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Velocity Estimation of Moving Target by GB-SAR Sensor Using MIMO Antennas

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Abstract

Many researchers and users have drawn their attention to the radars with Multiple Input-Multiple Output (MIMO) antennas in recent years. The reason is the capabilities that these systems provide to the users, including its low cost, the similarity of the output of MIMO antenna arrays compared to conventional systems with similar characteristics, and its strength. One of the applications of this system in Radar Remote Sensing is identifying the objects and their movement speed. This article's primary purpose is to identify the moving object and determine its speed by Doppler processing and Fourier transform.

For this purpose, firstly general topics related to MIMO systems are mentioned, and then available explanations on how to identify the moving objects are provided. Finally, the characteristics of the sensor used in the laboratory and the results of two different simulations in a software environment are presented. The first simulation is to determine the proper angle of transmission of waves to the object, and the second simulation is to identify two moving objects in two different modes: 1- moving two objects at different speeds while the sensor is stationary and 2- simultaneous movement of two objects and also moving the sensor at different speeds.

***Keywords**:* Multiple Input-Multiple Output RADAR, Low Cost, Synthetic Aperture Radar, Phased Array Toolbox, Simulation.

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1. Introduction

Radar technology was first invented in 1930 for military purposes. Since then, it has continuously been developing and progressing, some of which have been used in the protection and defence of countries (Hassanien and Vorobyov, 2010; Tarchi, Oliveri, and Sammartino, 2012). As radar progressed at all macro and micro scales, users raised more complex problems in other scientific and applied domains that required more robust and reliable solutions based on several different sensors (Akcakaya and Nehorai, 2011; Hassanien and Vorobyov, 2010). At the time, radar, which, unlike most sensors, was used day and night in various weather conditions, could be used among other sensors.

Synthetic Aperture Radar (SAR) is an evolved technology from combining an aperture larger than its actual size that uses the movement of the platform on which the antennas are located. Moreover, it is essential to note that Synthetic Aperture Radar (SAR) can be used on various space, air and ground platforms; each product has specific applications (P. Chen, Zheng, Wang, Li, and Wu, 2017; Li, Wang, Liu, and Himed, 2015). This article considers Ground-Base SAR (GB-SAR). These radars can be used to monitor and analyse the seismic behaviour of structures such as dams, tunnels, towers and mines, detect targets and features behind obstacles, and determine the physical parameters of the surface on a small scale by different polarizations. Considering the size of these radars and their low cost; they are much easier to implement and can be used in the first step of radar development, because assuming the uniform motion of these systems, some calculations can be ignored, including motion error compensation (Nekoee and Amini, 2019).

SAR technology is one of the most advanced types of imaging tools with high spatial resolution, and in some cases, the obtained data have a higher level of satisfaction than the information obtained from optical sensors (Tarchi et al., 2012; Yang, Yang, Tan, Dang, and Wang, 2016).

Over the past 40 years, several technologies have been developed for SAR systems, including Interferometry and Polarimetry and topographic information (Tarchi, Oliveri, and Sammartino, 2012; Yang, Yang, Tan, Dang, and Wang, 2016).

In recent years, the idea of a SAR system in the form of cheap Frequency-Modulated Continuous Wave (FMCW) has been developed and implemented. The idea is that with the development of low-cost electronic tools, it is possible to make tools that are now very expensive at the lowest possible cost. As a result, we can 1- expand the applications of previous systems or 2- find new solutions to existing problems (Tarchi et al., 2012).

Before the development mentioned above, the main idea of radar technology was based on the principle: The signal can be processed coherently in the transmitter/receiver so that the original signal itself is maintained, and radars that followed this principle were called Phased Arrays (Hassanien and Vorobyov, 2010).

Many researchers became interested in Multiple Input-Multiple Output (MIMO) technology and its benefits. Communication systems such as wireless used this technology at the beginning, and after a great deal of research, they were able to adapt it to radars and eventually use it (Du, Han, Jin, Hua, and Li, 2020; Robey, Coutts, Weikle, McHarg, and Cuomo, 2004; Sammartino, Tarchi, and Baker, 2011; Wang, 2012; Wang, Sellathurai, Chan, Xu, and Zhu, 2015).

