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Network protocol-driven real-time tracking radar trajectory simulation using GLG framework for test range applications

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Abstract

This research presents an innovative approach to developing a Tracking Radar Trajectory Simulator by integrating advanced network communication protocols and the GLG toolkit framework. The simulator processes raw real-time coordinate system data, specifically in ECEF, ENV, or LLA formats, and converts this to Radar-specific requirements. It serves as a crucial tool for real-time data transmission and visualization of key parameters such as Azimuth Angle, Elevation Angle, and Range, facilitating the study and analysis of Radar trajectory dynamics. The system employs socket programming to enable seamless communication between the simulator and external devices, allowing efficient data exchange in a networked environment. Additionally, it incorporates optimized algorithms to enhance performance and reliability while reducing the time complexity of the simulation. The proposed system surpasses existing state-of-the-art models in terms of agility and performance. Through rigorous experimentation and evaluation, the effectiveness and efficiency of the proposed approach are demonstrated, highlighting its potential applications in Radar technology research and development. This research advances the field of trajectory simulation by providing a robust and scalable solution for real-time data analysis and visualization, contributing significantly to the development of more agile and high-performing tracking systems.

Keywords: Radar; Trajectory; Simulation; GLG Toolkit; Network Communication Protocol

1. Introduction

The development of Radio detecting and Ranging (RADAR) technology in the early 1900s signaled a revolution in detecting capabilities. Visual observation was a major component of surveillance before RADAR, which limited detection of objects in the line of sight [1]. Both military and civilian uses were hampered by this limited range and precision. However, with the advent of RADAR, detection powers increased significantly. RADAR revolutionized surveillance in both the military and civilian domains by precisely detecting things beyond optical range through the transmission and reception of radio waves [2]. Significant developments in RADAR technology over time have made it possible for it to be integrated into a wide range of industries, including the aviation, meteorology, marine, and automotive sectors [3].

Radio waves are sent by RADAR and travel through the atmosphere until they come into contact with an object. When the waves come into contact with an item, they reflect towards the RADAR system [4]. RADAR determines an object's distance, direction, and speed by timing the return of these reflected waves and examining the Doppler effect, which causes a change in frequency. Echo ranging is the technique that underpins RADAR capabilities. A transmitter, which produces the radio waves, and a receiver, which picks up the reflected signals, are the main parts of RADAR systems [5][6]. For accurate measurements, the transmitted pulses are usually emitted in short bursts.

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The GLG Toolkit is a powerful software framework widely used in simulation applications for its capabilities in developing interactive graphical displays and real-time monitoring systems. Leveraging scalable vector graphics (SVG) technology, GLG allows developers to create dynamic and responsive user interfaces that are essential in simulation environments [7]. Its extensive library of widgets and components enables the representation of complex data sets and the integration of interactive controls for user interaction. For simulation purposes, the GLG Toolkit excels in visualizing and animating data generated from simulations, such as trajectory tracking in RADAR systems or dynamic modeling in aerospace simulations [8]. It supports the integration of real-time data feeds, facilitating the monitoring and analysis of simulated scenarios. Moreover, GLG's robust architecture and support for various programming languages make it adaptable for diverse simulation needs, whether in academic research, industrial training, or military applications [9]. Overall, the GLG Toolkit enhances simulation experiences by providing advanced visualization capabilities and interactive features crucial for understanding and interpreting simulated data in real-time [10].

This research experiment simulates a tracking radar. A specific type of RADAR called tracking RADAR is intended to track objects' movements and trajectories precisely. Tracking RADAR constantly tracks the position, velocity, and direction of certain targets, in contrast to surveillance RADAR, which is primarily concerned with identifying the existence of objects inside a specified region. To enable proactive reaction and decision-making, this kind of RADAR uses advanced tracking algorithms and processing techniques to forecast the future position of detected objects [11]. Their operational goals are one important way that tracking Radar differs from other kinds. While tracking RADAR delivers precise tracking and monitoring capabilities, which are crucial for applications like air traffic control and missile guidance systems, surveillance RADAR gives wider coverage and situational awareness [12].

2. Related Works

In the domain of RADAR simulation and visualization, numerous research efforts have explored varied methodologies to achieve optimal solutions. Carlo et al. conducted a notable study showcasing a digital radar simulator rooted in physical principles. Their approach involves generating artificial radar signals by summing contributions from all scatterers within a simulated meteorological environment [13]. This method carefully incorporates radar system characteristics, propagation effects, and wave polarization considerations. Similarly, Cheong et al. proposed an algorithm capable of generating sequential data samples collected by radar systems of diverse configurations. This advancement facilitates comprehensive testing and analysis of complex topics such as phased array antennas, clutter mitigation strategies, waveform design investigations, and spectral-based techniques [14].

