Analysis of Range and Speed Detection Using A Commercial RADAR module at 24GHz

Shalini Kashyap, Amit Birwal, Kamlesh Patel*

Department of Electronic Science, University of Delhi South Campus, New Delhi, India

*Corresponding Author: kpatel@south.du.ac.in

Abstract: In this work, the performance of OmniPreSense Module OPS243-C has been studied for range and speed detection, at 24 GHz, whose results are obtained using Fast Fourier Transform (FFT) commands using a MATLAB script and verified with the physical range of objects used. Four custom-made scenarios have been created, two using stationary objects namely a stand and a tripod for their range at two different distances, and two using moving objects, a person and a ceiling fan for their respective speed. A total of 10 observations for range detection are taken inside an anechoic chamber and reported with a range of percentage errors, which varies for objects and their range. The mean values of the tripod and stand range are detected at 4.06 m and 0.42 m, respectively, in scenario 1 whereas in scenario 2, the mean values of the tripod and stand range are found to be 2.56 m and 1.53 m, respectively. The standard deviations in these observations are found from 0.09 to 0.12 m for range detection. In scenario 3, the speed of a moving person is found to be varied from 2.0 m/s to -2.1 m/s for Inbound and Outbound directions from the module at a distance of 4.62 m. For scenario 4, a variation in the speed of the rotating fan is observed at the knob positions (0 to 4) from the OFF to ON condition of the fan and is found to be varied from 0.1 m/s to 4.9 m/s at different knob positions. In both scenarios 3 and 4, the speed data is found with a standard deviation less than 0.5 m/s from 10 observations. In this analysis, results confirm that the OPS243-C can detect stationary and moving objects successfully.

Keywords: Range, speed, TeraTerm, FFT, MATLAB, RADAR.

1. Introduction: RADAR (Radio Detection and Ranging) is an electromagnetic sensing technique that uses wireless technology to work on the principle of emitting and receiving radio waves reflected by an object or target. Based on this, the radar system is used to detect motion, speed, direction, shape, and angle estimation of distant objects. It can detect stationary (range) and moving targets (speed and motion). There are various RADAR systems available that operate in the frequency range between 2.4 GHz and 77 GHz. In a Probabilistic Data Association Filter (PDAF) method to monitor traffic on the road using a 24.1 GHz radar system [1], the radar uses Frequency Modulated Continuous Wave (FMCW) mode to estimate the distance, speed, and angle of the vehicle and reported a maximum detectable range of 300 m and a range resolution of 0.80 m, to detect vehicles in multiple lanes. Also, a detectable velocity is from -250 km/hr to 250 km/hr and the Field of View (FoV) is from -15° to 15°. A 24 GHz radar system is proposed using an envelope detection method and Constant False Alarm Rate (CFAR) threshold calculation algorithm to calculate target detection and angular measurements for automotive applications [2]. Authors reported a maximum target range of up to 20 m, object map update rates of 20 ms, and an angular range of approximately 5° to 40°. A radar network is developed that operates in Continuous Wave (CW) Mode with a bandwidth of 200 MHz at 24 GHz to detect range speed and angle (azimuthal and elevation) [3]. In this report, a maximum target range of up to 20 m, obstacle detections moving at the speed of more than 1 km/h, and the FoV of 12° azimuthal angle and 70° elevation angles are reported. A radar based on the FMCW mode System on Chip (SoC) is proposed for air writing characters or words in free space [4]. It uses Single Input Multiple Output (SIMO) antennas covering up to 4 GHz bandwidth from 23.5 GHz to 27.5 GHz. It shows the capability of a maximum measured velocity of 2.94 m/s, a range resolution of 4.63 cm, and a maximum detection range of 3 m.

Using a double negative index metamaterial structure for the transmitter and receiver antenna, a 5.8 GHz Doppler radar is made [5]. In this work, the maximum velocity of the ball (indoor experiment) is calculated as 4.15 m/s and the maximum velocity of the car (outdoor experiment) is approximately 44 km/hr when the car is 72.5 m away from the radar. A mm-wave radar remote monitoring system is developed for the elderly living in a home which monitors their breathing and heartbeat signals [6]. It consists of a 60 GHz FMCW system, a TIC3220 WiFi communication module, an IWR6843 mm-wave transceiver sensor and a cloud service software architecture for real-time data monitoring and database storage. The heartbeat is calculated by the radar system is 63 from a distance of 2.5 m.

