Analyze Transmission Data from a Multi-Node Patient's Respiratory FMCW Radar to the Internet of Things

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Abstract—This is the development of a system that has been made, FMCW radar for human or patient breathing which will then determine the type of disease or disorder in the patient just by looking at the type of breathing. This research uses data from FMCW Radar for human or patient breathing, which is then converted to data that can be read in real-time by the public, doctors, or medical teams through a web server; the web server used is iotmedis.brin.go.id. The novelty of this study is that various types of respiratory data are taken from various points so that it will cause new analysis, namely the process of transmitting data on server traffic or uplink and downlink processes. Specific data and research novelty is how Multi patient respiratory data from OmnipreSense or FMCW Radar can be processed by a microprocessor using MQTT, and multi-patient data can be displayed on the server in real-time.

Keywords—FMCW Radar data; realtime monitoring; internet of things; transmission data; multi node

I. INTRODUCTION

Biomedical technology is overgrowing with various modes or types of research using the latest devices, such as Internet of Things (IoT) modules [12]. Some IoT modules, such as WiFi module server ESP32 [8,9] or ESP 8266 used for server communication, continue to be developed to get the best performance from previous research using FMCW radar. FMCW radar [10,11] is an active type of radar sensor that transmits continuous transmission power such as continuous wave (CW Radar); the FMCW type Radar is measured based on the difference in phase or frequency between the signal emitted and the signal received. In this study, the focus is on the patient's respiratory condition, which is monitored from the FMCW Radar [13-15], as shown in Fig. 1. The principle of this Radar can be seen in Fig. 4. and the Block Diagram of FMCW radar sensor shown in Fig. 2 and Fig. 3. This research will focus on displaying radar data and analysis on the iotmedis.brin.go.id server, multipoint. One of the analyses performed is RF Propagation Radar between patients and Radar with different distances [5,6,7].

II. THEORY

A. FMCW Radar Module and Block Diagram

Radar Frequency Modulated Continuous Wave (FMCW) [16-20] is a specific type of Radar that continuously varies the frequency of a transmitted signal at a known rate over a set period, using a periodic linear function such as a sawtooth signal to modulate a sinusoidal radar signal [1]. An FMCW radar’s unique ability to differentiate between ranges is accomplished by frequency modulating an ongoing transmission. It can even calculate range, velocity, or phase simultaneously for multiple targets using a process known as IQ demodulation and multiple chirps [2].

Furthermore, Fig. 3 shows the concept of FMCW radar for non-contact detection [3]. The splitter splits the signal generated by the FMCW signal generator. A power amplifier amplifies the signal before the transmitting antenna transmits it. Electromagnetic waves sent out from the transmitting antenna are received by the receiving antenna. Low-noise amplifiers amplify low-power signals without significantly degrading the signal-to-noise ratio (SNR).

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Fig. 3. The concept of FMCW Radar for non-contact detection (personal research data).

Moreover, the signal split by the splitter and FMCW signal generator is combined with the output of the low noise amplifier at the mixer. A lowpass filter (LPF) is used to filter the signal frequencies. The LPF principle is a filter that passes signals with frequencies below the cutoff frequency. After passing through the LPF, the output signal can be computed with a Fast Fourier Transform (FFT) to determine the target range. The output signal contains phase shift information. The LPF output is affected by the phase difference between reflected and transmitted waves. The formula used in this calculation is the phase difference caused by propagation delay due to target range shift.

The phase computation of the LPF output can be used to calculate a small shift. Phase processing from the LPF output is accomplished by IQ demodulation of the RF circuit. Two double-balanced mixers are combined. By changing the In-phase (I) and quadrature (Q) inputs in the branches of the IQ demodulator (1), the LPF output is combined with a reference signal [4]. Reference signals are written as (2) [4]. The phase data can then be obtained using the arctangent computation. A sinusoidal signal phase shifted by 90 from the FFT output is used as the basis for the LPF output approximation. It can determine the frequency of the output signal from the LPF by applying the FFT and performing Fourier transform computations. The phase-shifted output of an FMCW radar system is formulated as (3).