Expanding on this linguistic context, Shelly et al. introduced SimHumalator, an open-source simulation program driven by motion capture data. This program generates extensive human micro-Doppler radar data within passive Wi-Fi environments. By integrating Wi-Fi standards and compliance transmissions with human animation data, the simulator produces micro-Doppler features that account for diverse human motion traits and sensor settings [15]. In a different approach, Thomas et al. presented a model that deconstructs high-level traffic scenario descriptions into the specific characteristics required for radar target simulation. This method enables the creation of realistic traffic scenarios, thereby enhancing the accuracy of automotive radar sensor testing [16]. Continuing the investigation, Olivier et al. developed a comprehensive radar simulator tailored for non-hydrostatic models with a fine resolution ranging from 1 to 4 kilometres. The simulator consists of modular components, each detailing specific physical mechanisms, with various formulas applied to these components. Furthermore, the microphysical parameterizations of the atmospheric numerical model align seamlessly with those of the radar simulator [17].

In contrast to existing research, this study introduces a Tracking RADAR Trajectory Simulator utilizing the GLG framework and User Datagram Protocol (UDP). The authors have implemented an enhanced model that accurately simulates critical parameters necessary for precise real-time data analysis. This includes detailed emulation of RADAR operations, such as continuous tracking of target movements and trajectories. This capability enables thorough analysis and assessment of RADAR performance under dynamic conditions.

3. Simulation Architecture

3.1. Model Implementation

In this study, the simulation model frontend is carried out by the GLG framework. Within the simulator, the GLG Toolkit facilitates the visualization of critical RADAR parameters such as the Azimuth Angle, Elevation Angle, and Range. This is achieved through the reception of UDP packets containing real-time data via DatagramSocket, which are parsed and bound to specific graphical elements using GLG Toolkit's animation functionalities (GlgAnimationValue). Figure. 1 gives the workflow representation of the model. These elements, represented as charts and meter displays, dynamically update their values and visual representations in response to incoming data.

