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

Rizky Rahmatullah[1], Puput Dani Prasetyo Adi[2]*, Suisbiyanto Prasetya[3], Arief Budi Santiko[4], Yuyu Wahyu[5], B.Berlian Surya Wicaksana[6], Stevry Yushady CH Bissa[7], Riyani Jana Yanti[8], Aloysius Adya Pramudita[9]
Research Center for Telecommunication, National Research and Innovation Agency (BRIN), Bandung, Indonesia[1,2,3,4,5,6,7,8]
Master of Electrical Engineering Program, Telkom University, Bandung, Indonesia[3,9]

***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).

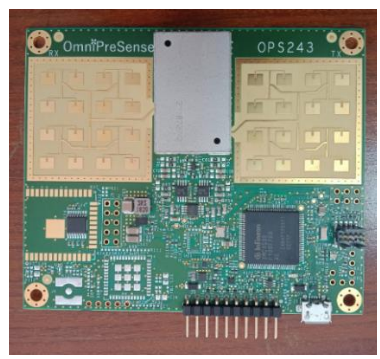

Fig. 1. OPS243-C FMCW and Doppler Radar Sensor used in this research (personal research data).

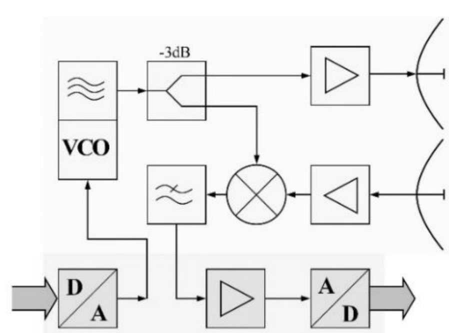

Fig. 2. Block Diagram of FMCW radar sensor (personal research data).

*Corresponding Author.

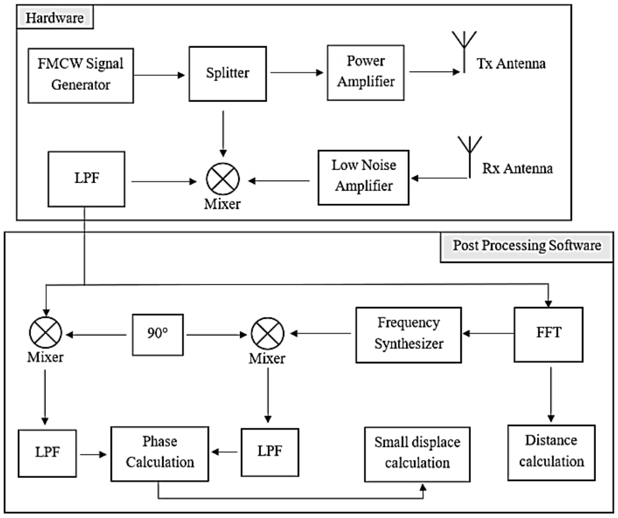

Fig. 3. The concept of FMCW Radar for non-contact detection (personal research data).

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).

$$S_{LPF} = S_{LPFO} COS(2\pi f_{\circ} \tau + 2\pi \frac{\Delta f_t \tau}{t_\tau} \quad (1)$$

$$S_{syi} = S_{sy} COS(2\pi \frac{\Delta f_t \tau}{t_\tau}) \quad (2)$$

$$\tau = 2\pi\pi f o^{-1} tan^{-1} \left(\frac{E_q(t)}{E_i(t)}\right) \quad (3)$$

$$\varphi(t) = tan^{-1}\left[\frac{Im\{Q(t)\}}{Re\{I(t)\}}\right] \quad (4)$$

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 $\boldsymbol{v}$ is the target speed, which can be written as Eq. 5. And the Doppler frequency is generally written with the formula by looking if $\boldsymbol{v}$ < c' or c'-$\boldsymbol{v}$ = c,' and $\boldsymbol{f_d} = 2\boldsymbol{v}\frac{\boldsymbol{f_t}}{\boldsymbol{c'}}$ as the equation 6.

$$f_r = f_t \left(\frac{1+\frac{v}{c}}{1-\frac{v}{c'}}\right) \quad (5)$$

$$\boldsymbol{f_d = f_r - f_t = 2v\left(\frac{f_t}{c'-v}\right)} \quad (6)$$

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 Δt. 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).