The MIMO technology is based on the use of multiple antennas to send orthogonal waves and multiple antennas to receive return waves by objects (Friedlander, 2013; Hassanien and Vorobyov, 2010). It is necessary to state that the internal arrays of each antenna must produce the same waveform (such as conventional systems of the phased array)(Liu, Liu, Hao, Gao, and Wang, 2021; Dong and Zeng, 2015). In other words, the MIMO technique commonly requires individual elements of transmitter antennas to transmit its wavelength. The orthogonality of the transmitted waves is one of the main conditions of the MIMO technique that causes the received waves in the receiving antenna to be different from each other. It is stated that each transmitter, which is ideally omnidirectional, sends its specific waveform (for example, a random zero-mean Pseudo noise (PN) code) that is perpendicular to the other waves (Wang, 2012; Dong and Zeng, 2015; Sammartino et al., 2011).

Over time, researchers were able to divide the principles of MIMO into two categories: 1- Waveform-Diversity MIMO (WD-MIMO) 2- Space-Diversity MIMO (SD-MIMO) (or angle) (Fortunati, Sanguinetti, Gini, Greco, and Himed, 2020; Hassanien and Vorobyov, 2010; Sammartino, Baker, and Griffiths, 2010; Sammartino et al., 2011; Tarchi et al., 2012).

The first category has the possible to combine the desired antenna array, starting from the right point, by sending several different waveforms simultaneously. In such cases, the distance between the antennas is limited by comparing the wavelengths. Due to the popularity of this principle among users, scientists split it into two general groups. In the first group, separate transmitter/receiver antennas are widely used to receive the levels of Radar Cross Sections of different objects)(Hassanien and Vorobyov, 2010; Tarchi et al., 2012). The second group is the category in which there are arrays of transmission/receiving antennas with very short distances and are employed to send coherent beams to a specific object and direction. In this situation, there are usually two presuppositions: 1- The target is at a far distance and 2- The transmitted waves are band-limited, and as a result, the signal model seems like a point source (Hassanien and Vorobyov, 2010).

The second category assumed in MIMO radars is distance variation that used angular differences to achieve Radar Cross-Section measurements, which increases the efficiency of the entire system in some ways and different points of view (Tarchi et al., 2012). This article does not address the second principle, distance diversity and the word MIMO in the text means the same as WD-MIMO.

As mentioned earlier, radars are operated in various arena of military fields, including the detection of weapons and the security of countries. Also, the other applications are such as urban domain like mapping, exploration of resources such as mines or oil reserves, and environmental protection, identifying and managing unpredictable natural disasters. As can be seen, in most of these applications, the detection of moving objects as well as the determination of other information such as speed, distance, and angle from the sensor is one of the fundamental processes, which is always a challenging task for processing related to SAR systems (Chen, 2009; Dong and Zeng, 2015; He, Lehmann, Blum, and Haimovich, 2010). There are always different solutions to solve these types of problems, some of them are very complex, but the latest technology used to solve this problem is the use of a long-track channels (P. Chen et al., 2017; Dong and Zeng, 2015; He, Lehmann, Blum, and Haimovich, 2010; Wang, 2012)

It can be demonstrated that the more channels, better the results in detecting the features and higher the resolution determination speed. Therefore, it can be said that the greater the number of virtual channels with different phase centers in MIMO systems, the return waves can provide good results for detecting a moving target (Yang et al., 2016). In this article, we tried to use MIMO radar technology to achieve a primary and less cost-effective but higher accuracy solution for detecting a moving object and estimating the speed of that moving object.

MIMO antennas have been generally discussed in this article. In the following, the different sections of the report are as follows: In Section 2 on how to detect moving objects, in Section 3 on the principle of a FMCW Radar and the characteristics of sensors used in the microwave remote sensing laboratory of the University of Tehran, and in Section 4, simulations related to the detection of moving objects in front of the sensor using the software are discussed, and finally, the conclusions are presented in Section 5.

2. Moving Object Detection

As mentioned in the introduction, moving object detection is one of the leading remote sensing radar systems applications. In this regard, it is necessary to state the general principles of identifying moving objects before presenting the simulation results.