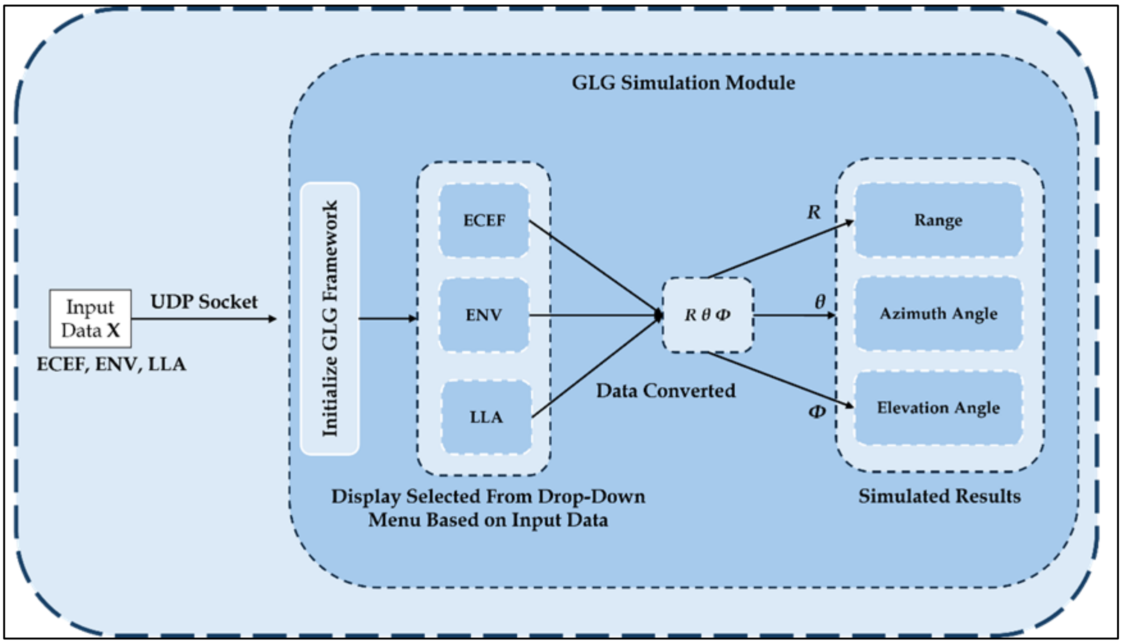


Figure 1 Model Workflow Diagram

In the backend integration of the model, the input coordinate data in Earth Centered – Earth Fixed (ECEF), East North Vertical (ENV), or Longitude Latitude Altitude (LLA) form is being analyzed and converted into spherical coordinates such as *R, θ* and *φ* parameters respectively. ECEF coordinates define positions relative to the Earth's center of mass, with axes fixed relative to the Earth's rotation [18]. The X-axis points towards the intersection of the prime meridian and the equator, the Y-axis towards 90 degrees longitude (East), and the Z-axis towards the North Pole. This system is particularly useful in satellite navigation systems like GPS, where precise global positioning is essential. ENV coordinates, on the other hand, are local-level Cartesian coordinates referenced to a local tangent plane [19]. The East axis increases with longitude, the North axis with latitude, and the Vertical axis is perpendicular to the tangent plane, pointing upwards. ENV coordinates are advantageous in localized navigation and mapping applications, providing a straightforward way to describe positions relative to a specific point on the Earth's surface [20]. LLA coordinates to describe positions using latitude, longitude, and altitude (or height above a reference ellipsoid). Latitude measures the north-south position relative to the equator, longitude measures the east-west position relative to the prime meridian, and altitude represents height above or below a reference surface. LLA coordinates are widely used in everyday applications like mapping services and aviation, offering intuitive geographical information that is easy to understand and work with. Equation (1), (2), and (3) gives the mathematical transforms for ECEF data conversions into spherical coordinates. *X, Y,* and *Z* represent the ECEF coordinates.

$$R = \sqrt{X^2 + Y^2 + Z^2} \;\ldots\ldots\ldots\ldots\ldots (1)$$

$$\theta = \tan^{-1}\left(\frac{Y}{X}\right) \;\ldots\ldots\ldots\ldots\ldots (2)$$

$$\varphi = \sin^{-1}\left(\frac{Z}{R}\right) \;\ldots\ldots\ldots\ldots\ldots (3)$$

The conversion from Earth-Centered Earth-Fixed (ECEF) coordinates to spherical coordinates *R, θ* and *φ* involves computing the radial distance *R* as the magnitude of (*X, Y, Z*) the azimuth angle *θ* using arctangent, and the elevation angle *φ* with arcsine, ensuring the proper handling of coordinate signs and quadrants. Similarly, ENV data points are converted to spherical coordinates using Equations (4), (5), and (6) respectively.

$$R = \sqrt{E^2 + N^2 + V^2} \;\ldots\ldots\ldots\ldots\ldots (4)$$

$$\theta = \tan^{-1}\left(\frac{N}{V}\right) \;\ldots\ldots\ldots\ldots\ldots (5)$$

$$\varphi = \tan^{-1}\left(\frac{V}{\sqrt{E^2+N^2}}\right) \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Converting Geodetic coordinates (Latitude, Longitude, Altitude) to spherical coordinates (R, θ, φ) involves a series of mathematical transformations. Since geodetic coordinates cannot be directly converted into spherical coordinates, the process first involves converting them to Earth-Centered, Earth-Fixed (ECEF) coordinates. This intermediate step is then followed by a conversion to spherical coordinates using Equations (1), (2), and (3). The specific transformations from Geodetic to ECEF coordinates are explained by Equations (7), (8), and (9), where N is the prime vertical radius of curvature, h is the altitude, ϕ is the latitude, and λ is the longitude. This two-step conversion ensures accurate and precise transformation from geodetic to spherical coordinate systems, facilitating various geospatial and engineering applications.

$$x = (N + h)\cos(\phi)\cos(\lambda) \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$y = (N + h)\cos(\phi)\sin(\lambda) \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$z = (N(1 - e^2) + h)\sin(\phi) \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

These equations are fundamental in geospatial applications for converting geographic coordinates into a format suitable for spherical trigonometry, facilitating navigation, mapping, and astronomical calculations with accurate positioning relative to Earth's surface and center.

In radar simulation, using spherical coordinates is essential for accurately representing and analyzing radar targets in three-dimensional space. These coordinates provide a comprehensive way to describe the position of targets relative to the radar system [21]. The radial distance R denotes how far a target is located from the radar, which is crucial for determining range and assessing potential threats or objects of interest. The azimuth angle θ specifies the horizontal direction of the target from the radar's perspective, facilitating precise tracking and directional control of the radar beam [22]. Similarly, the elevation angle φ indicates the vertical direction of the target, aiding in the assessment of altitude and enabling radar systems to distinguish between targets at different heights.

