Detecting Targets by 24GHz FMCW Radar Technique

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Abstract: Radar technique has an important role in industrial and agricultural sectors. However, in the past, radar technique was used to detect target, which was approximately 5 cm or greater. Detecting small targets by radar is very useful for agricultural industry. This research aims to apply radar techniques and equipment to enhance detection capabilities. The OPS243 module is conveniently used to adjust internal parameters to perform experiments and analyze the data by Python program. The target sizes in this study were 5, 4, 3, 2, 1, and 0.5 cm. The study revealed that target of a sizes indicated above might be detected by a radar fitted with an OPS243 module. However, it was unable to detect 0.5 cm target. In conclusion, the radar system can be applied to detect target with sizes of 1 cm or more.

Keywords: *FMCW radar, radar, 24 GHz.*

1. Introduction

FMCW radar systems are commonly used for military and automotive applications. Small targets are, therefore, one of the challenges of radar technology. This system is now becoming accepted and is still an important topic that receives more and more attention nowadays.

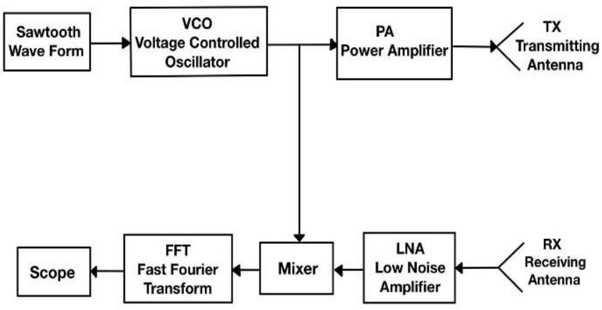

Fig. 1. FMCW Radar Block Diagram

Fig 1 shows FMCW Radar Block Diagram Chirp Signal, often referred to as FMCW Radar Signal, is created by modulating a continuous wave signal with a linear periodic signal. This enhances the capability of determining the detected target's range and speed. By sending a linear periodic waveform to a Voltage Controlled Oscillator (VCO), amplifying the chirp signal it produces, and transmitting it with a suitably directional antenna, it is possible to create an FMCW radar system. The echo signal is received and amplified by Low Noise Amplifier (LNA) and mixed with the original signal to get a signal which obtains Beat frequency. For the last convert, the resultant signal to frequency domain (Fast Fourier Transform) FFT to obtain range data [1]. According to survey results in the past years, FMCW Radar has been receiving more and more attention continuously. Based on data from Google Scholar, recent radar research has found that compact radar devices are accessible.

Table 1. Number of publications on FMCW radar according to Google Scholar.

Years (2015-2021)	Amount
2015-2016	3,330
2016-2017	3,890
2017-2018	4,360
2018-2019	5,220
2019-2020	5,810
2020-2021	6,730

Google Scholar also points out the ability to detect small targets with a size of less than 5 cm [2]. Such as detecting nano drones or pests. Frequency-modulated continuous wave radar (FMCW radar) is deployed to solve such problems because radar can detect at close range. It is also one of the essential elements of technology since it is no longer affected by harsh environments. This radar is also very flexible, with no blind range and high resolution. Although many publications on FMCW radar have been carried out as shown in Table 1. The FMCW Radar has seldom been used to detect very small targets. From literature review, the smallest target captured by FMCW radar was 5 cm nano drone [3]. Speed of nano drone can be 0.05m/s (slow), 0.13m/s (medium), 0.5m/s (fast) [4]. Detection of small targets are extremely useful for application to detect insects in farms which is very important in agricultural industry. The objective of this research is to conduct experiment and analyze detection capability of FMCW radar.