A novel vital sign application is developed using a 24 GHz flexible antenna for Doppler radar, which uses a Vector Network Analyzer (VNA) for measuring S21 parameters and implements these parameters in MATLAB program for filtering, FFT, and peak detection [7]. The average chest displacement from the heartbeat and breathing is found to be 0.2-0.5 mm and 4-12 mm. A pulse coherent radar at 60 GHz is proposed for online monitoring of the withering of leaves [8]. In this work, the authors used the XM112-XB112 module evaluation kit (EVK) and reported that a decrease in water content in the leaf causes a gradual decrease in signal strength. Nowadays, different models of commercial radars are available for the above applications. A complete characterization is required for optimum application of these radars at their respective operating frequency. At the same time, these radars should report the range and speed detection with proper accuracy.

In this paper, the results of range and speed detection of various stationary and moving targets are reported which are obtained using a commercial radar model OPS243-C from Omnipresence firm at 24 GHz. The outputs of these results are extracted using custom-made MATLAB coding for two scenarios of range detection and two scenarios of speed detection. The values of range detection are verified from the physical range of the objects used. The percentage error is found from -250% to 27.77% in range detection for stationary targets. The standard deviation is evaluated from 10 observations for each scenario.

2. OmniPresense OPS243-C Radar module: The OmniPreSense module OPS243-C is a short-range radar that provides motion detection, speed detection, direction (Inbound/Outbound), and range reporting at 24 GHz [9]. It has two types of sensors, an FMCW RADAR sensor for reporting range and a Doppler radar sensor for reporting motion, speed, and direction. Two basic principles used by this module are the Doppler frequency shift to detect speed and direction and the FMCW time of flight (TOF) to detect range. It has a capability of range and speed detection up to 100 m and up to 348 mph, respectively, at 24 GHz [9]. It can be operated using two interfaces: Tera Term and Putty. Using the command instructions of the interface, the object range, speed, motion, and direction from the radar module of stationary and moving objects are detected [10].

The range and speed detection results of the OmniPreSense module can be verified and analyzed physically with a meter scale and speedometer, respectively. The data extracted using the Tera Term/Putty are the range FFT and speed FFT command output of the module and then plotted using MATLAB script [10]. A flowchart representing the complete process is shown in Figure 1.

3. Experimental procedure: The experimental data of the OmniPreSense radar module is obtained using the interface, i.e. Tera Term, with its command instructions. For this, the OmniPreSence module OPS243-C is placed over a rotating motor to scan the surrounding environment in a 360° field of view.

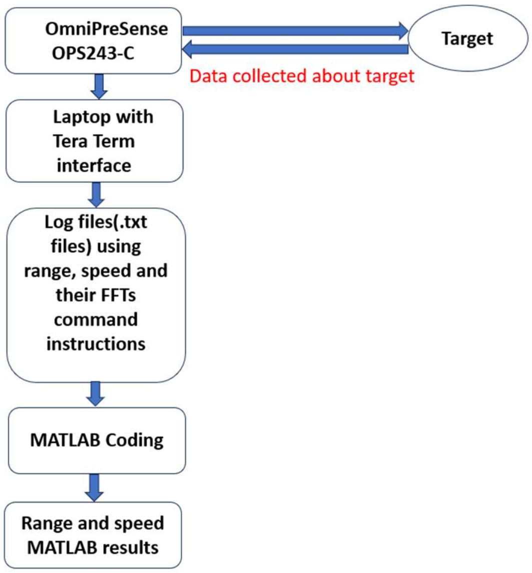

Figure 1. Flowchart of extracting data of OmniPreSense module OPS243-C.

Different scenarios created for the experimental purposes are:

a) Scenario 1: One tripod and one stand are kept as objects at a distance of 3.76 m and 0.2 m in an anechoic chamber, respectively, from the module.
b) Scenario 2: The same tripod and stand are kept as objects at different distances i.e. 2.39 m and 1.8 m in an anechoic chamber, respectively, from the module.
c) Scenario 3: For speed detection, a person's movement is experimentally done in the lab.
d) Scenario 4: For speed detection, the rotational movement of the ceiling fan from the OFF state to the ON state at different control knob positions (1 to 4) is considered a moving object.
These scenarios are shown in Figure 2 and Figure 3. The range and speed FFT data outputs detected by the module are obtained for four scenarios i.e. range resolution multiplied by the bin value or speed resolution multiplied by the bin value. Such experiments are being performed for the first time in four scenarios, which involved data recording with Tera Term and MATLAB commands, so 10 observations in range detection are considered for standard deviation estimation.

