Performance Analysis of 77 GHz mmWave Radar Based Object Behavior

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Abstract —In this paper, performance analysis of the object behavior using mmwave radar is proposed. The AWR1642 mmwave radar with frequency 77 GHz that has advantages over the other sensors, especially in penetrate materials and high accuracy, is utilized in this research. The paper presents an analysis of object behavior in the experimental method in the indoor environment. The radar will detect an object by sending a chirp signal and receiving it again after it is reflected. The mmwave radar shows the performances in the distance, number of objects, radiation pattern, and velocity. The measurement results show that the object can be detected up to 3 m in the indoor environment with a high level of accuracy and stability. Then, the radar can detect multiple objects in the Line-of-Sight (LOS) condition, where the received power level would be attenuated by about 10 dB after penetrating the first object. The research results showed the beamwidth of the radar is 140 degrees with a directional radiation pattern from 20 degrees to 160 degrees. In this system, radar has been able to identify the velocity of the object accurately. It appears that increasing the speed will affect the Central Processing Unit (CPU) usage on the radar too. The proposed system showed excellent performance in object behavior analysis, and it can be utilized in Synthetic Aperture Radar (SAR) applications.

Index Terms—Mmwave radar sensor, object behavior, 77 GHz, Synthetic Aperture Radar (SAR), indoor environment

I. INTRODUCTION

Recently, object detection, which is the technology of several applications, i.e., surveillance, tracking, and patient monitoring, has attracted many researchers. However, applications are currently limited using cameras [1] or infrared sensors [2]. Although the camera has high accuracy and can be relied upon for these applications, some disadvantages are related to privacy issues. This sensor is also influenced by light and environmental conditions [3]. And the sensor also cannot penetrate some material as well as walls, trees, and other materials. In Synthetic Aperture Radar (SAR) application, this condition will be an issue where this function is essential in the object detection process where some materials can hinder the measurement. In addition, a high degree of accuracy is required in such applications.

Therefore, we need sensors that can overcome these deficiencies and have high accuracy. Based on several studies, Ultra Wide Band (UWB) sensors which are contactless sensors, have been widely used. However, the sensor that works at a frequency of 24 GHz has weaknesses, i.e., having an insufficient level of accuracy so that another radar sensor with a higher resolution is needed [4]. Then, the European Telecommunications Standards Institute (ETSI) and the Federal Communications Regulations and Standards Committee (FCC) have banned new products using 24 GHz since September 2018. The products which using the 24 GHz will be phased out in 2022 [5], [6]. This policy will also result in the use of UWB Sensors being deprecated in future technologies and systems. The use of sensors with high resolution can be done by increasing the working frequency of the radar used. The commercial radar sensors with a higher frequency than UWB Radar works on the milliwave spectrum with 42 GHz [7], 60 GHz [8], and 77 GHz. In this research, the 77 GHz frequency of radar is utilized, considering that the higher the frequency, the better the possible performance and availability of hardware devices on the market.

Recently, the single-chip mmwave radar systems have been applied to several new applications, such as automotive radars, health monitoring radars [9], radars on unmanned aerial vehicles (UAVs) [10], radar as a robot director, and other applications [11]. It also is found in the automotive industry, autonomous cars, and driving assistance systems [12]. In this application, micro-Doppler signatures are obtained to recognize targets through dynamic time warping [13], studies of human kinematics [14], and object tracking [15]. This sensor possible can be applied to identify object behavior, especially in Synthetic Aperture Radar (SAR) applications.

TABLE I: SENSOR TECHNOLOGY COMPARISON. [16]

Sensors	mmwave	Camera	LIDAR	Ultrasonic
Detection range	Long	Medium	Long	Short
Detection angle	Narrow & wide	Medium	Narrow & wide	Wide
Range Resolution	Good	Medium	Good	Good
Information	Velocity, range, angle	Target classification	Velocity, range, angle	Range
Bad Weather	Good	Poor	Poor	Poor
Night operation	Yes	No	No	No

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Table I shows that the mmwave radar has advantages in object detection applications compared to several other sensors, such as camera, light detection, ranging (LIDAR), and ultrasonic. It has a much wider detection range than an ultrasonic and camera, and it also has a wide detection angle compared to cameras that tend to be narrow. The Information parameters obtained in applications that use this sensor are speed, range, and angle, unlike ultrasonic, which only gets distance information, and cameras that get classification information from objects. Besides that, the main advantage of this sensor besides distance is that none of the sensors, whether camera, LIDAR, or ultrasonic, can operate in bad weather and at night dark conditions. Furthermore, this sensor is very robust and stable. Although LIDAR has performance characteristics that are almost similar to mmwave radar, it has an average weight of 16 g, compared with mmwave radar with 7.5 g, affecting weight-sensitive applications, such as UAVs. It is shown in Table II.