2. Technique

2.1 FMCW radar

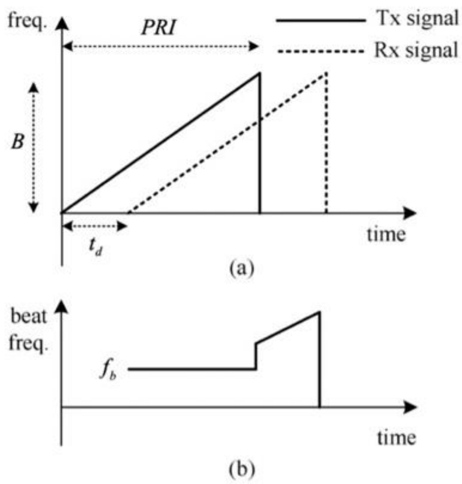

Fig. 2. (a) the transmitted signal and the received signal (b) beat signal [5].

The FMCW radar is a continuous frequency-modulated microwave transmission. Figure 2 shows the transmitted signal frequency with sawtooth modulation. The received signal is reflected from the target. The two signals are combined in the frequency domain. This signal is called a pulsation signal, as shown in Figure 2(a) where t_d is the delay time between the transmitted and received signals. A standard method for FMCW radar is a spectral analysis of the beat signal, i.e., the beat frequency can obtain via FFT (Fast Fourier Transform) processing as follows.

$$R = (C \cdot PRI \cdot f_b)/(2 \cdot B) \tag{1}$$

Where
R = The range of the target
C = Speed of light
B = Modulation bandwidth
f_b = Beat frequency
PRI = Pulse repetition interval, which is the chirp period

The range step ΔR is computed as follows.

$$\begin{aligned} \Delta R &= (C \cdot PRI \cdot f_b)/(2 \cdot B) \\ &= (C \cdot PRI)\ (f_s/N_{fft})/(2 \cdot B) \end{aligned} \tag{2}$$

N_{fft} = The FFT point
f_s = ADC (analog-to-digital converter) sampling rate

Maximum PRI is determined by

$$PRI = 1/(2 \cdot f_{maxD}) \tag{3}$$

$$N = C(2 \cdot f_c \cdot PRI \cdot \Delta v) \tag{4}$$

N = The number of ramps
f_c = Rising beat frequency
Δv = Velocity resolution
f_{maxD} = Maximum doppler frequency to be detected

2.2 Radar equation

The power received by the radar is computed using the following equation.

$$P_R = P_T(\sigma^0 A)\left[\frac{G^2\lambda^2}{(4\pi)^3 R^4}\right] \tag{5}$$

P_R = Total power received
P_T = Power transmitted (Power transmitted)
σ^0 = Radar dispersion per unit area or the scatter coefficient (Radar scatter coefficient)
A = Cross-sectional area (RADAR cross section)
G = Antenna gain
R = Distance in range (Range)
λ = Wavelength

2.3 24 GHz

Each frequency range of electromagnetic waves is well known and used for many benefits. The wave with a frequency of Giga Hertz is a type of microwave wave with a frequency in the range of 10^8-10^{12} Hz or a wavelength of 1 mm - 10 cm [6]. It is used for long-distance telecommunication, especially used as a radar signal, since microwaves can reflect metal well.

2.4 Far field method

Antenna radiation pattern measurement of the relative magnitude and phase of an electromagnetic signal received were used to create a pattern measuring antenna. The far field was calculated for the design using the followed equation.

$$R > \frac{2D^2}{\lambda} \tag{6}$$

λ = Wavelength
D = The largest size of the antenna
R = The distance from the antenna to the remote field area

3. Analysis

3.1 Antenna Pattern

Based on Far Field Theory, the detection range of the OPS243 depends on the object to be detected and the RCS (cross-sectional radar) [7]. As the object moves more to the right or left of the module center, it will reduce the detection range.

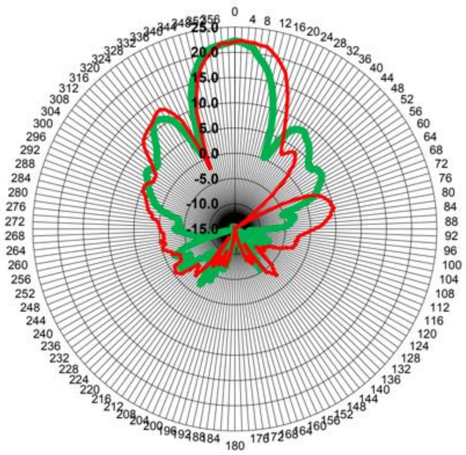

Fig. 3. Module FMCW 24 GHz Antenna Pattern [8].