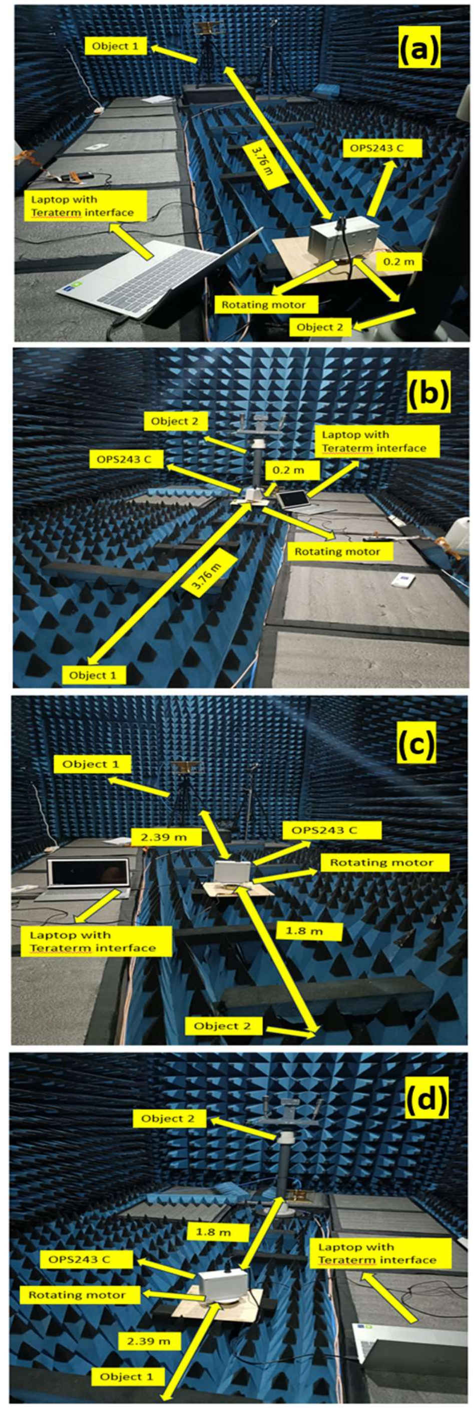

Figure 2. Experimental setup of OPS243-C radar module with rotating motor, (a) Tripod (Object 1) and stand (Object 2) placed at 3.76 m and 0.2m distance from the radar, respectively, (b) Tripod and stand (as seen from the tripod end) at 3.76 m and 0.2m distance from the radar module (c) Tripod and stand at 2.39 m and 1.8m distance from the radar, respectively, and (d) Tripod and stand (as seen from the tripod end) at the distance of 2.39m and 1.8m away from the radar, respectively.