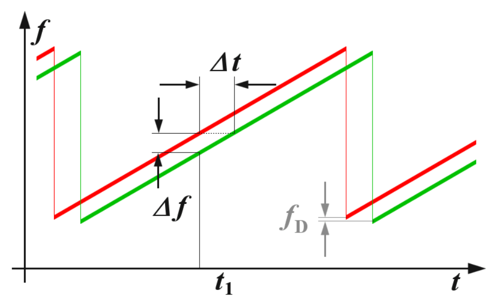

Fig. 4. Ranging with an FMCW system (personal research data).

$$R = \frac{C_0\,|\Delta t|}{2} = \frac{C_0\,|\Delta f|}{2\left(\frac{d(f)}{d(t)}\right)} \quad (7)$$

C_0 = Speed of light (3.10^8 m/s)

Δt =delay time (s)

Δf= measured frequency difference (Hz)

R = distance between the antenna and reflecting object (ground) (m)

$\frac{df}{dt}$ =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.

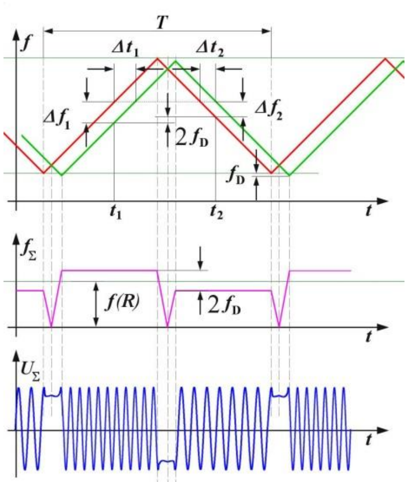

Fig. 5. Triangular modulation pattern (personal research data).

$$\Delta f_{FFT} = \frac{1}{T} = \frac{d(f)}{d(t).(f_{up} - f_{down})} \quad (8)$$

Δf_{FFT} = slightest measurable frequency difference

$\frac{d(f)}{d(t)}$ = Steepness of the frequency deviation

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

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

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

$$y(t) = cos\{2\pi[f_c + B\cos(2\pi f_m t)]t\}, \text{ where } B = \frac{f_\Delta}{f_m} \quad (9)$$

Moreover, Eq. (9) is applied to the condition of the radar transmission to the reflector or object, as in Eq. (10) and (11). Where δt is the time delay. Then, the transmitted signal is eliminated; this is due to the time delay and modulation index value in the data transmission process from the Radar to the object or reflector.

$$y(t) = cos\{2\pi\,[f_c + B\cos(2\pi f_m(t+\delta t))](t+\delta t)\} \cos\{2\pi[f_c + B\cos(2\pi f_m t)]t\} \quad (10)$$

$$y(t) \approx \cos\{-4t\pi B sin(2\pi f_m(2t+\delta t)\sin(\pi f_m \delta t) + 2\delta t\pi B\cos(2\pi f_m(t+\delta t))\} \quad (11)$$

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

$$\text{MSS} \approx 2\,(\text{B}+1)2(B+1)f_m\sin(\delta t) \quad (12)$$

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).

$$f(R) = \frac{\Delta(f_1) + \Delta(f_2)}{2} \quad (13)$$

$$f(D) = \frac{|\Delta(f_1) + \Delta(f_2)|}{2} \quad (14)$$

$f(R)$ = frequency as a measure of distance determination

$f(D)$ = Doppler frequency as a measure of the speed measurement

$\Delta(f_1)$ = frequency difference at the rising edge

$\Delta(f_1)$ = 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
--Remove Noise
--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

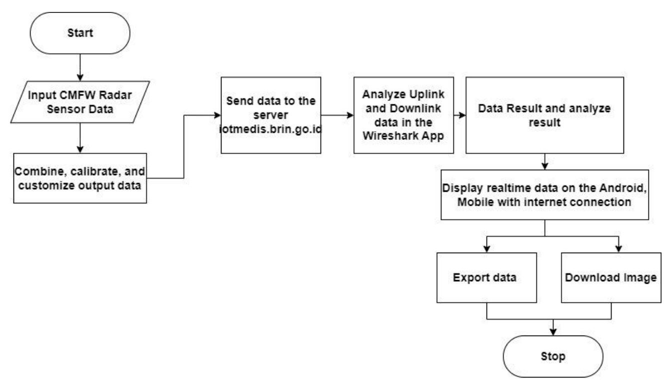

Fig. 6. Flowchart system (personal research data).

