, Mohd Muzafar Ismail, Hamzah Asyrani Sulaiman, Mohamad Harris Misran, Maizatul Alice Meor Said, Ridza Azri Ramlee

Universiti Teknikal Malaysia Melaka

An Analysis of 5.8 GHz Microwave Doppler radar for Heartbeat Detection

***Abstract**. Non-contact heartbeat detection is one of the current emerging technologies in various fields, especially in health care service. Proper distance and power level is more preferable in a system design to provide better health care monitoring system. The purpose of this paper is to present a filtering technique using Matlab, and the correlation in distance and power level of heartbeat detection based on Doppler Effect principle. An experiment was conducted at 5.8GHz with varied the distance and power level. A comparative study is carried out based on experimental results.*

***Streszczenie.** W artkule analizowano możliwości bezkontaktowego śledzenia pracy serca. Zastosowano technikę filtrowania i korelację między dystansem a mocą pozyskiwaną. Do badań wykorzystano efekt Dopplera. (**Analiza mikrofalowego radaru 5.8 GHz stosowanego do badania pracy serca**)*

Keywords: Hearbeat, Microwave, Doppler Radar, Respiration.
Słowa kluczowe: praca serca, radar, efekt Dopplera.

Introduction

The basis theory of an electromagnetic was formulated in 1864 by James Clerk Maxwell [1,2] and validated by Heinrich Hertz in his experiment during 1888 [3,1]. Hence, many new findings, inventions and applications took place in various fields with applying of electromagnetic wave. For instance, Radio Detection And Ranging (radar) [4] is a system which was developed during World War II for military usage and widely spread and adopted in many sectors later. Radar is an object detection system. It can be classified according to their system waveform usage. Commonly, radar use radio wave to identified range, altitude, direction, location, speed and other feature of objects. The frequency wavelength (λ) between 1 millimeters to 1 meter is one of the radio wave type which called as microwave.

According to history, in 1842, Doppler effect was described by Christian Andreas Doppler, who is an Austrian physicist by observing the light frequency and sound waves, related effect by the motion of source and detector. In 1975, the first suggestion of non-invasive Doppler radar of respiration monitoring of physiological signal was suggested [5]. Next, in 1979, heart rate detection using X-band Doppler transceiver was demonstrated [6]. Following that, various researches were carried out with a system that basically adopts the Doppler radar concept [7-12] which has the potential to be applied in various monitoring fields. For instance, it can be applied in health home monitoring [6], long range life signs detection [13,17], cardiopulmonary monitoring [14,17], heart rate observation [15], detection of early breast cancer [18,19] and human physiological parameters monitoring [20].

The benefit of non-contact heartbeat detection is an effective and easy way in treatments by saving time, and provides a ubiquitous solution. On the other hand, the system radiates and consumes small power, exists with combination other instruments, and it is robust to interference and multipath [17]. Following that, the non-contact heartbeat detection system also did not require additional physical contact such as chest straps or gel and can measure throw clothes. In some way, it led to high integration technology with others system, equipment and software.

Doppler radar used the Doppler effect signal principle for motion detection. Generally, the chest displacement due to respiration and heartbeat variation are ranged between 4mm to 12mm [16] and 0.2mm to 0.5mm consequently. On the other hand, variation of respiration rate in rest position is between 0.1Hz to 0.3Hz, while the interval of heart beat rate varies between 1Hz to 3Hz. Thus, the signal contains both respiration and heart beat where the respiration displacement are large than heartbeat. Therefore, a filtering technique is needed to filter noise and unwanted signal from raw detected signal [18].

This paper is aimed to present an experiment of heart respiration measurement by varied distance (feet) and transmitted power level (dBm) consequently. Based on the experimental results, the relation among these two variables and phase displacement are explored. The rest of the paper elaborate about background information regarding this experimental, basic microwave radar principle, experimental setup, results and discussion and conclusion based on the experimental results provided.

Background Information

An electrocardiogram (ECG or EKG) is used to measure and record electrical activity of heart, as revealed on the surface of the body [21]. Figure 1 shows a cycle of the typical ECG signal. The common ECG signal contains P, Q, R, S and T wave position, with an interval and segment portion.