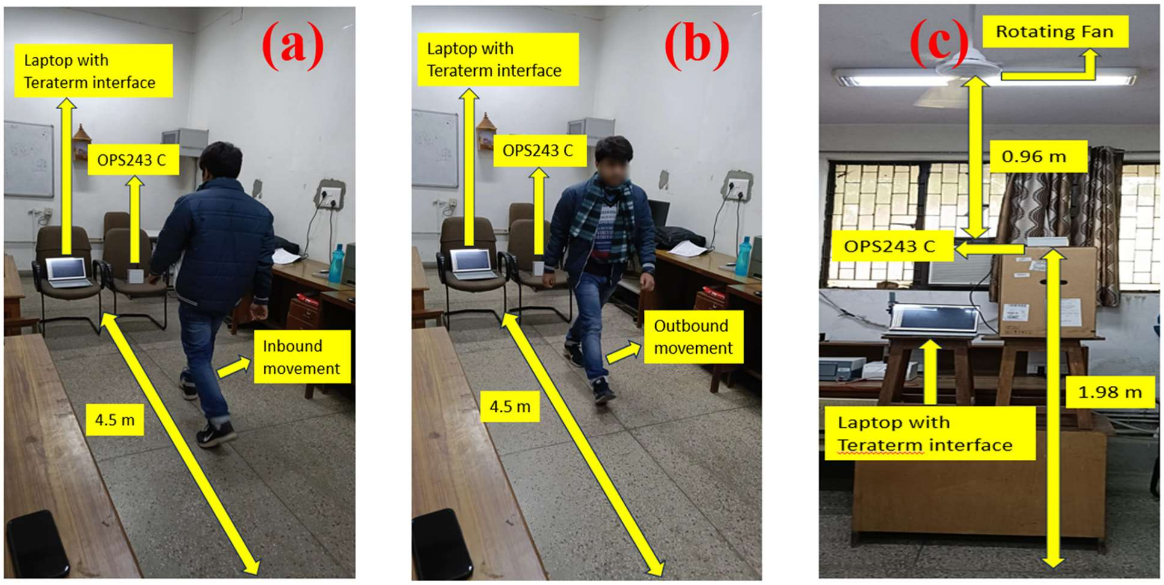

Figure 3. Experimental setup of OPS243-C radar module, (a) Person's inbound movement from 4.5m distance from the radar, (b) Person's outbound movement from 4.5m distance from the radar, and (c) Rotating fan speed at different knob (state) position at a distance of 2.94 m from the floor.

4. Results & Discussion:

A. Range Detection: As discussed above, 10 observations are taken for scenario 1 where the tripod and stand are placed at 3.76 m and 0.2 m distance from the radar module. The results of these 10 observations are given in Figure 4.

As can be seen from Figure 4(a-j), the detection range is obtained in a range of 0.3-0.7 m and 3.8-4.1 m for the stand and the tripod, respectively, using the OPS243-C radar in scenario 1, when these objects are kept at 0.2 m and 3.76 m from the radar module inside the anechoic chamber as illustrated in Figure 2(a) and Figure 2(b).

The obtained ranges are a little higher than the actual ones in all 10 observations for both objects. For scenario 2, when the tripod and stand are at a distance of 2.39 m and 1.8 m from the radar, respectively, the results of 10 observations are shown in Figure 5(a-j).

The range values are found from 1.3 to 1.6 m for the stand and from 2.5 to 2.8 m for the tripod inside an anechoic chamber as shown in Figure 5. So, the radar module detects the objects and shows a little higher range than the actual one for Tripod, a little lower for the stand. As the difference between the actual and measured ranges is almost the same in all 10 observations, the additional coding in MATLAB programming can be helpful to get the correct detection of targeted objects with the removal of systemic error.

To analyse these differences in 10 observations, the results from MATLAB coding are compared with the actual physical distance of these objects. The percentage error in the detection range can be calculated using the formula (1):

$$\frac{\text{Actual distance} - \text{Measured distance}}{\text{Actual distance}} \times 100\% \quad \text{---(1)}$$

The percentage errors in 10 observations for range detection in two scenarios 1 and 2 are shown in Table 1.

Further, the standard deviation in 10 observations for range detection is shown in Table 2.

So, for objects near the radar module, as in the example in scenario 1, the standard deviation is higher than for the object away from the module, which indicates the radar module gives better values for objects kept a little far (>1.8 m) from the module.