The OPS243 is a simple, short-range radar sensor that provides motion detection, speed, direction, and range information [9]. The onboard ARM processor handles all radar signal processing. The basic principle of the sensor utilizes the Doppler frequency shift to detect speed and direction and FMCW time of flight (TOF) to detect range. The detection range of the OPS243 covers a narrow 20° azimuth (horizontal) and 24° altitude (vertical) beam width (measured at -3dB point). The detection range is 10-20 m (82 ft) for a person and 50-100 m (328 ft) for large metal objects such as vehicles [8].

3.2 Experiment

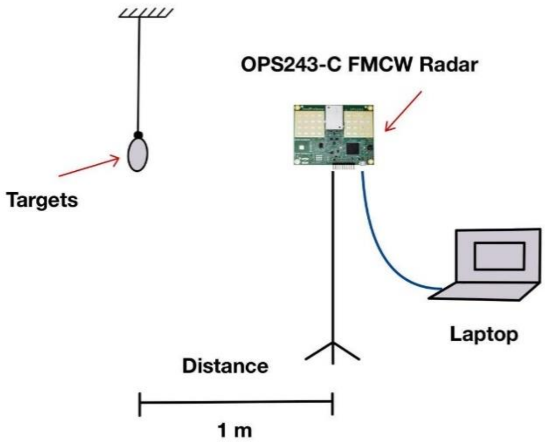

Fig. 4. Experiment setup

Before starting an experiment, radar module parameters were set up using API commands to suit the experimental needs. To simulate insects, this study used ellipse-shaped aluminum foil as detection target. Six sizes of aluminum foil were 5, 4, 3, 2, 1, and 0.5 cm., respectively. The example of target is shown in Figure 5.

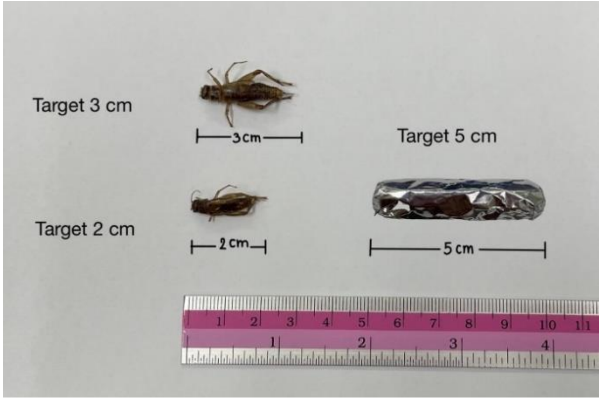

Fig. 5. Example of target.

To simulate movement of target, each aluminum foil was swung in front of the radar until it stopped. The experiment of each target size was run one at a time. The distance from the target to the radar was 1 m. for the target sizes of 5,4,3, and 2 cm., whereas that for the target sizes of 1 and 0.5 cm. was 0.6 m. Then, Tera Term program was used to collect the experimental results. All data were then analyzed by Python program to determine the ability of detecting the smallest targets that the 24 GHz FMCW radar could detect. This research used 24 GHz frequency in K Band [10]. This study focused on detecting movement of object only, whereas speed testing was irrelevant.

3.2 API Method

The FMCW OPS243-C radar module can conveniently detect the movement, speed, direction, and range of objects in the field of vision. Moreover, it can adjust various parameters to suit the application. [8]. Therefore, this module can reduce development costs and time. The radar board was set up through the Tera Term program using the API command to adjust the settings when available.