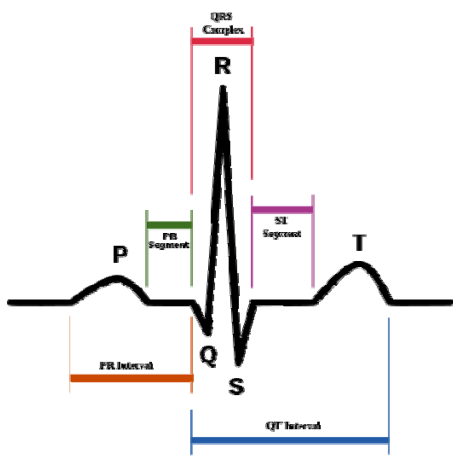


Fig.1. A cycle of typical ECG signal [22].

The electrical activity transvers myocardium results from an ECG electrical vector of heart measurement. In nature, heart activity is fired by sino-atrial (SA) node which result the depolarization across three atria tract. It reflects the electrical activity contraction of the atria. This even reflected in ECG signal as P wave. Usually, the P wave amplitude varies from 0 to 0.3mV and the duration is up to 0.1 seconds [23]. The QRS complex in ECG signal indicates the depolarization wave which passes through the ventricles. The Q wave is well defined as the downward deflection. The R wave is first positive deflection following by S wave is negative deflection. The R and S wave can vary in amplitude from 0 to 2.8mV and 0 to 0.8mV [23]. Typically, the QRS duration lies between 0.05 to 0.1 seconds. The ventricular repolarization is defined by T wave. The T wave is also known as an upward deflection and range from 0 to 0.8mV with 0.1 to 0.25 second of duration periods. The flat segments which start from the end of the QRS complex to T wave beginning is defined as ST segment. ST segment is used to determine some cardiac disease.

The usage of this ECG study is to identify an individual health status from any disease such as heart block, hypertrophy, arrhythmias, myocardial Infarction and many more. The chest displacement due to respiration is 4mm to 12mm [16] and heartbeat variation is between 0.2mm to 0.5mm. The variation of respiration rate in rest position is between 0.1Hz to 0.3Hz, while the interval of heart beat rate varies between 1Hz to 3Hz.

Basic Principle

The microwave Doppler radar principle covers a wide range of knowledge and principles. The microwave field deployed the fundamental of electromagnetic concepts. It is probably because of radar which being the first major application of microwave technology since World War II [24]. These entire fields still explored and keep active with current technology and developments. There are few important formulas and information need to understand basically in this microwave Doppler radar for heartbeat detection.

The Doppler frequency (f_d) is the differences between transmission (f_t) and reception frequency (f_r). It can be calculated as formula 1 below, where the speed of light (c) is 3 x 10^8 ms^{-1} and object velocity is (v) [11].

$$(1)\quad f_d = |f_r - f_t| = f_t\left(\frac{c+v}{c-v}\right) = \frac{2v}{c-v} f_t \cong \frac{2v}{c} f_t$$

When any object or target in periodic movement x(t) with no net velocity, the phase variation Δθ(t) can be calculated by the equation below:

$$(1)\qquad \Delta\theta(t) = \frac{4\pi\Delta x(t)}{\lambda}$$

where, in this experiment $\Delta x(t)$ is variation of chest displacement and λ is transmitted signal wavelength [25]. The equation shows the relation among phase variation $\Delta\theta(t)$, chest displacement $\Delta x(t)$ and transmitted signal wavelength λ.

Experimental Setup

Generally, the transmitted signals generate from Vector Network Analyzer (VNA) and signal propagation directed towards subject chest by using an antenna as showed in figure 2. Consequently, the signal will reflect by subject chests and measured again received signal by the same antenna. The Doppler effect is applied in to measure the phase modulation by time varying of reflected signal by chest position. The data collected from chest displacement contain heartbeat and respiration of subjects. As usual, some noise or interference will exist in measurements which are caused by respiration or environment. In order to get a clear signal, a smoothing or filter technic is carried out to detect heartbeat. Theoretically the heartbeat is identified by the R- peak signal in the electrocardiogram (ECG).