The fundamental concept in radar systems is that they generate a signal with a known frequency and increase linearly with time. This signal is called chirp. The chirp is transmitted by a transmit antenna. After this signal contacts with the target, it returns toward the receiver antenna. Finally, chirps are stored in the sensor memory as raw data.

Now we want to distinguish between a moving target and a stationary one. If a target moves, there will be a shift in the center of the frequency of the receiving signal compared with the transmitting signal. It is called the Doppler frequency. Depending on the direction of the target's movement, it can be said that this frequency shift will be positive or negative. Additionally, to estimate the speed of a target, the Fourier transform is used (S. C.-Y. Chen, 2009; He et al., 2010; Mahafza, 2003; Ulaby and Long, 2015).

3. Introducing the AWR1642 Boost Sensor

In the AWR1642 sensor, the waves are in millimeters and continuous, which is a particular group of radar technology that uses short-wavelength waves, which is the advantage of these sensors because it can detect movements in millimeters and by receiving the return waves from the targets, we can determine their distance, speed or angle. Other advantages of these sensors are their small size as well as their high accuracy.

The traditional system used discrete waves, which increases consumption and ultimately its cost. Texas Instruments solved this problem in this model of production.

As mentioned, this sensor is a particular class of millimeter technology that uses frequency-modulated waves. These sensors use a frequency-modulated continuous-wave (FMCW) to measure distance, angle, and velocity compared with traditional systems that send pulsed waves (Cesar Iovescu, 2017).

The AWR1642 sensor used to detect the moving object and its various features and parameters are shown in Figure 1 and Table 1. This information has been used to simulate sensors in a software environment. An essential and practical point about this sensor is the frequency variation of the signals from 76GHz to 81GHz. In this paper, the frequency value was considered to be 77 GHz (Bhutani et al., 2019; Cesar Iovescu, 2017).

Figure 1. Image of AWR1642 Boost sensor

Table 1. Introduction of values and parameters of AWR1642 Boost sensor

Parameters	**Amounts**
Sensor model	TI-AWR1642Boost
No. transmitters antenna	2
No. receiver antenna	4
frequency	76-81 GHz
Peak power	1.5mW
Noise figure	15dB
Bandwidth	<4GHz
Beat signal bandwidth	5MHz
Transmitter gain	30dB
Receiver gain	30dB
Chirp duration	60µs

4. Simulation Results

In this section, we presented the results of AWR1642 sensor simulation in a software environment. This simulation is performed to check the following:

The effect of distance between transmitter and receiver antenna elements was considered. In this section, two different states are created according to the amount of space between the elements. When the distance between the elements (both in the transmitter antenna and in the receiver antenna) is equal to $\lambda/2$, the state is called a fully array. If the distance between the elements became more extensive than $\lambda/2$, it is called a thin array. The last case is that the receiving antennas were considered virtual, and the distance between the transmitting antenna elements was assumed $\lambda/2$.

Detection of the moving object at different distances. This section presents the issue in two ways: 1- moving object and fixed sensor 2- object and sensor, both moving.

The results of the first simulation are presented in Figures 2 and 3.

In Figure 2, from a to d, the distance between the elements in the transmitter and receiver is equal to $\lambda/2$ (fully array), and it is considered at different angles of 10 degree, 30 degrees, 45 degrees and 60 degrees. Figure 3 shows a case where the distance between the sending elements is greater than $\lambda/2$, but the distance between the receiving elements is still equal to $\lambda/2$. In this figure, the transmitter angle is assumed as before. As shown in Figure 2, the smaller the transmission angle, the larger the main lobe, and there are smaller side lobes so that at a 10-degree angle, there are no side lobes at all. Therefore, it can be said that the power will be more with the small transmission angle and, consequently, the smaller the side lobes. The same thing can be seen in Figure 3, and it can be said that it is better to use smaller angles to send waves to have the least effect of noise from the side lobes.