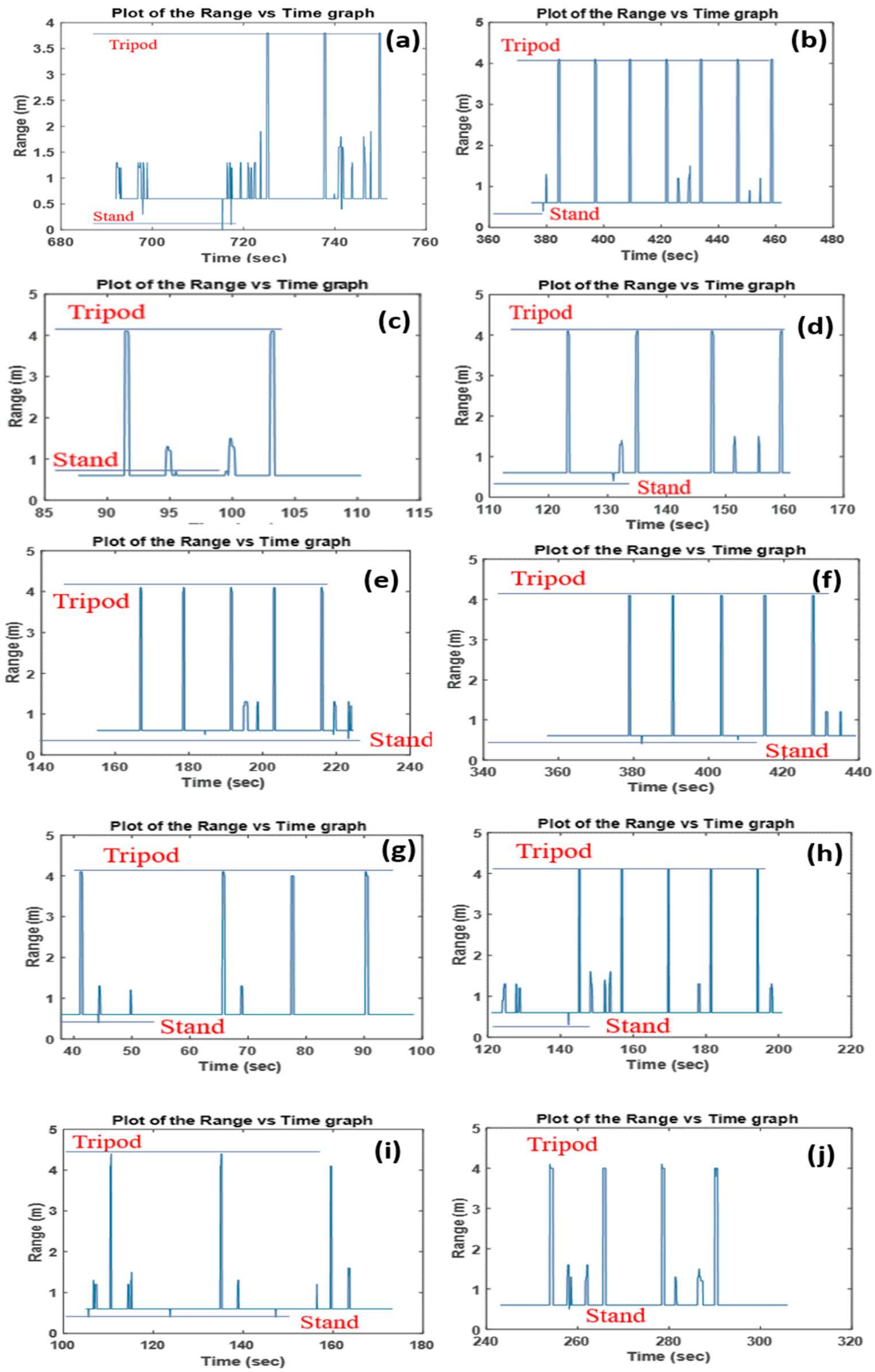

Figure 4. Experimental results of 10 observations (a)- (j) for Scenario 1 when the tripod and stand kept at a distance of 3.76 m and 0.2 m from the radar, respectively.