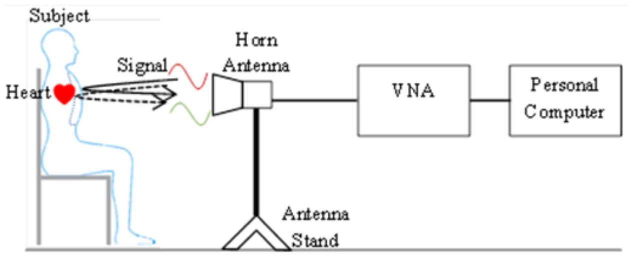


Fig.2. Doppler Effect for heart rate measurement.

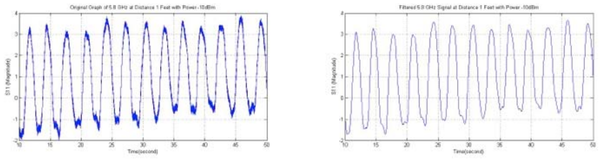
The subject is 27 age male human being, who was positioned by sitting on chairs. The sitting body posture is approximately 90º to avoid the body movement maximally. A horn antenna is placed directly opposite with desired distance of the subject chest. An appropriate antenna height can be achieved with the adjustable antenna stand. A Vector Network Analyzer (VNA) from Agilent Technologies N5242A is used to generate and measure desired signal and parameters. The advantage of using the VNA is easy in accessibilities of desire features such as frequency, signal sweep time, s-parameters, input or output power, measurement points and types of signal graph. In this experiment, 5.8 GHz Continuous Wave (CW) signal with 50 seconds of sweep time was applied. On the other hand, the distance and the transmitted power level were varied consequently. The varied distance is 1, 2, 3, and 4 feet between subject chest and the antenna with fixed the power level to -10dBm. Following by, the -30dBm and 30dBm power level of transmitted signal adjusted by fixed the distance to 1 feet. A personal computer is used in collecting and simulated the data or results from VNA by using many simulation software tools. In this experiment, the Matlab version 7.12.0.635 (R2011a) 64-bit (win64) was used. All instrument specifications, description and range are listed in table 1 below in detail.

Table 1. Instrument characteristic and description

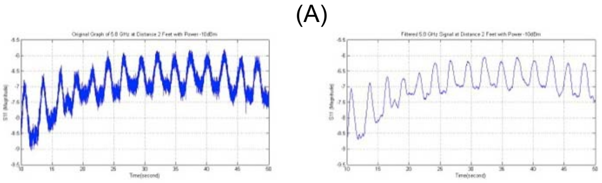
Instrument	Description	Range Specification
VNA, Agilent Technologies N5242A, PNA-X Network Analyzer.	Sweep time	50 seconds
	Frequency Range	1GHz to 18GHz
	Port	Have total 4
	Advance Connectivity	LAN, USB and GPIB
	Electronic Calibration Module	Agilent N4433A
	Frequency Range	1 to 18 GHz
	Dimensions (Length × Width × Height)	290 mm × 250 mm × 160 mm
	Power Levels (dBm)	-30dBm to 30dBm
Horn Antenna HF 906 (ROHDE &SCHWARZ)	Gain	7 to 14 dBi
	VSWR	<1.5
	Nominal Impedance	50Ω
Personal computer	Matlab	Version 7.12.0.635 (R2011a)

Experimental Results and Discussions

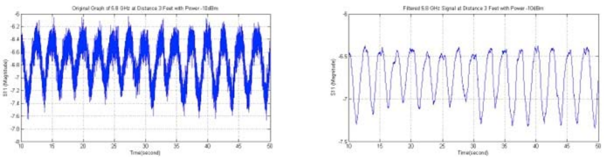
An experiment was conducted at 5.8GHz microwave frequency by fixing the transmitting power to -10dBm and varied the distance between subject and antenna from 1feet to 4 feet. Following that, the 2 different transmitted power levels such as -30dBm and 30dBm at fixed 1 feet are tested. Then, the measured signal will be filtered by using Butterworth filter in Matlab. The Figure (3 & 4) and tables (2 & 3) below show the results of the experiment.