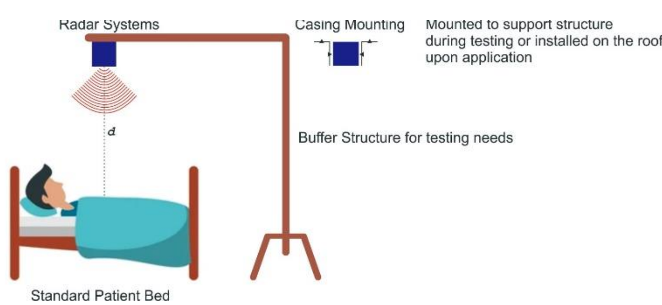

Fig. 7. Positioning of FMCW Radar during respiratory measurement (personal research data).

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.

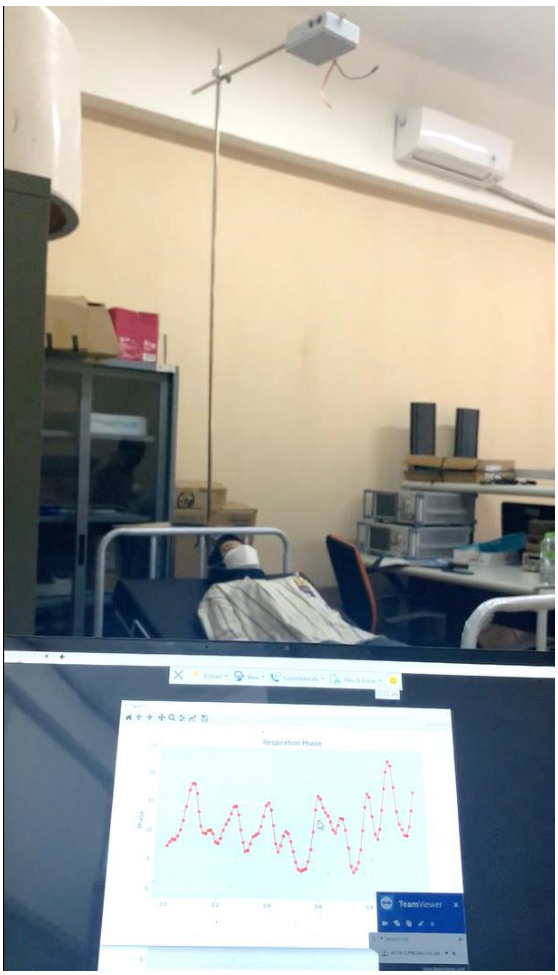

Fig. 8. Breathing GUI display of FMCW radar results (personal research data).

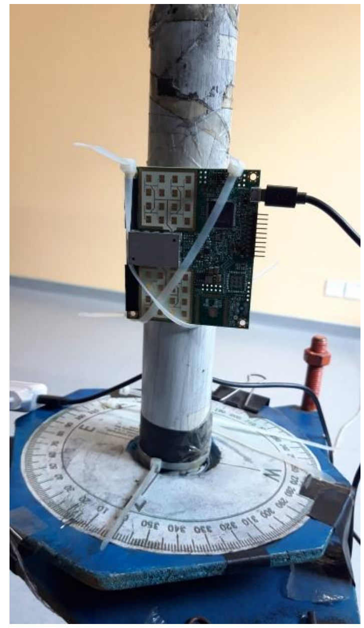

Fig. 9. Positioning of FMCW Radar on this research prototype (personal research data).