TABLE II: COMPARISON OF SIZE AND WEIGHT OF MMWAVE SENSOR AND LIDAR [17]

Sensors	Mmwave module	LIDAR module
Module size	38 x 38 x 7.5 mm	20 x 48 x 40 mm
Module wight	7.5 g	16 g

The micro-Doppler signatures generated from mmwave radar are used to detect an object. This shortwave radar has many advantages. It has high accuracy, is not sensitive to light, can penetrate walls and certain material, and is also resistant to environmental conditions such as snow, rain, and fog [18], [19]. These effects are produced by micromotion dynamics of a target or its structure, such as vibrations, rotations, falls, and cone motions, generally present in radar target motion [20]. The Micro-Doppler effect depends on the received angle of the target. For targets moving at 0 degrees and 180 degrees assuming Line-of-Sight (LOS), the Micro-Doppler frequency reaches maximum capture, and at an angle of 90 degrees, the frequency will be zero. Due to several aspects of this angular problem, some parts of the target cannot be seen by the Radar [21].

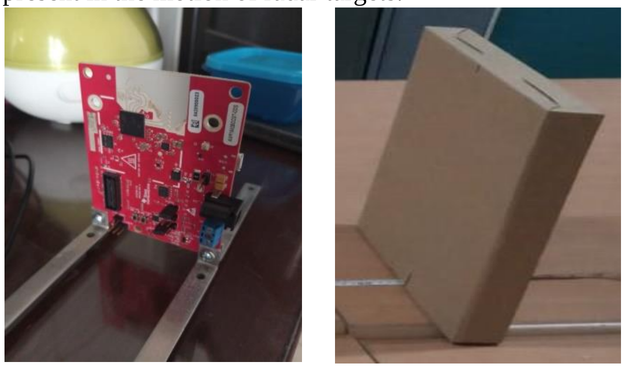
In this research, we propose to analyze the performance of mmwave radar as a sensor used to identify an object behavior based on distance, number of objects, radiation pattern, and velocity. This research contributes to resolving the issue where it takes a sensor that can penetrate the material and has a high level of accuracy, especially in the utilization of SAR in various applications.

II. METHODS

Millimeter waves (mmwave) are special class wave radar technology that uses shortwave electromagnetic waves between 10 to 1 millimeter. Millimeter waves occupy a spectrum of 30 - 300 GHz, categorized as Extremely High Frequency (EHF). The high frequency of millimeter waves and their special propagation characteristics make them useful for various applications, including transmitting large amounts of data on computer networks, cellular communications, and radars. This technology can provide very high accuracy, penetrate walls and certain materials, and resist snow, rain, and fog. Another advantage of short wavelengths is high resolution. The mmwave system has accuracy in the mm range at 76 – 81 GHz.

The system will send electromagnetic waves to the target and then reflect it. By capturing the reflected signal, radar can determine the object's distance, velocity, and angle. The mmwave radar system includes a radio transmitter (Tx) and receiver (Rx). In addition, it has high frequency (RF) components, including analog components such as clocks and digital such as Analog-to-Digital Converter (ADC), microcontrollers (MCU), and digital signal processors (DSP).

The micro-Doppler signatures are generated from mmwave radar due to the micro-Doppler effect. The Micro-Doppler effect is produced by the dynamics of micromotion of a target or its structure, such as vibrations, rotations, falls, and cone motions, which are generally present in the motion of radar targets.