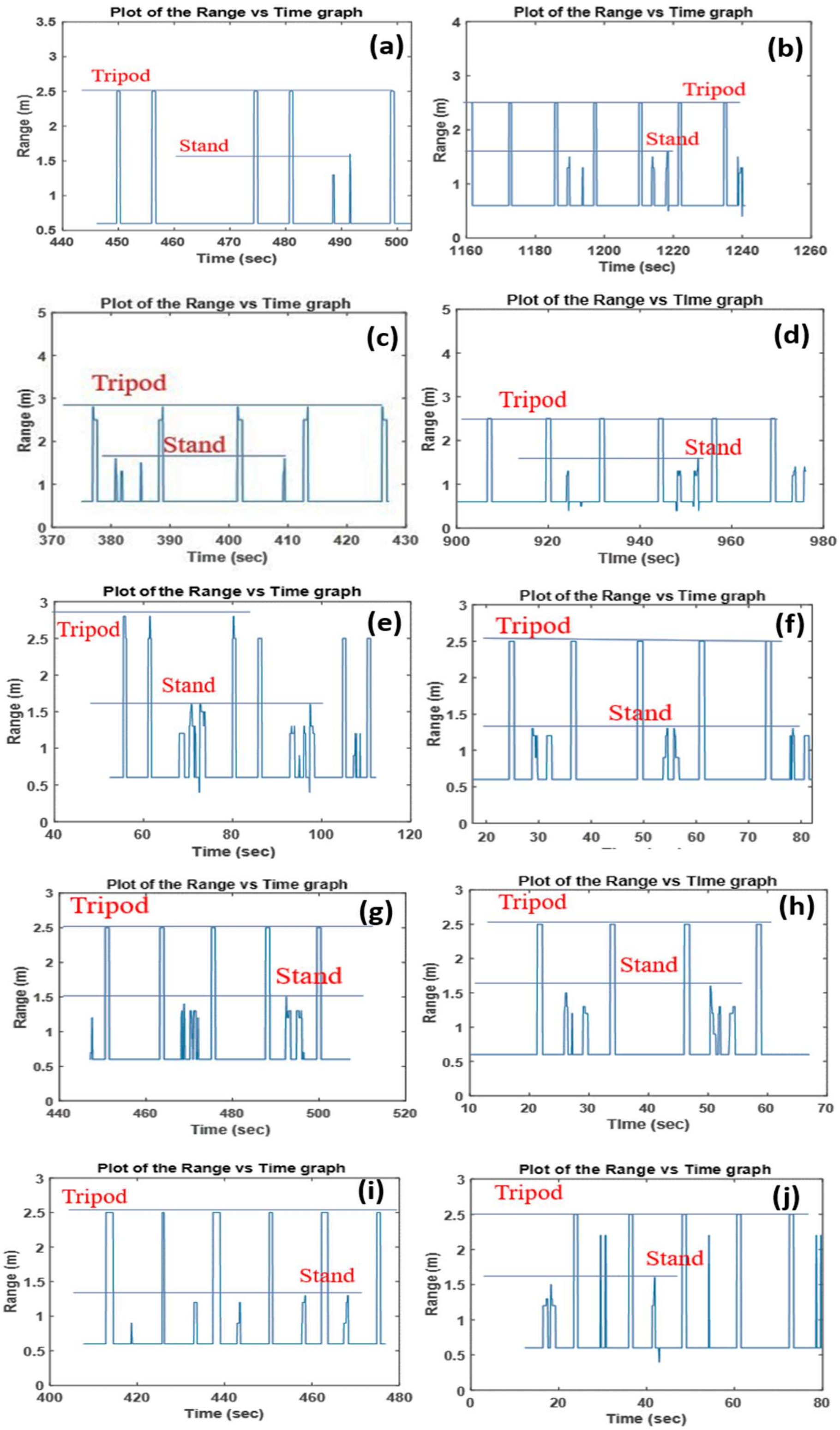

Figure 5. Experimental results of 10 observations (a)- (j) for Scenario 2 when the tripod and stand were kept at a distance of 2.39 m and 1.8 m from the radar, respectively.

Table 1. Percentage errors in 10 observations for range detection in Scenario 1 and Scenario 2.

Observations	Scenario 1		Scenario 2	
	Tripod	Stand	Tripod	Stand
1st	-1.06 %	-50 %	-4.60 %	11.11 %
2nd	-9.04 %	-100 %	-4.60%	11.11 %
3rd	-9.04 %	-250 %	-17.15 %	11.11 %
4th	-9.04 %	-100 %	-4.60%	11.11%
5th	-9.04 %	-100 %	-17.15%	11.11%
6th	-9.04 %	-100 %	-4.60%	11.11%
7th	-9.04 %	-100%	-4.60%	11.11%
8th	-9.04 %	-50%	-4.60%	11.11%
9th	-9.04 %	-100%	-4.60%	27.77%
10th	-6.38%	-150%	-4.60%	11.11%

Table 2. Standard deviation for range detection in Scenario 1 and Scenario 2.