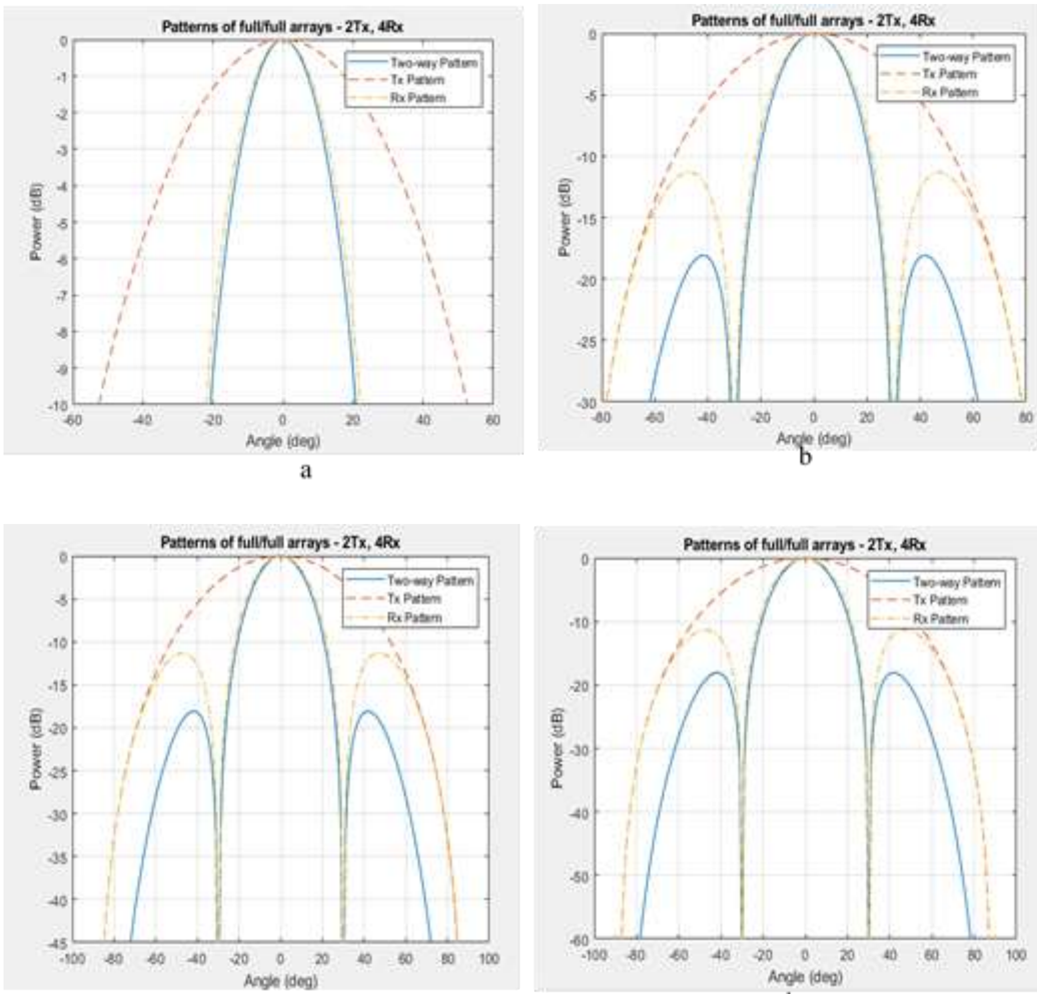
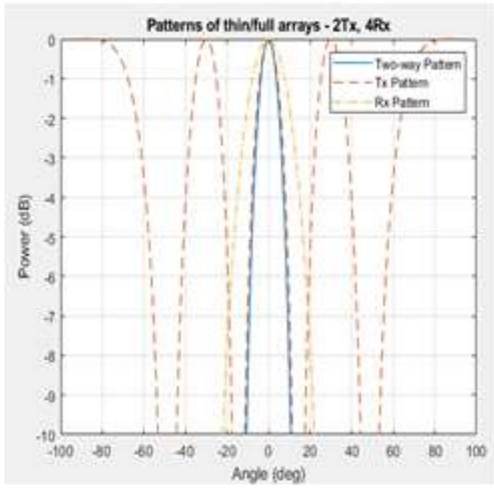
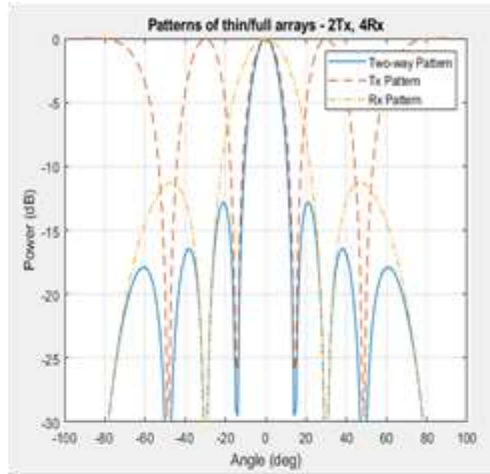