(a) (b)

Fig. 1. (a) Mmwave radar and (b) The object

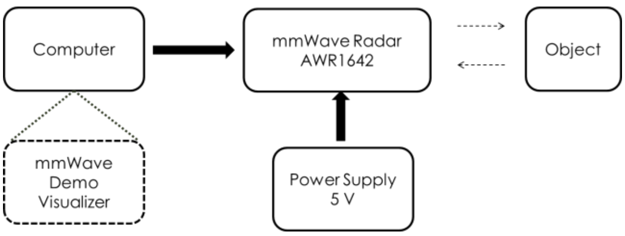


Fig. 2. Diagram block in object detection.

In this research, mmwave performance in analyzing an object behavior will be done. Fig. 1 (Left) is a mmwave Radar, and an object is shown in Fig. 1 (Right). The mmwave Radar from Texas Instruments (TI) is utilized. TI has two mmwave sensor families, i.e., AWR mmwave sensors for automotive and mmwave IWR sensors for industrial, drone, and medical applications. The type of mmwave radar used in this research is AWR1642 type, with a frequency of 77 GHz. The AWR1642 chipset is an integrated frequency modulated continuous wave

(FMCW) radar sensor that has 2 Transmitters (T_X) and 4 Receivers (R_X) systems with a analog to digital converters (ADC) and phase lock loop (PLL). It is capable of operation in the 76-77 or 77-81GHz band with 12.5 dBm T_X power. It also integrates the C674x-based DSP subsystem and processor subsystem responsible based on ARM R4F for radar signal processing [22], [23]. In this research, the object is utilized with carton material, which has a size 30 cm x 5 cm x 30 cm (length x width x height).

Fig. 2 shows the diagram block in object detection. The figure shows the computer is connected using a cable with mmwave Radar AWR 1642 supplied with a voltage of 5 V. The mmwave Demo Visualizer installed on a computer is used as a visualization tool to show system performance by considering several parameters in object detection. The radar will detect an object by sending a pulse signal (chirp) and receiving it again after the object reflects it.

III. Results and Discussion

Several measurements consider several parameters, i.e., distance, number of objects, radiation pattern, and velocity, in the indoor environment.

A. Distances Measurement

In the first measurement, the mmwave radar is connected by a computer, and it is utilized to detect an object. Then, the object is placed at certain distances from the radar to measure the system's performance. Also, in this section, the accuracy and stability of the object detection system are measured.

measures

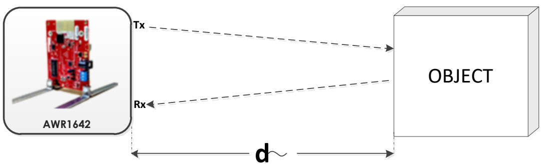


Fig. 3. Distance measurement method

Fig. 4. Distance measurement implementation

Fig. 3 shows a block diagram of distance measurement in object detection, whereas Fig. 4 shows the implementation of the distance measurement.

Fig. 5 shows object detection visualization of 1 m in the scatter plot (left) and statistics plot (right). The scatter plot show distance along the lateral axis vs. distance along the longitudinal axis. And the statistics plot shows the received power level caused by the detection of an object at a certain distance. The object detection is indicated by the detected point, which will only appear when the object is detected. In addition, range profile values will appear along with the measured distance on the graph.

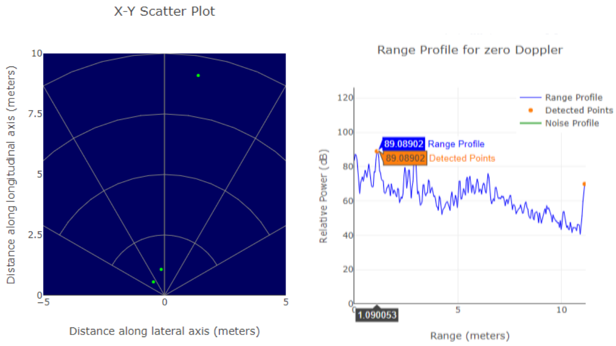


Fig. 5. Object detection visualization results in 1 m

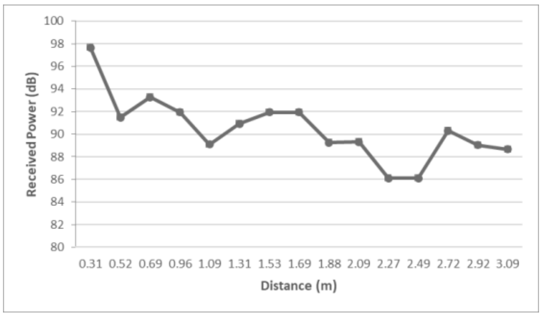


Fig. 6. Measurement results in various distances

Fig. 6 shows the measurement results in various distances from 0.2 m to 3 m with a step of 0.2 m. It appears that the farther the detection distance of the subject, the received power level will be relatively dynamically reduced due to interference in the form of reflections from the other object in the room.