Standard deviation	Scenario 1	Scenario 2
Tripod	0.09 m	0.12 m
Stand	0.10 m	0.09 m

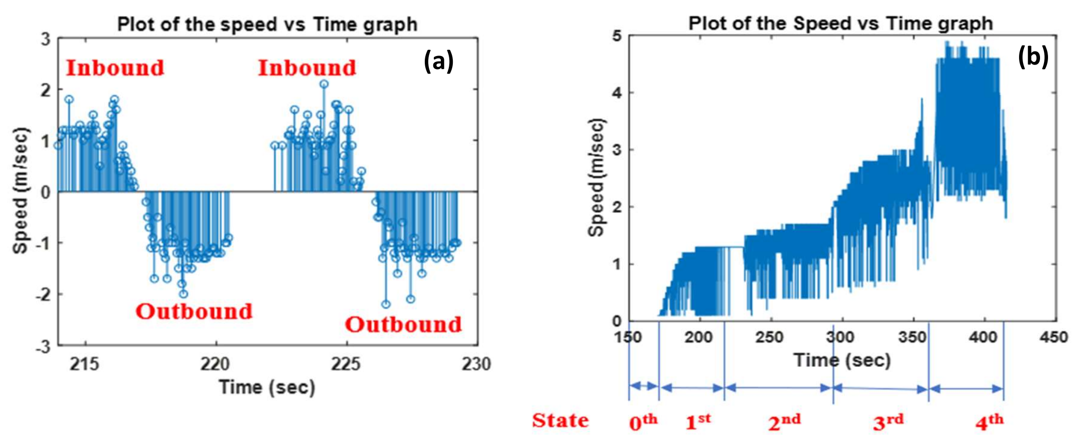

Fig.6(a) Speed (m/s) vs Time (s) graph of person's movement at 4.5 m towards (Inbound) and away (Outbound) from the radar (b) Speed (m/s) vs Time (s) graph of the ceiling fan at different knob positions (states) from OFF to ON at a distance of 2.94 m from the floor.

4.2. Speed Detection: For speed detection using the OPS243-C module, two scenarios 3 and 4 are considered where a person's movement (inbound and outbound) and the speed of the ceiling fan are observed as shown in Figure 3 (a-c), respectively. The results of scenarios 3 and 4 are given in Figure 6.

Figure 6(a) shows the speed range of a person moving towards (inbound) and away (outbound) from the radar module, which is observed in the range of 2.0 m/s to -2.1 m/s. On taking 10 observations of the same person's movements, the average values are found to be 1.10 m/s (Inbound) with a standard deviation of 0.37 m/s and -1.25 m/s with standard deviation of 0.31 m/s.

Figure 6(b) shows the variation in the speed of the rotating fan from OFF state to ON state with various knob positions (0 to 4). The speed of rotational movement is detected at 0 m/s in the 0th state and its speed increases from 0.1 m/s to 1.3 m/s in the 1st state. When the fan is kept at the 2nd state of the knob positions its speed is recorded from 0.1 m/s to 1.7 m/s. Further, at the 3rd and 4th states of the knob positions, the speed of the rotational movement is observed from 0.6 m/s to 3.0 m/s and from 1.1 m/s to 4.9 m/s, respectively. So, with the increasing state of knob positions, the fan rotates faster and hence the frequency of receiving signals from the fan becomes larger. However, the speed is growing slightly as the ceiling fan is at one position only i.e. stationary. To verify this, 10 observations are recorded in the scenario 4. The average speed data are evaluated as 0.71 m/s with standard deviation of 0.26 m/s, 0.95 m/s with standard deviation of 0.18 m/s, 1.48 m/s with standard deviation of 0.31 m/s and 2.44 m/s with a standard deviation of 0.50 m/s for state 1, 2, 3 and 4 of the knob positions for the rotating fan. Thus, the OPS243-C radar module can detect a person's movement and the speed of the ceiling fan with a small deviation of less than 0.5 m/s. To obtain the percentage error in the speed, the results of this radar module can be compared with the data obtained from a calibrated speedometer.

5. Conclusions: In this paper, range and speed detection is performed by OmniPreSense firm OPS243-C Module which works both on FMCW and Doppler mode at 24 GHz. The TeraTerm is used to extract data from the module and MATLAB coding is performed to plot the results. Four different scenarios of detection are considered for two stationary and two moving objects. From the experimental results, it can be concluded that the module is detecting the range of the stationary objects quite efficiently with percentage errors of -250% to 27.77% (in case of close range) in range detection. The standard deviation in the range detection is obtained from 0.09 m to 0.12 m, while for speed detection, it is less than 0.5 m/s. The measurement results verified that the system is capable of detecting the object's range and speed at far distances better. In future work, MATLAB coding is required to reduce the error for precise detection of objects with more numbers of scenarios.

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