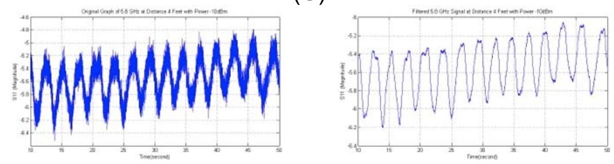
(A)



(B)



(C)



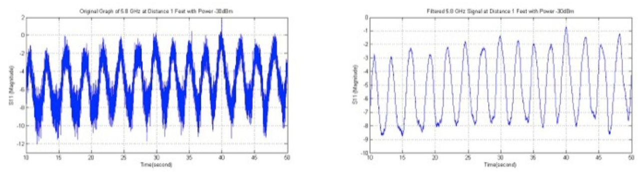
(D)

Fig.3. 5.8 GHz respiration magnitude detection and filtered signal with fixed power -10dBm at different distance (A: at 1 feet, B: at 2 feet, C: at 3 feet and D: at 4 feet)

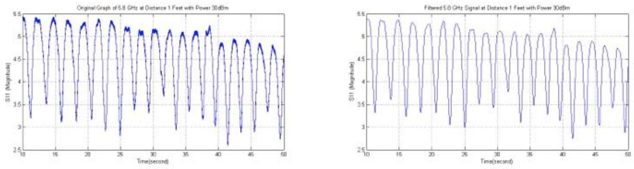
Table 2. 5.8 GHz microwave Doppler radar heartbeat detection by varied distance (1, 2, 3 and 4 feet) with fixed -10dBm power

Varied Distance	Average Measured Respiration $\Delta\Theta(t)$	Average Measured Respiration Magnitude (dBm)	Average Respiration Interval (seconds)
1 feet	17.3°	4.5	3.10
2 feet	13.1°	1.1	2.46
3 feet	8.5°	0.8	2.55
4 feet	7.5°	0.7	2.81

Regarding to the experiment results in figure 3 and table 2, it clearly showed that the nearest distance 1 feet can detect more accurate with higher sensitivity and persist signals properties, than the far ones. When the distance increased, the detectable magnitude of heart respiration signal contains noise and interference. Furthermore, the detectable or measured magnitude of heartbeat power level decreased when the distances are increased. In comparison, the measured phase variation $\Delta\theta(t)$ and magnitude of signal between 1 feet and 4 feet is about 9.8º and 3.8dBm consequently. The detected average of respiration between 1 feet and 4 feet are reduced about 0.29 seconds.



(A)



(B)

Fig.4. 5.8 GHz respiration magnitude detection and filtered signal with fixed distance 1 feet at different power (A: at power -30dBm and B: power 30dBm)

Table 3. 5.8 GHz microwave Doppler radar heartbeat detection by varied power (-30dBm and 30dBm) with fixed 1 feet distance

Varied Power Level (dBm)	Average Measured Experiment $\Delta\Theta(t)$	Average Measured Magnitude (dBm)	Average Respiration Interval (seconds)
-30	98.5º	6.3	2.67
30	36°	1.9	2.26

Regarding to the experiment results in figure 4 and table 3, 30dBm power level at fixed distance 1feet, contain noise or unwanted signal interference. At 30dBm power level, the detected signals are more clearly visible compared to -30dBm. The magnitude of detected signal for power variation is 4.4dBm between -30dBm and 30dBm transmitted signal. As the power level of signal increase, the magnitude and accuracy of detected signal without noise increase. However, in term average of respiration interval is reduced from 2.67 to 2.26 seconds.