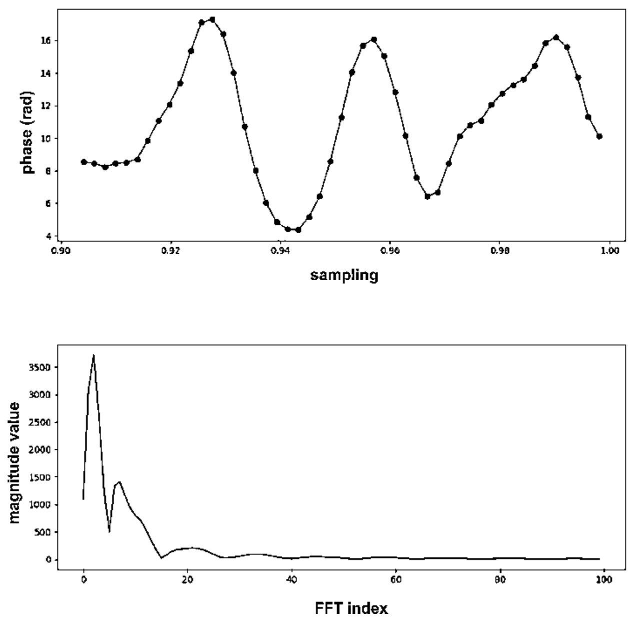

Fig. 10. Radar output for a respiratory patient at a distance of 30 cm.

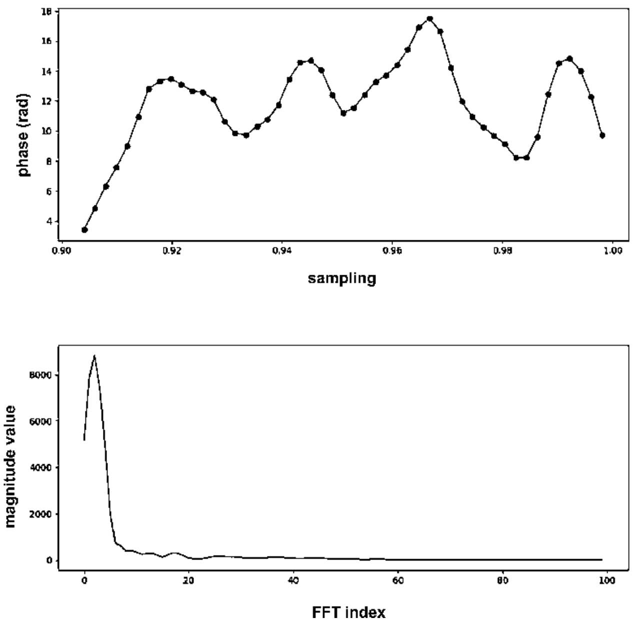

Fig. 11. Radar output for a respiratory patient at a distance of 60 cm.

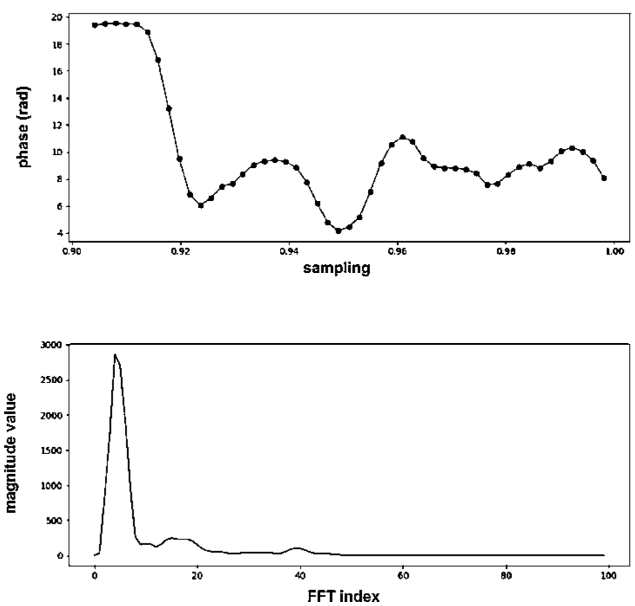

Fig. 12. Radar output for a respiratory patient at a distance of 100 cm.