\[ S_{LPF} = S_{LPFG} \cos (2\pi f_s \tau + 2\pi \frac{df}{dt} \frac{\tau}{\tau}) \]  
\[ S_{syn} = S_{syn} \cos (2\pi \frac{df}{dt} \frac{\tau}{\tau}) \]  
\[ \tau = 2\pi f \sigma \frac{1}{\tau} \left( \frac{E_{ref}(\tau)}{E_{ref}(\tau)} \right) \]  
\[ \varphi (\tau) = \tan^{-1} \left( \frac{\text{Im}[Q(\tau)]}{\text{Re}[Q(\tau)]} \right) \]  

**B. Doppler Effect and FMCW Equation**

The Doppler effect principle of this formula is used for systems on Radar, including FMCW; for that, it is necessary to understand the formula for the Doppler effect, which is affected by the Speed of light (c). The Doppler frequency (f_r), which is determined by the Speed of light in air with the formula c' = c/1.0003, is slightly slower than in a vacuum, and \( v \) is the target speed, which can be written as Eq. 5. And the Doppler frequency is generally written with the formula by looking if \( v < c' \) or \( c' - v = c'(1 - \frac{v}{c'}) \) as the equation 6.

\[ f_r = \frac{f_t (1 + \frac{v}{c'})}{1 - \frac{v}{c'}} \]  
\[ f_d = f_r - f_t = 2v \left( \frac{f_r}{c' - v} \right) \]  

Furthermore, in FMCW Radar, the signal is transmitted by periodically increasing and decreasing the frequency; when the echo signal is received, there will be a change in frequency or a time delay denoted by \( \Delta t \). In FMCW radar, the phase and frequency differences between the transmitted and received signals are both measured. The signal from the radar position \( R \) radiates to a certain plane or object shown in Eq. (7).

\[ R = \frac{c_0 |af|}{2} = \frac{c_0 |af|}{2 \left( \frac{df}{dt} \right)} \]  
\[ C_0 = \text{Speed of light (3.10}^8 \text{m/s)} \]  
\[ \Delta t = \text{delay time (s)} \]  
\[ \Delta f = \text{measured frequency difference (Hz)} \]  
\[ R = \text{distance between the antenna and reflecting object (ground) (m)} \]  
\[ \frac{df}{dt} = \text{frequency shift per unit of time} \]

Furthermore, for the Range Resolution of FMCW radar, the bandwidth BW of the transmitted signal is decisive, as in chirp radar. However, the technical possibilities of the Fast Fourier Transform are limited by time, i.e., by the duration of the sawtooth \( T \) as Eq. (8). The resolution of an FMCW radar is determined by the frequency changes that occur within this time limit.
\( \Delta f_{\text{FFT}} = \frac{1}{\pi} \frac{d(f)}{d(t)} (8) \)

\( \Delta f_{\text{FFT}} = \frac{\text{slightest measurable frequency difference}}{\text{steepness of the frequency deviation}} \)

\( f_{\text{up}} = \text{Upper frequency (end of the sawtooth)} \)

\( f_{\text{down}} = \text{Lower frequency (start of the sawtooth)} \)

In the sinusoidal frequency modulation theory in Fig. 5, the time domain formula is obtained \( y(t) \) value.

\[ y(t) = \cos(2\pi f_c B \cos(2\pi f_m t)) \]

\[ y(t) = \cos(2\pi f_c B \cos(2\pi f_m t + \delta t)) \]

\[ y(t) \approx \cos(-4\pi B \sin(2\pi f_m (2t + \delta t) \sin(2\pi f_m \delta t) + 2\pi B \cos(2\pi f_m (2t + \delta t))) \] (11)

And the modulation spectrum spread (MSS) formula is as in Eq. (12) with an equal range of 0.5C/\( \delta t \).

\[ \text{MSS} \approx 2(B+1)2(B+1)f_m \sin(\delta t) \] (12)

The relationship between the adjusted Doppler frequency of the distance determination and the Doppler frequency of the moving target is shown in Eq. (13) and (14).

\[ f(R) = \frac{\Delta f_1 + \Delta f_2}{2} \] (13)

\[ f(D) = \frac{\Delta f_1 + \Delta f_2}{2} \] (14)

\( \Delta f_1 = \text{frequency difference at the rising edge} \)

\( \Delta f_2 = \text{frequency difference at the falling edge} \)

III. METHOD

The method in this research is shown in Fig. 7 by looking at a more specific step-by-step process in the flowchart, Fig. 6. While the real-time respiratory Radar is documented in Fig. 8. In the case of these radar-based respiratory patients, it is essential to understand the algorithm shown in Algorithm 1.