The noise and interference may due to the environmental, instruments, and other factors. The body movement either went respiration or without recognized which is an uncontrolled error, also one of the major impacts in collecting accurate and precise data signal. Under different situation of breathing such as hold or stop breathing for few seconds can lead to precise detection [12]. However, the noise, interference and unwanted signal can be filtered out by using appropriate filtering technic. Here, the Butterworth filter technique is applied to smooth the signals by using Matlab simulation tools. The smoothing technique is worth in an increased the accuracy of heartbeat detection or heart rate variability (HRV) [26]. The chest displacement can be calculated manually, if we know the value of heartbeat variation (mm) and operation frequency wavelength (λ). The chest displacement 2.784º and 6.96° is calculated by using formula 2, due to heartbeat variation of 0.2mm and 0.5mm consequently. As the safety precaution and consideration under Federal Communications Commission (FCC), the transmitted signal used in this experiment is 0.1mWatt or -10 dBm, where the allowed limit is 1Watt. In this experiment, the detectable losses such as cable loss and other are subtracted.

Conclusion

An experiment for respiration magnitude and heartbeat detection using 5.8GHz microwave Doppler radar was conducted and an example of Butterworth filtering is applied to filter the unwanted noise and interference.when we increase the distance between subject and an antenna, the detectable small displacement decrease, hence low sensitivity and small phase variation identified. The magnitude and Interval of detected respiration signals also decreases went distance increase. It is due to propagation distance and looses in open space. On the other hand, the responses of heartbeat respiration are easily detectable simultaneously when the distance between subject and an antenna is small. The detected respiration displacement are large than heartbeat. Furthermore, the measured phase variation is directly proportioned to chest displacement. As transmitted power levels increase, the accuracy and strength of detected signal increase. Theoretically, the wavelength of transmitted signal is indirectly proportioned to phase variation. This experiment will be continued in future by varying different transmitted power level in term in small scale such as -20,-10, 0, 10, and 20 dBm at 5.8GHz with fixed distance 1 feet.

Acknowledgment

First and foremost, the author would like to thank Universiti Teknikal Malaysia Melaka, Malaysia (UTeM) for financial assistance under project grant PJP/2012/KEKK (43C) S1047 and cooperative support. Besides that, the authors also would like to thank the project coordinating surpervisors, lecturers and those involved direct and indirect, for their moral supports, contribution and cooperation in completing this task.

REFERENCES

[1] Sengupta D. L., Yu Zhang, "Maxwell, Hertz, the Maxwellians and the early history of electromagnetic waves," Antennas and Propagation Society International Symposium, IEEE, (2011), vol. 1, 14-17

[2] Bern Dibner, "Ten founding fathers of the electrical science: X. James Clerk Maxwell: And electromagnetic forces mathematically demonstrated," Electrical Engineering, (1955), vol. 74, no. 1, 40-41

[3] http://www.ieeeghn.org/wiki/index.php/ Heinrich_Hertz_(1857-1894)

[4] Murai K., Hayashi Y., Stone L. C., Inokuchi S., "Basic Study of Navigator's Recognition of Radar Target Direction," Systems, Man and Cybernetics (SMC) IEEE, (2006), vol. 1, 796-801

[5] Lin J. C., "Non-invasive microwave measurement of respiration," Proceedings of the IEEE, (1975), vol. 63, no.10, 1530

[6] Lin J. C., Kiernicki J., Kiernicki M., Wollschlaeger P. B., "Microwave Apexcardiography," Microwave Theory and Techniques, IEEE Transactions, (1979), vol. 27, no. 6, 618-620

[7] Lubecke O. B., Ong P. W., and Lubecke V. M., "10 GHz Doppler radar sensing of respiration and heart movement," Northeast Bioengineering Conference, (2001), 55–56

[8] Chioukh L., Boutayeb H., Ke Wu, Deslandes D., "Monitoring vital signs using remote harmonic radar concept," European Radar Conference (EuRAD), (2011), 381-384

[9] Obeid D., Issa G., Sadek S., Zaharia G., El Zein G., "Low power microwave systems for heartbeat rate detection at 2.4, 5.8, 10 and 16 GHz," Applied Sciences on Biomedical and Communication Technologies, ISABEL, (2008), 1-5

[10] Sadek S., Ghattas L., Fawaz L., "A wireless microwave sensor for remote monitoring of heart and respiration activity," Mediterranean Microwave Symposium (MMS), (2010), 374-376