4. Result and discussion

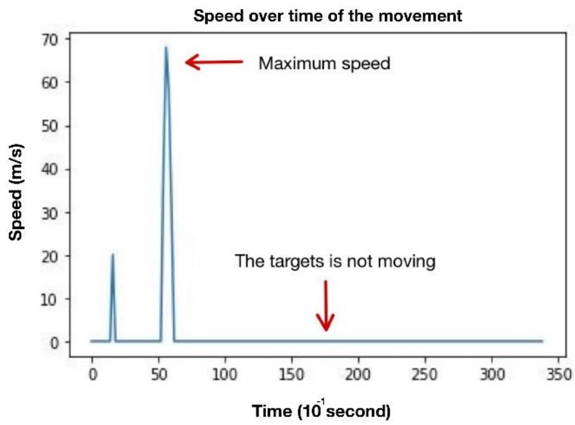

Fig. 6. Result of 5 cm target detection

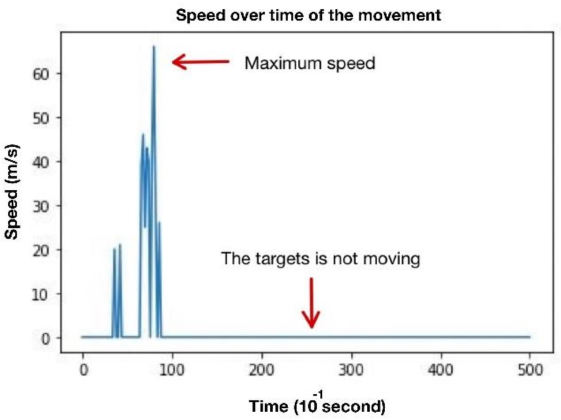

Fig. 7. Result of 4 cm target detection

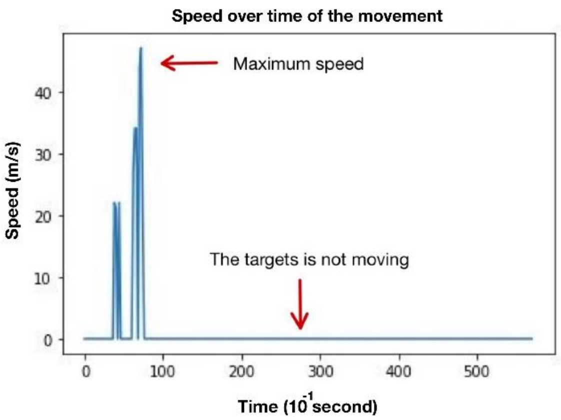

Fig. 8. Result of 3 cm target detection

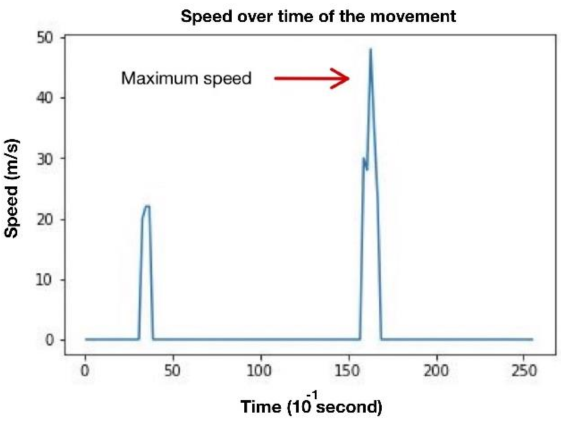

Fig. 9. Result of 2 cm target detection

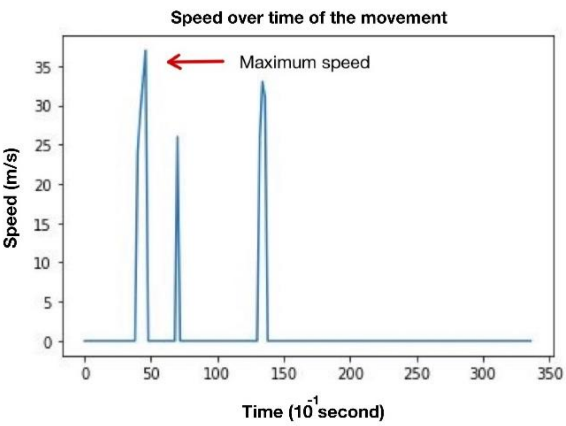

Fig. 10. Result of 1 cm target detection

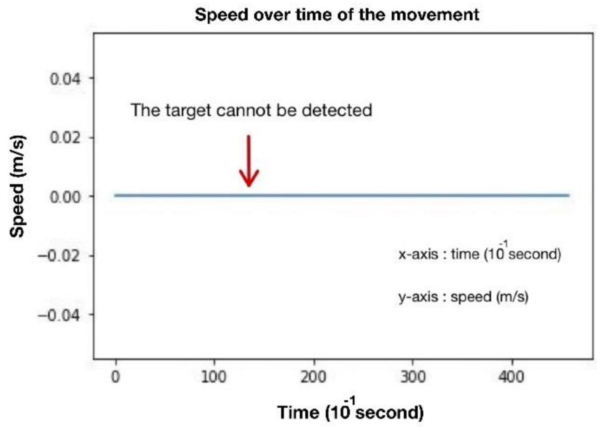

Fig. 11. Result of 0.5 cm target detection

Figure 6-11. shows results of the experiment. The analyzed data are displayed in the form of graphs which show the speed over time of the movement of various objects. Obviously, the radar was unable to detect 0.5 cm target since the graph shows horizontal line. The horizontal line means that there is no movement data received. However, the radar detected movement of rest target sizes.

For 5 cm target movement, the maximum speed was approximately 69 m/s which occurred at the fifth second. After that, the target stopped moving. For 4 cm target movement, the maximum speed occurred at the ninth second. Then, the target stopped moving. For 3 cm, 2 cm, and 1 cm, movement of target was detected. However, movement of 0.5 cm target was undetected. Therefore, based on above results, using radar with module OPS243 equipped with API command can detect target sizes of 2-5 cm at the distance of 1 m. and also target size of 1 cm at the distance of 0.6 m.

5. Conclusions

From the experiment, the conclusions drawn are as follows.

1. The radar with module OPS243 equipped with API command used in the experiment helps detecting small target well.