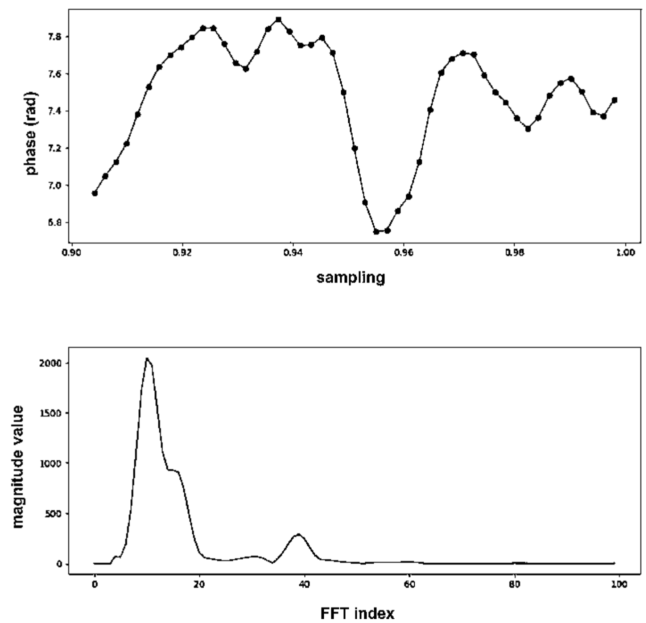

Fig. 13. Radar output for a respiratory patient at a distance of 300 cm.

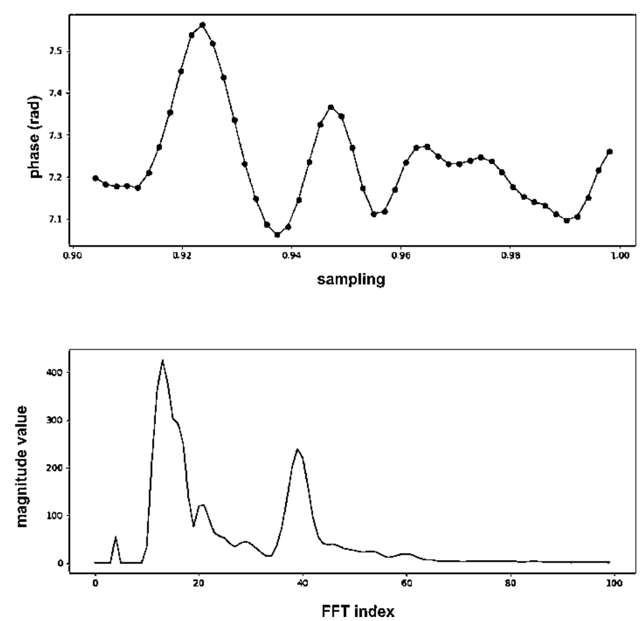

Fig. 14. Radar output for a respiratory patient at a distance of 450 cm.

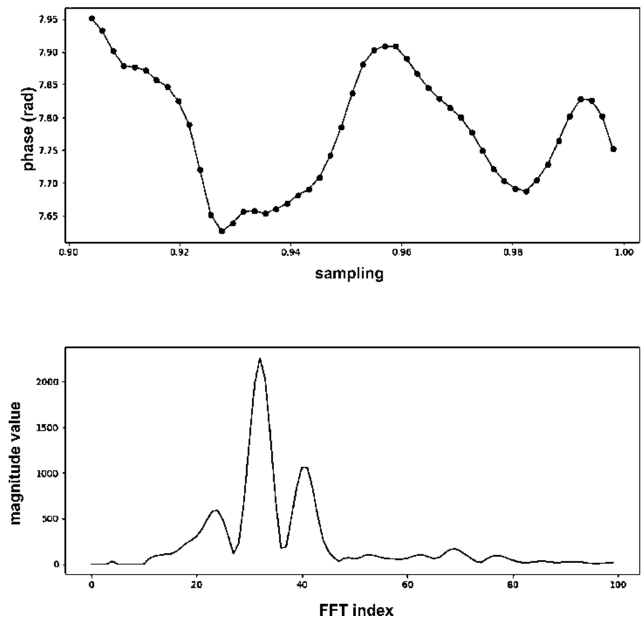

Fig. 15. Radar output for a respiratory patient at a distance of 1000 cm.

