Implementation of Multi-Frequency Continuous Wave Radar for Respiration Detection Using Software Defined Radio

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***Abstract*— Utilizing Continuous Wave Radar System (CW) radar for non-contact human respiratory detection using the Continuous Wave Radar System (CW) has a weakness in determining the target distance. Therefore, it can't support in a radar feature in detecting multiple target. A number of CW radar are required in the detection of several targets simultaneously. Development of respiratory radar capability to detect distance needs to be done. In this paper, an implementation study on multi-frequency CW method was performed and proposed to overcome this weakness. The implementation of Continuous Wave Multi-Frequency Radar System (MFCW) using Software Define Radio (SDR) is carried out to prove the ability of the MFCW radar system in respiratory detection. The results show that the MFCW radar system can detect respiratory patterns and target distances.**

Keywords—MFCW, respiration, SDR.

I. INTRODUCTION

Small displacement in the order of millimeters to centimeters is used as physical phenomenon that is observed to identify a number of problems in several fields such as monitoring the health of building structures [1-2], landslides [3-4] and also in the health sector such as breathing and heart rate [5-7] can be seen as a phenomenon of small displacement on the chest or abdominal wall. In this paper devoted to discussing minor shifts in the abdominal or chest wall which correspond to breathing activity.

The medical devices that are used for respiration measurement generally work in contact operation, for example a method that based on acoustic wave, airflow measurement, and Electrocardiogram (ECG) Derived Respiration Rate [8]. The device has the disadvantage issue in meeting the comfort and hygienic aspect for patient. This device can prevent the spread of virus that transmit through air and droplet like the Covid-19 case. Radar system potentially to be developed in the detection of small displacement which is more efficient for multi target monitoring by operating in non-contact mode [9]. Therefore, the radar system as non-contact sensor can be an employ to overcome the problems of respiration contact sensor usage. A number of radar systems have been proposed as radar systems for respiratory detection. For CW radar at 10 GHz has studied for human respiratory monitoring [10]. However, CW radars do not have the ability to detect target distances. UWB radar has also been proposed for respiration detection [11]. However, the system occupies large bandwidth that potentially contributes interference problem. Radar breathing systems that are able to detect target distances and use low bandwidths need to be developed.

Previous research has discussed the Multi-Frequency Continuous Wave (MFCW) method for detecting small displacement [12]. MFCW also demonstrates its capability in detecting the target distance. MFCW system provides the lower bandwidth and lower power operation in detecting a small displacement in comparison with FMCW and UWB radar system, therefore it potentially to be elaborated as a radar system for respiration detection. However, this method has not been tested for its ability to detect small displacement in respiration activity. In this paper this method will be tested for the detection of small displacement in human respiration. Software Defined Radio (SDR) is a technology used to develop radio systems by using computer programming scheme [13]. A number of radar system studies have been carried out using SDR [14-16]. SDR provides a flexibility in configuring the radar system that need to be realized in a radar experiment. A study on the implementation of the MFCW radar system for respiratory detection by using an SDR device was carried out in this study. Blade RF is one type of SDR device which is then used in experiments.

The discussion in this paper is divided into five parts, the first part explains the background of the problem and the proposed method, the second part explains the MFCW radar system, then the third part explains the implementation of MFCW using the SDR device, the fourth discusses the results and analysis and concludes with a conclusion.

II. MULTI FREQUENSI COUNTINOUS WAVE RADAR SYSTEM

The development of MFCW system is motivated from Continuous Wave system. A number of signal generators are used to overcome weaknesses in the CW system. A number of experiments on detecting the human respiration using the CW radar system have been carried out [14]. However, the detection of the target was not provided by the CW radar system. The use of a multi-frequency signal generator allows the radar system to detect target positions, so that information about small displacement and the position of small displacement can be obtained using the system.

The MFCW system uses several signal generators on the transmitter. To determine the target distance, cross correlation between received multi-frequency signal and the loop back multi-frequency signal is performed. The shifting on peak of multi-frequency signal indicates the target distance. To determine the small displacement, it is sufficient to use one frequency as a reference signal. The signal with the lowest frequency is chosen as the reference signal. Regarding the phase detection position in proposed radar

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system that is performed on the computational level, the lowest frequency selection allows a smaller amount of data to be processed. The block diagram of the MFCW radar is depicted in Fig. 1.