[11] Sekine M., Maeno K., "Non-contact heart rate detection using periodic variation in Doppler frequency," Sensors Applications Symposium (SAS), IEEE , (2011), 318-322

[12] Chioukh L., Boutayeb H., Lin Li, Yahia L., Ke Wu, "Integrated radar systems for precision monitoring of heartbeat and respiratory status," Asia Pacific Microwave Conference (APMC), (2009), 405-408

[13] Chen K.-M., Misra D., Wang H., Chuang H.-R., Postow E., "An XBand Microwave Life-Detection System," IEEE Transactions on Biomedical Engineering, (1986), vol. BME-33, NO. 7, 697 - 701

[14] Changzhi Li, Jenshan Lin, Yanming Xiao, "Robust Overnight Monitoring of Human Vital Signs by a Non-contact Respiration and Heartbeat Detector," Engineering in Medicine and Biology Society (EMBS), IEEE , (2006), 2235-2238

[15] Boric-Lubecke O., Massagram W., Lubecke V. M., Host-Madsen A., Jokanovic B., "Heart Rate Variability Assessment Using Doppler Radar with Linear Demodulation," European Microwave Conference (EuMC), (2008), 420-423

[16] Obeid D., Sadek S., Zaharia G., and El Zein G., "A Tunable System for Contact-less Heartbeat Detection and a Modeling Approach," Medical Applications Networking (MAN), IEEE ICC, (2009), 1- 5

[17] Lazaro A., Girbau D., Villarino R., Ramos A., "Vital signs monitoring using impulse based UWB signal," European Microwave Conference (EuMC), (2011), 135,138

[18] Chia M. Y. W., Leong S. W., Sim C. K., Chan K. M., "Through-wall UWB radar operating within FCC's mask for sensing heart beat and breathing rate," European Microwave Conference (EuMC), (2005), vol. 3, 4

[19] Bond, Essex J., Xu Li, Hagness S. C., Van Veen B. D., "Microwave imaging via space-time beamforming for early detection of breast cancer," Antennas and Propagation, IEEE, (2003), vol. 51, no. 8, 1690-1705

[20] Das V., Boothby A., Hwang R., Tam Nguyen, Lopez J., Lie D. Y. C., "Antenna evaluation of a non-contact vital signs sensor for continuous heart and respiration rate monitoring," Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS), IEEE, (2012), 13-16

[21] Gary E. Wnek, Gary L. Bowlin, Encyclopedia of Biomaterials and Biomedical Engineering, Marcel Dekker, New York, (2004), 523-533

[22] http://en.wikipedia.org/wiki/Electrocardiogram

[23] Rawlings C. A., Traditional Electrocardiographic Voltages In Electrocardiography, Spacelabs, Inc., Red-mond, Washington, (1991), 24-47

[24] David M. Pozar, Microwave Engineering, John Wiley and Sons, Inc, United State, America, (2005), 370 – 406

[25] Obeid D., Sadek S., Zaharia G., El-Zein G., "A tunable-frequency system for touch-less heartbeat detection and HRV extraction," Signals, Circuits and Systems (ISSCS), (2009), 1-4

[26] Obeid D., Zaharia G., Sadek S., El-Zein G., " ECG vs. single-antenna system for heartbeat activity detection," International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL), (2011)

Authors

Mohd Azlishah Othman. Mohan Sinnappa, Hazwani Azman, Mohamad Zoinol Abidin Abd Aziz, Mohd Nor Hussein, Mohd Muzafar Ismail, Hamzah Asyrani Sulaiman, Mohamad Harris Misran, Maizatul Alice Meor Said, Ridza Azri Ramlee, Centre for Telecommunication Research and Innovation (CeTRI), Faculty of Electronic and Computer Enginerring, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia. E-mail: azlishah@utem.edu.my , smohan_1985@yahoo.com, awie_tmri@yahoo.com, mohamadzoinol@utem.edu.my, drmohdnor@utem.edu.my, muzafar@utem.edu.my, asyrani@utem.edu.my, harris@utem.edu.my, maizatul@utem.edu.my, ridza@utem.edu.my.