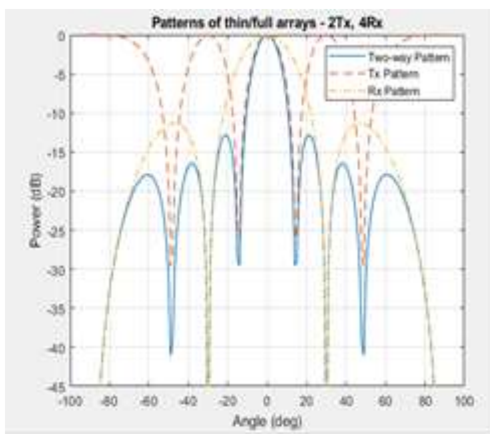
Figure 2. Transmission arrays, receiver, the final shape of the simulated patterns with the distance between the λ/2 element for the transmitter and receiver at different angles (a). 10-degrees angle (b). 30-degrees angle (c). 45-degrees angle (d). 60-degrees angle



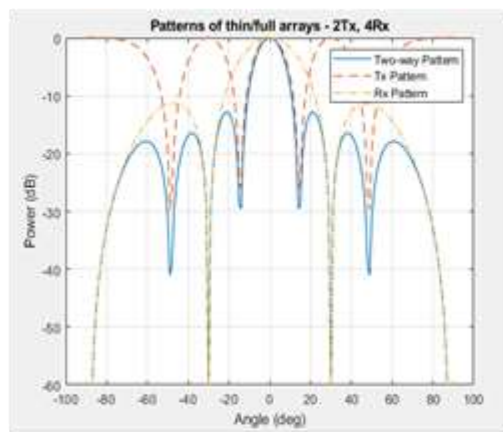
a



b



c



d

Figure 3. Transmission arrays, receiver, the final shape of the simulated patterns with the distance between the element for the transmitter larger than $\lambda/2$ and for receiver equal to $\lambda/2$ at different angles (a). 10-degrees angle (b). 30-degrees angle (c). 45-degrees angle (d). 60-degrees angle

Figure 4 shows a situation in which the receiving antennas are virtually equivalent to 8 antennas. However, the distance between the transmitter antenna elements is still considered $\lambda/2$, which has been examined according to the previous cases in 4 angles of 10, 30, 45 and 60 degrees.