2. The FMCW radar can detect small target with a size of 1-5 cm, but it is unable to detect target with a size of 0.5 cm.

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References

[1] A. Hegazy and M. Mossad, "FMCW Software Defined Radar for Range and Speed Estimation," *IUGRC.*, vol. 1, pp. 29-29, 2016.

[2] A. Noskov, J. Bendix, and N. Friess, "A Review of Insect Monitoring Approaches with Special Reference to Radar Techniques." *Sensors, 21*, 1474 2021.

[3] S. Zulkifli and A. Balleri, "FMCW Radar Prototype Development for Detection and Classification of Nano-Targets," *2020 IEEE International Radar Conf. (RADAR)*, pp. 738-743, 2020.

[4] M. Longhi, and G. Marrocco, Flying sensors: Merging Nano-UAV with radio frequency identification, *Proc. 2017 IEEE International Conference on RFID Technology & Application (RFID-TA), 2017.*

[5] Y. Ju, Y. Jin, and J. Lee, "Design and Implementation of a 24 GHz FMCW Radar System for Automotive Applications," *2014 International Radar Conference*, pp. 1-4, 2014.

[6] European Space Agency, *Satellite Frequency Bands*, 2022.

[7] S. Park and Y. Kim, "Design of a low resolution FMCW radar for small target detection under ground clutter," 2011 3rd International Asia-Pacific Conference on Synthetic Aperture Radar (APSAR), pp. 1-1, 2011.

[8] OmniPreSense, *OPS243 Datasheet*, United States, 2022.

[9] C. Jason, V. Drake and D. Reynolds, "Recent Insights from Radar Studies of Insect Flight." Annu. Rev. Entomol, pp.56:337-56, 2011.

[10] W. Charlotte, S. Phillip, R. Don, and R. Andy, "Investigating vertical motion of small insects in atmospheric boundary layer using millimetre-wavelength radar and Doppler LIDAR." *J.Eng.*, vol.2019, Iss. 20, pp.6906-6909, 2019.

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