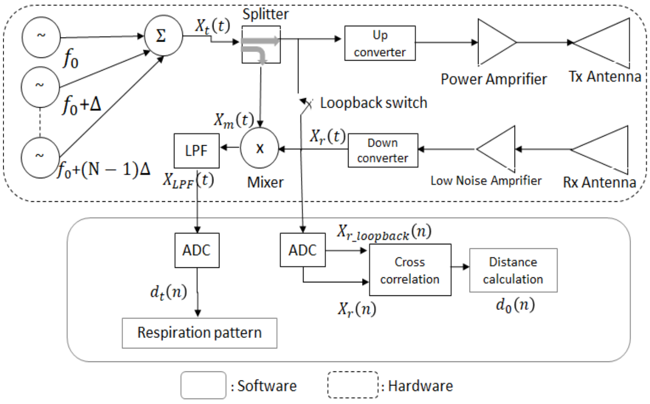

Fig. 1. Block diagram of Multi frequency CW radar that proposed for detection of small displacement.

The multi-frequency signal that is transmitted then can be written as (1) where N, A_n, and θ_n are stand for the number of frequency that employed in the system, amplitude of each multi frequency components and their initial phase. The received signal that come from the target reflection then can be expressed as (2) with λ_n is the wavelength with respect to the multi frequency signal components. After that, the received signal is multiplied by reference signal at mixer and the output can be determined as (3). The phase difference component from the mixer output consists of dc component that indicate the phase shift that occurred during a propagation. The dc component is then filtered by employing the LPF. the output of LPF can be determined as (4). Information regarding the distance of the target to the radar can be identified from the peak shift that occurred on multi frequency signal.

$$S_{TX}(t) = \sum_{n=1}^{N} A_n \cos(2\pi f_n t + \emptyset_n) \tag{1}$$

$$S_{RX}(t) = \sum_{n=1}^{N} B_n \cos\left(2\pi f_n t + \emptyset_n + \frac{4\pi d}{\lambda_n}\right) \tag{2}$$

$$S_M(t) = \begin{matrix} \sum_{n=1}^{N} C_n \cos(2\pi(f_n + f_1)t + \emptyset_n + \frac{4\pi d}{\lambda_n}) + \\ \sum_{n=1}^{N} D_n \cos(2\pi(f_n - f_1)t + \emptyset_n + \frac{4\pi d}{\lambda_n}) \end{matrix} \tag{3}$$

$$S_{LPF1}(t) = E_n \cos(\emptyset_n + \frac{4\pi d(t)}{\lambda_n}) \tag{4}$$

$$S_{Loopback}(t) = \sum_{n=1}^{N} F_n \cos(2\pi(f_n - f_1)t + \emptyset_n) \tag{5}$$

$$r_{LR}[k] = E(S_{TX}[k].S_{Loopback}[l-k]) \tag{6}$$

Switch that used to connect the splitter to the cross correlator unit which is applied to obtain the loop back component. The loop back signal is stored in memory and then can be used to calculate the cross correlation. Afterward, the target distance (d_o) can determined from cross correlation result and the loop back is employed as reference in measuring the shift. The cross correlation can be calculated as written in (6).

The analysis from theoretical perspective that is already discussed in this section describes that that the MFCW method has an ability to detect the target distance (d_0) and the small shift (d_t) that appeared at the target. The MFCW method can be overcome the problem of CW method in determining the small displacement location, while still exhibit a low bandwidth.

III. Multi Frekuensi Countinous Wave Implementation Using SDR

SDR is a technology used to realize a wireless system through a programming activity. This technology makes it easy to realize wireless systems including radar systems. Therefore, the implementation study of MFCW system for detecting respiration was performed using an SDR device. SDR devices developed include USRP, Blade RF, Hack RF and Lime RF. In this study Blade RF is used as an SDR device to realize a respiratory detection system using MFCW.

The block diagram in Fig. 1 is realized on SDR by employs of block programming on GNU Radio. GNU Radio is a programming interface for SDR devices that is open source. The programming in the GNU Radio block diagram is depicted in Fig. 2.