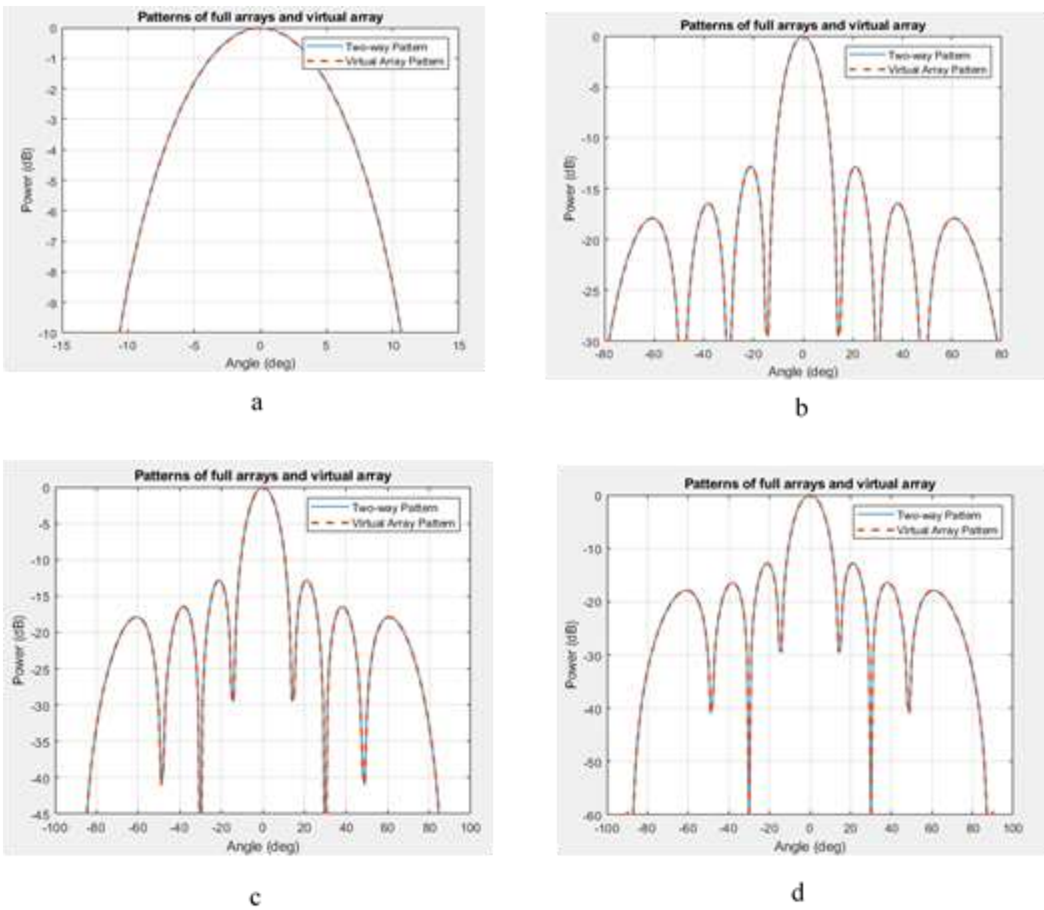
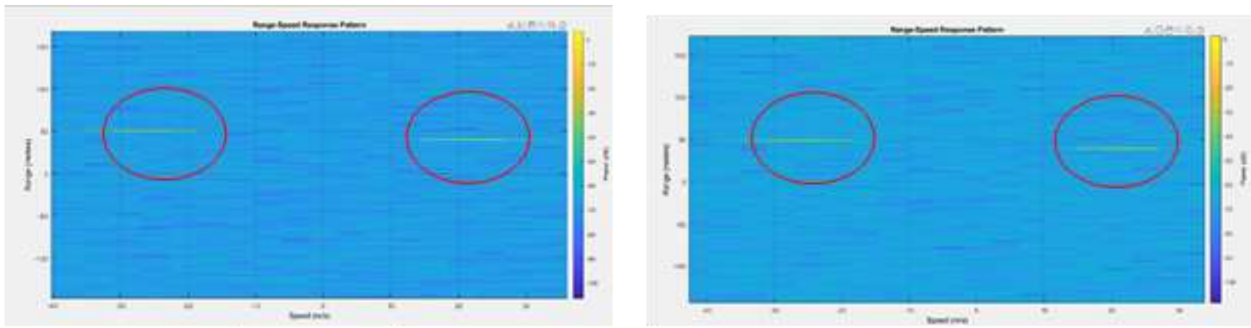


Figure 4. Transmission arrays, receiver, the final shape of the simulated patterns with the distance between the element for the transmitter equal to ʎ/2 and virtual receiver antennas at different angles (a). 10-degrees angle (b). 30-degrees angle (c). 45-degrees angle (d). 60-degrees angle