It affects the receiver gets several reflections that reduce each other and increase the received power level. Fig. 6 also shows that the object could be detected up to the maximum distance of 3 m because of the limited indoor environment. The mmwave radar should be utilized to a more extended range for the real application due to the received power level still high in the maximum distance.

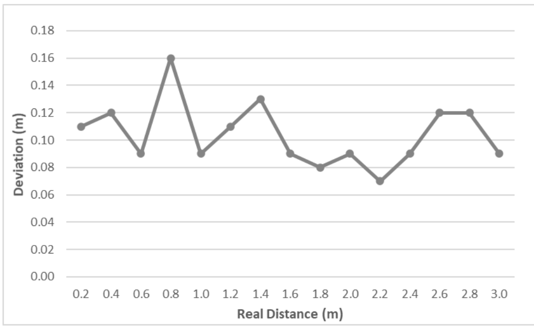


Fig. 7. Deviation graph of the real and measured distance

Fig. 7 shows the deviation graph between real distance and measurement distance. It shows an average deviation of approximately 0.1 m, where the higher distance, the relative accuracy level will be higher too. The figure shows that object detection with mmwave radar has a high level of accuracy.

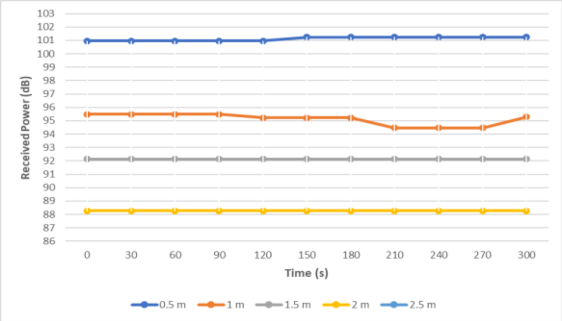


Fig. 8. Received power stability based on measurement time

Also, Fig. 8 shows measurements in 300 s at five distances. It shows the object detection system has a high level of stability. This result is proving that the level of power received is constant at each distance measured.

B. Multiobject Measurement

In this section, measurements are taken by placing a second object with metal material in diameter of 15.5 cm and height of 24 cm behind the first object. The purpose of this measurement is to evaluate whether the radar can detect multiple objects in the Line of Sight (LOS) condition.

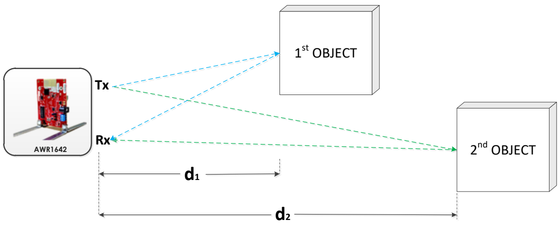


Fig. 9. Multiobject measurement method

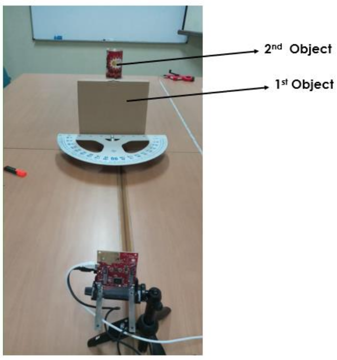


Fig. 10. Multiobject measurement implementation

The first object is placed in 1 m (d_1) from radar, whereas the second object is placed in 2,7 m (d_2). It is shown in Fig. 9 and Fig. 10.

The chirp signal from the radar can be received by the first object and reflected. The signal is forwarded to another object that will occur the same phenomenon as in the first object. Fig. 11 shows that the radar can detect the second object behind the first object with a reduction in the received power level. Fig. 11 also shows that the received power level will be attenuated by about 10 dB after penetrating the first object. This depends on the cross-sectional area and the material used. The measurement result proves that the radar can detect other objects even if obstructed by another object in the LOS condition. Based on these measurement results, mmwave radar can detect an object behind a material such as a wall or even a human body.