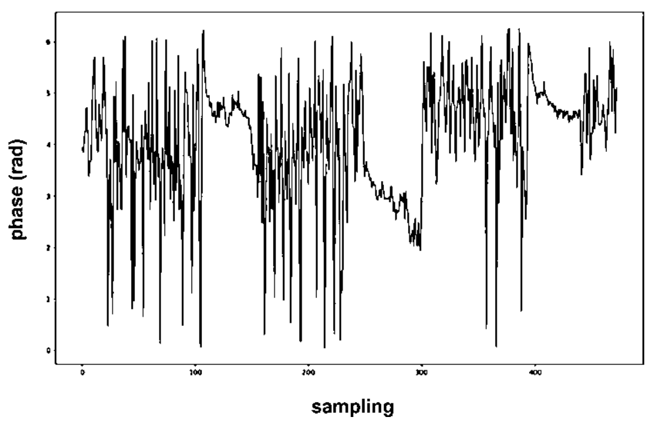

Fig. 16. Radar output for a respiratory patient detail.

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 realtime 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.

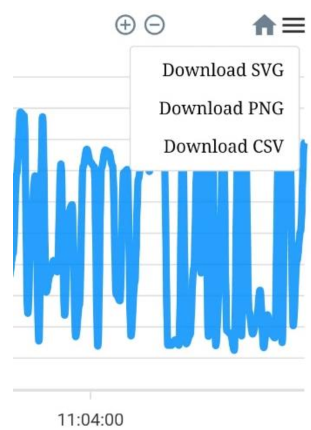

Fig. 18. Download realtime data.

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 respire 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.

Acknowledgment

Thank you to the National Research and Innovation Agency (BRIN) of the Republic of Indonesia, especially colleagues at the BRIN Telecommunications Research Center, who have struggled to find data for the current research, and thanks to the team from Telkom University who helped complete this research. Hopefully, this research can continue to be developed by other researchers for the perfection of the study and can be a good reference for similar research, especially in the medical.

References

[1] M. Skolnick, Radar Handbook, 3rd Ed., America: McGraw-Hill Education, 2008.

[2] Axel Trange, "FMCW mmWave Radar for Detection of Pulse, Breathing and Fall within Home Care," in Degree Project in Electrical Engineering, Second Cycle, 30 Credits, Stockholm, Sweden, 2021.

[3] Y. Wahyu, R. J. Yanti, S. Prasetya, B. B. S. Wicaksana, B. E. Sukoco, F. Ridhia, A. A. Pramudita, "24 GHz FMCW Radar for Non-Contact Respiratory Detection," in 2022 6th International Conference on Information Technology, Information Systems and Electrical Engineering (ICITISEE).

[4] H. Pratiwi, M. R. Hidayat, A. A. Pramudita, and F. Y. Suratman, "Improved FMCW Radar System for Multi-Target Detection of Human Respiration Vital Sign," Jurnal Elektronika dan Telekomunikasi, vol. 19, no. 2, pp. 38-44, Dec. 2019. doi: 10.14203/jet.v19.38-44 [5] Mark A Richards et al. Principles of modern Radar. Citeseer, 2010.

[5] Adi, P.D.P, et.al, "LoRaWAN Technology in Irrigation Channels in Batu Indonesia", December 2021, Jurnal Ilmiah Teknik Elektro Komputer dan Informatika, DOI: 10.26555/jiteki.v7i3.22258.

[6] P. D. P. Adi et al., "Application of IoT-LoRa Technology and Design in irrigation canals to improve the quality of agricultural products in Batu Indonesia," 2021 2nd International Conference On Smart Cities, Automation & Intelligent Computing Systems (ICON-SONICS), Tangerang, Indonesia, 2021, pp. 88-94, doi: 10.1109/ICON-SONICS53103.2021.9617175.

[7] P. D. P. Adi et al., "ZigBee and LoRa performances on RF Propagation on the Snow Hills area," 2021 International Conference on Converging Technology in Electrical and Information Engineering (ICCTEIE), Bandar Lampung, Indonesia, 2021, pp. 36-41, doi: 10.1109/ICCTEIE54047.2021.9650623.