As mentioned, two situations are considered to determine the moving object. The results are in two different situations where the sensor has different locations presented in Figures 5 and 6. To simulate two moving objects which are 1 meter apart at 20 degree angle, we also considered other conditions, which are: the maximum distance from the sensor is 200 meter, the distance between the objects and the sensor for the first and second objects are equal to 40 and 50 meters, respectively, the maximum speed of the object is 250 km per hour, the objects move away from the sensor at a speed of 80 km/h, and approach the sensor at 96 km/h, the sampling rate is 150 MHz, spatial resolution is 0.25, bandwidth is 0.6 GHz, Radar Cross Sections (RSC) are 20 and 40 decibels, respectively. The situation of the sensor in two different modes [1, 1, 1] and [0,0,0] are considered. As can be seen, the results in Figure 5-b are clearer and better than in Figure 5-a. In Figure 6, since that the radar has a speed of 10 km/h too, and in position [1,1,1], the result of identifying the second object is not clear enough. As a result, it can be said that it is better to use the sensor at fixed so that the results have the appropriate quality and resolution.

Nevertheless, to the best of our knowledge, no studies are available assessing MIMO antennas for estimating the velocity of a moving target.



a b

Figure 5. Simulation of two moving objects and a fixed sensor (unit of measurement of the speed of objects is in meters per second) (a). sensor characters [0,0,0] (b). sensor characters [1,1,1]

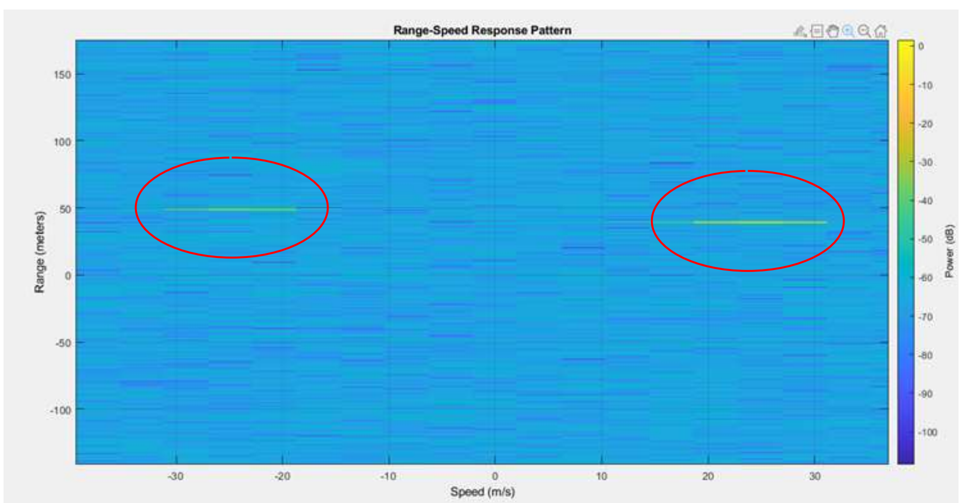


Figure 6. Simulation of two moving objects and moving radar with 10 km per hour at placement [1, 1, 1]

5. Conclusion

As mentioned earlier, the purpose of this paper, considering the advantages of using MIMO antennas, was to use these sensors to detect moving objects. In this regard, given to characters of the used sensor, some stimulations were performed, considering the presented results. It can be seen that the smaller the angle of transmission of the waves towards the object, the greater the power of the transmitted wave. As a result, the return wave and the sum of the return wave will be more powerful; this is due to the small size of the side lobes of the return waves, which increases the power of recognizing and identifying the objects in the image. In addition, to identify the two moving objects, depending on whether the sensor is moving or stationary, different results were obtained, which was the best result when the sensor is fixed [1,1,1].

References

Akcakaya, M., & Nehorai, A. (2011). MIMO Radar Sensitivity Analysis for Target Detection. *IEEE Transactions on signal processing*, *59*(7), 3241-3250. doi:10.1109/TSP.2011.2141665

Bhutani, A., Marahrens, S., Gehringer, M., Göttel, B., Pauli, M., & Zwick, T. (2019). The Role of Millimeter-Waves in the Distance Measurement Accuracy of an FMCW Radar Sensor. *Sensors*, *19*(18), 3938. Retrieved from https://www.mdpi.com/1424-8220/19/18/3938

Cesar Iovescu, S. R. (2017). *The fundamentals of millimeter wave sensors*. Retrieved from Texas Instrument.