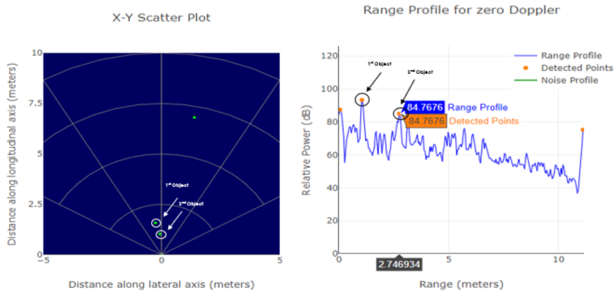


Fig. 11. Multiobject measurement results

C. Radiation Pattern Measurement

In this section, the measurement is done to determine the radar radiation pattern based on the system's transmit angle. Fig. 12 shows the method where the object is rotated with the radar as its axis in the direction of elevation (left and right) and azimuth (top-down).

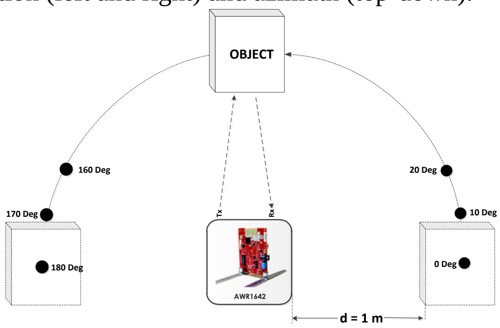


Fig. 12. Radiation pattern measurement method

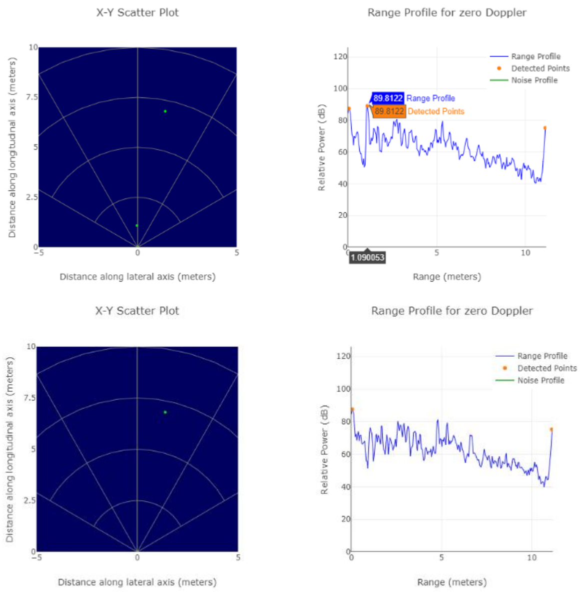


Fig. 13. Radiation pattern measurement visualization results

Fig. 13 (above) shows measurement results where the object is detected in the angle of 90 degrees, and Fig. 13 (below) shows the object cannot be detected at an angle of 180 degrees.

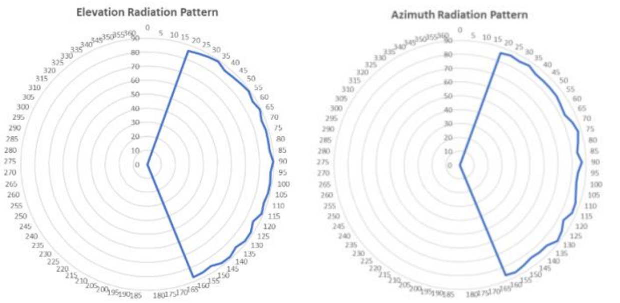


Fig. 14. Radiation pattern results

Also, Fig. 14 shows the radiation pattern of the radar in elevation and azimuth have directional conditional, where the radar beamwidth from 20 degrees until 160 degrees. It shows the radar cannot detect the object at the angle of 0 degrees until 20 degrees and 160 degrees until 360 degrees. Based on this measurement result, the mmwave radar has a wide-angle to be implemented in synthetic aperture radar (SAR) applications, such as unmanned aerial vehicles (UAVs), vehicles, etc.