[8] P. D. P. Adi and A. Kitagawa, "A Review of the Blockly Programming on M5Stack Board and MQTT Based for Programming Education," 2019 IEEE 11th International Conference on Engineering Education (ICEED), Kanazawa, Japan, 2019, pp. 102-107, doi: 10.1109/ICEED47294.2019.8994922.

[9] P. D. P. Adi, A. Kitagawa and J. Akita, "Finger Robotic control use M5Stack board and MQTT Protocol based," 2020 7th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), Semarang, Indonesia, 2020, pp. 1-6, doi: 10.1109/ICITACEE50144.2020.9239170.

[10] M. Jankiraman, B. J. Wessels and P. Van Genderen, "Pandora multifrequency FMCW/SFCW radar," Record of the IEEE 2000 International Radar Conference [Cat. No. 00CH37037], Alexandria, VA, USA, 2000, pp. 750-757, doi: 10.1109/RADAR.2000.851929.

[11] C. S. Chaves, R. H. Geschke, M. Shargorodskyy, R. Brauns, R. Herschel and C. Krebs, "Polarimetric UAV-deployed FMCW Radar for Buried People Detection in Rescue Scenarios," 2021 18th European Radar Conference (EuRAD), London, United Kingdom, 2022, pp. 5-8, doi: 10.23919/EuRAD50154.2022.9784490.

[12] P.D.P.Adi, V.M.M.Siregar, "A Soil moisture sensor based on Internet of Things LoRa", Internet of Things and Artificial Intelligence Journal, Vol.1, Issue.2, 2021, May, DOI:10.31763/iota.v1i2.495.

[13] E. Hyun, Y. -S. Jin and J. -H. Lee, "Moving and stationary target detection scheme using coherent integration and subtraction for automotive FMCW radar systems," 2017 IEEE Radar Conference (RadarConf), Seattle, WA, USA, 2017, pp. 0476-0481, doi: 10.1109/RADAR.2017.7944250.

[14] S. Murali, K. Subburaj, B. Ginsburg and K. Ramasubramanian, "Interference detection in FMCW radar using a complex baseband oversampled receiver," 2018 IEEE Radar Conference (RadarConf18), Oklahoma City, OK, USA, 2018, pp. 1567-1572, doi: 10.1109/RADAR.2018.8378800.

[15] M. H. Moghaddam, S. R. Aghdam, A. Filippi and T. Eriksson, "Statistical Study of Hardware Impairments Effect on mmWave 77 GHz FMCW Automotive Radar," 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 2020, pp. 1-6, doi: 10.1109/RadarConf2043947.2020.9266605.

[16] S. Rao and A. V. Mani, "Interference Characterization in FMCW radars," 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 2020, pp. 1-6, doi: 10.1109/RadarConf2043947.2020.9266283.

[17] T. Zhang, G. Liao, Y. Li, T. Gu, T. Zhang and C. Chen, "A Time-domain strip-map processing scheme for FMCW imaging," 2021 CIE International Conference on Radar (Radar), Haikou, Hainan, China, 2021, pp. 228-231, doi: 10.1109/Radar53847.2021.10028593.

[18] Z. Xu, Y. Wang, J. Luo, M. Che, H. Wang and D. Zhang, "Potential of Reducing FMCW Radar Mutual-interference Using Nonlinear FM Signals," 2021 CIE International Conference on Radar (Radar), Haikou, Hainan, China, 2021, pp. 2852-2855, doi: 10.1109/Radar53847.2021.10028399.

[19] L. Wang and J. Wang, "Radon-Fourier Transform in FMCW Radar," 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 2020, pp. 1-6, doi: 10.1109/RadarConf2043947.2020.9266324.

[20] M. Altmann, P. Ott, N. C. Stache, D. Kozlov and C. Waldschmidt, "A Cognitive FMCW Radar to Minimize a Sequence of Range-Doppler Measurements," 2020 17th European Radar Conference (EuRAD), Utrecht, Netherlands, 2021, pp. 226-229, doi: 10.1109/EuRAD48048.2021.00065.