Chen, P., Zheng, L., Wang, X., Li, H., & Wu, L. (2017). Moving Target Detection Using Colocated MIMO Radar on Multiple Distributed Moving Platforms. *IEEE Transactions on signal processing, 65*(17), 4670-4683. doi:10.1109/TSP.2017.2714999

Chen, S. C. Y. (2009). *Signal processing algorithms for MIMO radar*. California Institute of Technology.

Dong, Z. M., & Zeng, J. K. (2015). Research on MIMO Radar Based on Orthogonal Signal in the Present of Non-Ideal Factor. *The Open Electrical & Electronic Engineering Journal, 9*(1), 579-583.

Du, J., Han, M., Jin, L., Hua, Y., & Li, S. (2020). Target Localization Methods Based on Iterative Super-Resolution for Bistatic MIMO Radar. *Electronics, 9*(2), 341. Retrieved from https://www.mdpi.com/2079-9292/9/2/341

Fortunati, S., Sanguinetti, L., Gini, F., Greco, M. S., & Himed, B. (2020). Massive MIMO Radar for Target Detection. *IEEE Transactions on signal processing, 68*, 859-871. doi:10.1109/TSP.2020.2967181

Hassanien, A., & Vorobyov, S. A. (2010). Phased-MIMO radar: A tradeoff between phased-array and MIMO radars. *IEEE Transactions on signal processing*, *58*(6), 3137-3151.

He, Q., Lehmann, N. H., Blum, R. S., & Haimovich, A. M. (2010). MIMO radar moving target detection in homogeneous clutter. *IEEE Transactions on Aerospace and Electronic Systems, 46*(3), 1290-1301.

Li, H., Wang, Z., Liu, J., & Himed, B. (2015). Moving Target Detection in Distributed MIMO Radar on Moving Platforms. *IEEE Journal of Selected Topics in Signal Processing, 9*(8), 1524-1535. doi:10.1109/JSTSP.2015.2467355

Liu, W., Liu, J., Hao, C., Gao, Y., & Wang, Y. L. (2021). *Multichannel adaptive signal detection: Basic theory and literature review*. Science China. Information Sciences. doi:10.1007/s11432-020-3211-8

Mahafza, B. R. E., & Atef, Z. (2003). MATLAB simulations for radar systems design: CHAPMAN & HALL/CRC.

Nekoee, M., & Amini, J. (2019). *Design and Implementation of a S-band FMCW GB-SAR Imaging System*. Master Thesis, University of Tehran, Iran.

Robey, F. C., Coutts, S., Weikle, D., McHarg, J. C., & Cuomo, K. (2004). MIMO radar theory and experimental results. Paper presented at the *Conference Record of the Thirty-Eighth Asilomar Conference on Signals, Systems and Computers*, 2004/300-304

Sammartino, P., Baker, C., & Griffiths, H. (2010). Range-angle dependent waveform. Paper presented at the *IEEE Radar Conference*/511-515.

Sammartino, P., Tarchi, D., & Baker, C. (2011). MIMO radar topology: A systematic approach to the placement of the antennas. Paper presented at the *International Conference on Electromagnetics in Advanced Applications*/114-117.

Tarchi, D., Oliveri, F., & Sammartino, P. F. (2012). MIMO radar and ground-based SAR imaging systems: equivalent approaches for remote sensing. *IEEE Transactions on Geoscience and Remote Sensing*, *51*(1), 425-435.

Ulaby, F., & Long, D. (2015). *Microwave radar and radiometric remote sensing*. Artech House.

Wang, W. Q. (2012). Virtual Antenna Array Analysis for MIMO Synthetic Aperture Radars. *International Journal of Antennas and Propagation*, 587276. doi:10.1155/2012/587276

Wang, W. Q., Sellathurai, M., Chan, F. K. W., Xu, W., & Zhu, S. (2015). MIMO Antennas in Radar Applications. *International Journal of Antennas and Propagation*, 696790. doi:10.1155/2015/696790

Yang, D., Yang, X., Tan, X., Dang, H., & Wang, K. (2016). Ground moving target detection in MIMO-SAR system. Paper presented at the *IEEE International Geoscience and Remote Sensing Symposium* (IGARSS)/1062-1065.