D. Velocity Measurement

In the last measurement, the object detection system detects a human object with a different velocity, i.e., walking and running conditions at various distances. The objective measure is to analyze the effect of velocity on the performance of the systems. Fig. 15 shows the measurement method where a human is walking and running around a radar.

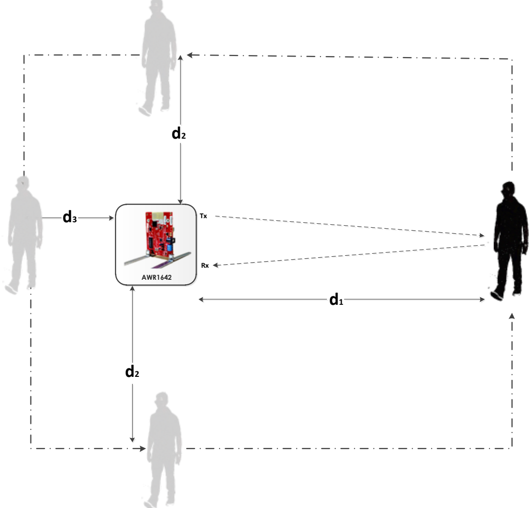


Fig. 15. The measurement based on velocity method

Fig. 16 shows the velocity measurement results for moving human objects. Fig. 16 (above) shows the result when the human is walking where the velocity of around 0,4 m/s. And Fig. 16 (below) shows the measurement results when the human is running with the velocity value of around 0,9 m/s. In this system, radar has been able to detect the velocity of the object properly. It appears that increasing the speed will affect the central processing unit (CPU) usage on the radar too. The faster the object moves, the CPU will work more too. And the slower the object, the CPU will work lighter.

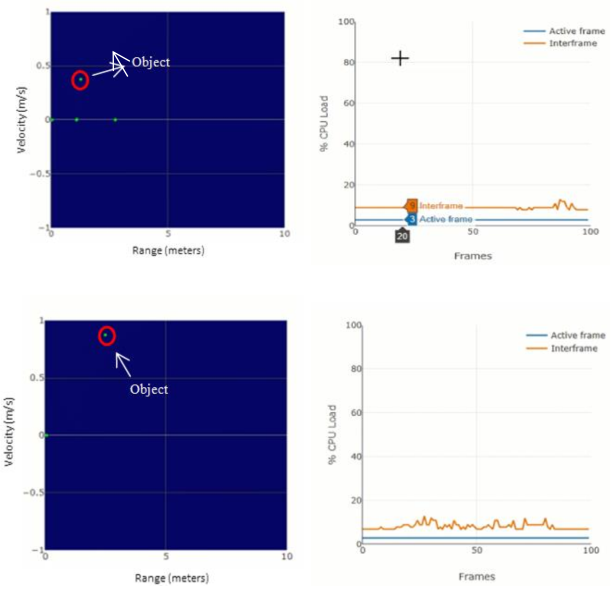


Fig. 16. The human walking and running measurement result

IV. Conclusion

This research showed the performance of the object behavior system using mmwave radar. It was shown that the object could be detected up to 3 m, where the farther the detection distance, the received power level would be relatively dynamically reduced due to reflections from the other object in the room with an average deviation of approximately 0.1 m. In the higher distance, the relative accuracy level will be higher too. It showed that object detection with mmwave radar has a high accuracy and a high level of stability. Besides that, the radar can detect other objects even if obstructed by another object in the line-of-sight (LOS) condition, where the received power level would be attenuated of about 10 dB after penetrating the first object. This depends on the cross-sectional area and the material used. It also showed the radiation pattern of the radar in elevation and azimuth have directional conditional, where the radar beamwidth was 140 degrees from 20 degrees until 160 degrees. In this system, radar has been able to detect the velocity of the object properly. Nevertheless, it appears that increasing the speed will affect the central processing unit (CPU) usage on the radar too. The proposed system showed excellent performance in object behavior analysis. In the future, It can be utilized in synthetic aperture radar (SAR) applications.

Conflict of Interest

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

BK and ARD designed and implemented the experiments; BK, ARD, and NI analyzed the data and wrote the paper.

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