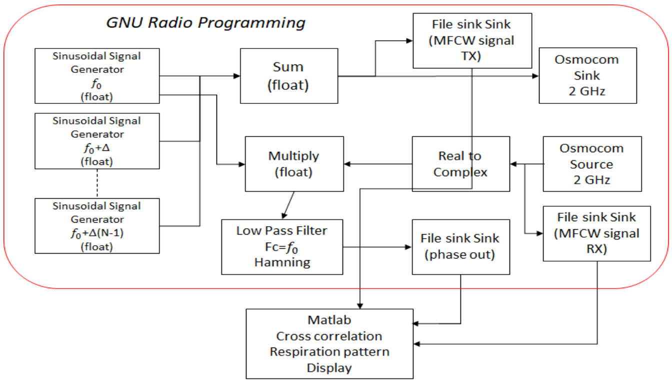

Fig. 2. SDR realization in GNU Radio

The multi-frequency signal generator in MFCW is realized with a number of Signal Generators blocks which are then added to the Sum block. The transmitter part consisting of up converter and power amplifier is realized with Osmocom Sink block. In the receiver section which consists of a Down Converter and Low Noise Amplifier realized with the Osmocom Source block. Then the output from the Osmocom source in the form of complex will be converted to real form using the Real to Complex block. The mixer section is realized with the multiply block. Low pass filter is realized using the LPF block by employing Window Hamming. The File Sink block is used to record multi-frequency signals emitted, multi-frequency signals received and respiration patterns. To calculate the cross correlation, the resulting data is then processed in Matlab. MFCW is realized on Blade RF by adding multi-frequency signals$[f_1, f_1 + \Delta, f_1 + 2\Delta, \ldots f_1 + (N-1)\Delta]$ where f_1 is the lowest frequency valued at 10KHz, Δ = 10 KHz and N is number of multi-frequency component. The width of the pulse is obtained from N and Δ.

IV. RESULT & ANALYSIS

Experiments on the realization of the MFCW radar system for respiratory detection using an SDR device were carried out with a laboratory experimental that the setup is shown in Fig 3. Distance of the SDR radar from the target is set of 1 meter. There are 2 targets used consisting of women as target-I and men as target-II. The respiration activity that include inhale and exhale then recorded in a certain time period. The recorded signals are then plotted using matlab to observe the results.

Fig. 4. shows the breathing pattern of the target-I detected by the MFCW radar system in the experiments that have been carried out. From these results the peaks and valleys of the phase detector output signal represent inhale and exhale activities. The number of repetitions of a signal over a given period of time can illustrate the rate of breathing. The size of the amplitude illustrates the respiratory amplitude. The DC offset on the phase detection results due to the influence of the distance of the target from the radar. From the result in Fig. 4 there are 12 respiratory cycles detected over 30 seconds observation. Therefore, the respiration rate of the target-I can be estimated as 24 / minute.

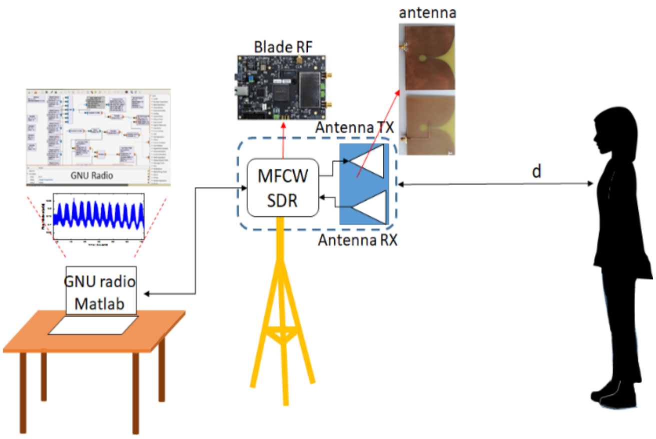

Fig. 3. Measurement Setup

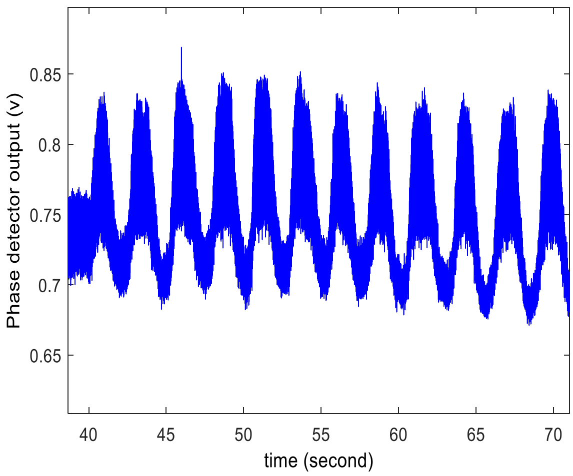

Fig. 4. Target-I breathing pattern

Fig. 5. Shows the breathing pattern on target-II detected by MFCW radar. From the result in Fig. 5 there are 7 respiratory cycles detected over 30 seconds observation. Therefore, the respiration rate of the target-II can be estimated as 14 / minute. The results in Fig. 4 and 5 show those differences in respiratory rate and respiratory amplitude in target-I and target-II can be detected by the proposed radar system.