**Algorithm 1:** Radar-based respiratory system readout

Start

Initialize of Radar

While Radar Capture loop

- For (Patient’s position ready), do
  - Capture and read respiratory patient data from Radar
  - Perform Filtering
  - Perform respiratory motion detection
  - Calculate the respiratory frequency
  - Display the reading result
  - Pause for a few seconds to allow the next breath to be detected

if (Respiratory patient’s data is not readable)

- Restart the Radar Functionality and restart the detection of the respiratory patient.
else

- Radar Error

Finish

End

![Fig. 6. Flowchart system (personal research data).](image)

![Fig. 7. Positioning of FMCW Radar during respiratory measurement (personal research data).](image)
IV. RESULT AND ANALYSIS

The analysis results show the respirometer and magnitude of the Radar and patient with different distances, namely 30 cm, 60 cm, 100 cm, 300 cm, 450 cm, and 1000 cm or 10 meters. The respirometer and magnitude are different from each distance difference, and this is due to the Doppler frequency of the distance determination.

Fig. 9 shows the position of the FMCW Radar that has not been given a mounting case, this is for initial testing and to obtain signal accuracy.

Specifically, Data Radar for respiratory patients is shown in Fig. 10 (30 cm), Fig. 11 (60 cm), Fig. 12 (100 cm), Fig. 13 (300 cm), Fig. 14 (450 cm), Fig. 15 (1000 cm), and precisely or detail respiratory patient in Fig. 16 the difference is in the distance, which is the closest distance of 30 cm to 10 meters.
Fig. 11. Radar output for a respiratory patient at a distance of 60 cm.

Fig. 12. Radar output for a respiratory patient at a distance of 100 cm.

Fig. 13. Radar output for a respiratory patient at a distance of 300 cm.

Fig. 14. Radar output for a respiratory patient at a distance of 450 cm.
Fig. 15. Radar output for a respiratory patient at a distance of 1000 cm.

Fig. 16. Radar output for a respiratory patient detail.

Furthermore, by sending MQTT-based data, with Raspberry Pi 4 as a processor, Radar data can be displayed on the Application Server iotmedis.brin.go.id in real-time from several patients or multi-nodes, as shown in Fig. 17. In Fig. 17, sample data is taken from four different patient conditions, namely with varying conditions of breathing, in taking samples, there is a conditioning of patient breathing, namely fast breathing, slow breathing, holding the breath, and normal breathing, this is done to get different results to get the most accurate radar reading system. As for the download process, it can be done quickly. Real-time patient respiratory data can be downloaded in SVG, PNG, and CSV formats, as shown in Fig. 18.

Fig. 17. Multi-data respiratory patient from server real-time and smartphone.

Fig. 18. Download realtime data.
V. CONCLUSION

FMCW radar can accurately detect breathing from each experiment, for example, when the patient is sitting, standing, or running results, or from differences in male and female gender who have different lung volumes. The experiments conducted produce respiratory data that is in accordance or synchronized with the FMCW radar measurement data. Next is to send breathing data to the iotmedis.brin.go.id server. While the server functions very well by displaying the respiration meter and magnitude display of human or patient breathing results, this data can be viewed in real-time with Multi data Respiratory Patients' real-time use of Android and a smartphone with an internet connection. Finally, downloading real-time graphs of respiratory data can be done easily on a smartphone device. Specific data and research novelty is how Multi patient respiratory data from OmnipreSense or FMCW Radar can be processed by a microprocessor using MQTT, and multi-patient data can be displayed on the server in real-time; this process was a success and was successfully tested.

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REFERENCES