In Fig. 6. shows the multi-frequency signal emitted and the multi-frequency signal received at the receiver. From these results it appears that there is a difference in position between the peak of the multi-frequency signal emitted and the multi-frequency signal received. The difference shows the delay that occurs in the waves emitted by the radar reflected back to the receiver. From this data we can obtain the target distance to the radar data. This shows that the MFCW system can overcome the weaknesses of the CW system. The repetition that occurred in the multi frequency signal is caused by sampling that is done in frequency domain in generating multi frequency signal. The repetition period will give limitation to the maximum distance detection of the radar system.

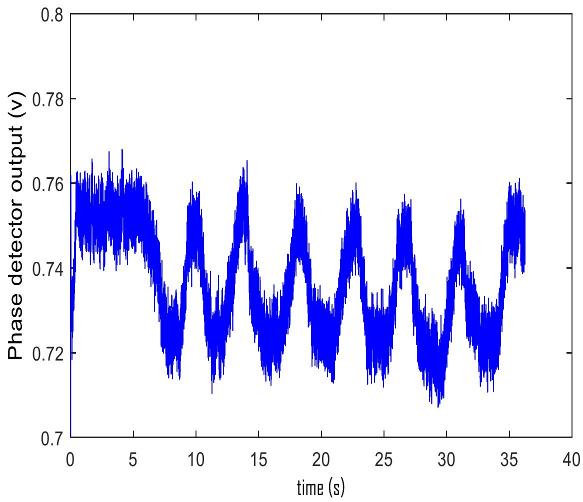

Fig. 5. Target-II Respiratory Pattern

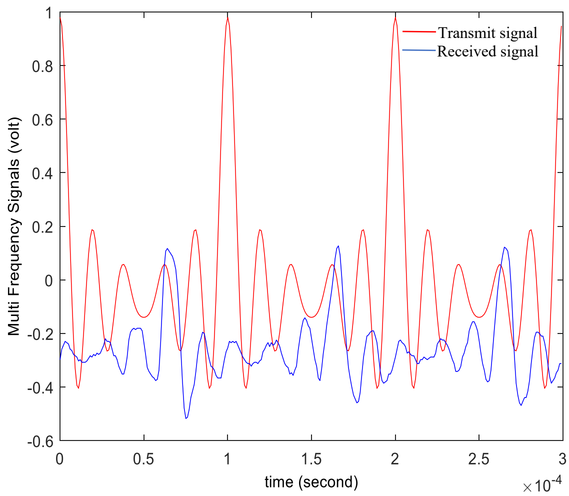

Fig. 6. Multi-frequency signals that transmitted and received by the MFCW radar system

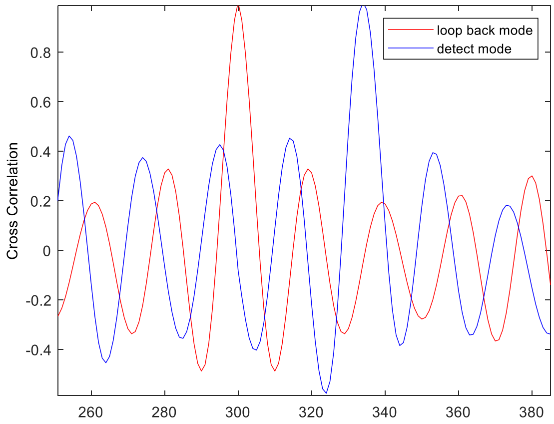

Fig. 7. Cross correlation results from the MFCW radar system during loop back mode and detection mode.

In Fig. 7 shows the cross correlation results from the MFCW radar system during loop back mode and detection mode. From the result in Fig. 7, it appears that the peak cross correlation between loop back mode and detection mode are located in a different position. The distance between the two peaks can be used for obtaining the distance of the target from MFCW system. The next research to develop the MFCW radar system to detect breathing is to test the performance of the MFCW under noise conditions, measuring the ability of the RF parts to support detection capabilities.

V. Conclusion

The Realization of MFCW radar for detecting human respiration was present in this paper and SDR technology is employed as a realization platform of MFCW radar for respiration detection. Laboratory experiments were conducted to study the realization of the radar system in detecting two different targets. From all the results obtained, it can be concluded that the implementation of the MFCW radar system using SDR shows that pattern, rate, and amplitude of human breathing can be obtained by using the MFCW radar. The target distance from the radar can be obtained from the cross correlation result between received MFCW signal and loop back signal. Regarding the capability detection of the radar system in identified the target distance, we can conclude that the radar system is potentially used for multi target detection operation.

Acknowledgement

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