In radar simulation software, converting targets' positions into spherical coordinates allows for realistic modelling of radar operations. It supports accurate simulation of radar coverage, target detection based on their spatial coordinates, and visualization of radar displays that reflect real-world scenarios. This capability is crucial for training purposes, operational planning, and the development of radar technologies. Moreover, spherical coordinates integrate seamlessly with navigation systems and geographical information systems (GIS), enabling comprehensive spatial analysis and coordination of radar data with other sources of spatial information [23].

3.2. Graphical User Interface

The GUI is divided into several main components: a top panel featuring headers and images, a central panel housing multiple charts arranged in grids for displaying converted and raw data, and a bottom panel containing a dropdown menu and a button for file selection and data sending operations. The heart of the application lies in its ability to dynamically convert and visualize coordinate data. Charts, powered by the JFreeChart library, are initialized and updated using XYSeries collections to represent different aspects of the data [24]. Each chart is configured to display relevant information such as Range, Azimuth Angle (θ), Elevation Angle (φ), and raw input values over time, providing users with comprehensive visual feedback. The application's functionality includes reading data from selected CSV files using JFileChooser and sending it over UDP using DatagramSocket and DatagramPacket to a specified IP address and port.

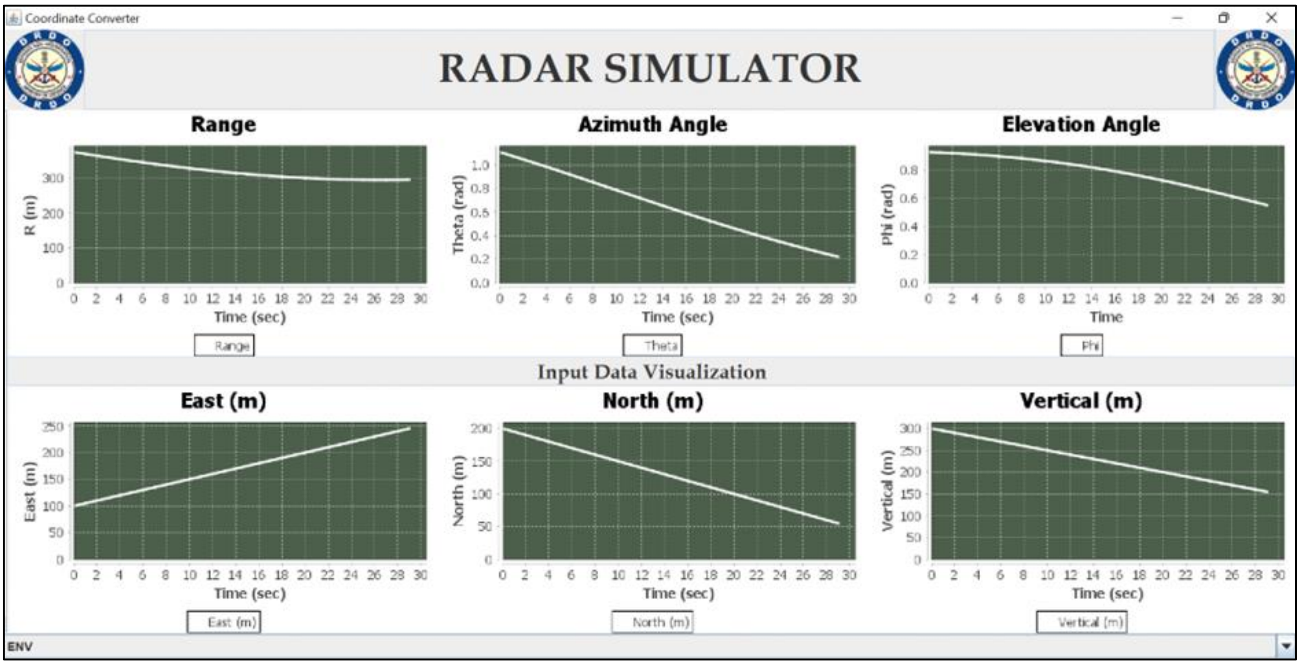


Figure 2 Model Graphical User Interface

This setup ensures real-time data transmission and visualization, crucial for radar simulation and analysis tasks. Error handling is implemented to manage file I/O exceptions (IOException) and socket initialization errors, ensuring smooth operation under various conditions. Figure. 2 gives the GUI for the model. Event listeners for the dropdown menu and file selection button enhance user interaction by dynamically updating chart labels based on the selected coordinate system. The application also utilizes timer tasks to periodically read data from the file, convert it based on the selected system, update the charts, and display converted coordinates in a text area.

4. Experimentations and Results

Table 1 Performance Metrics

Epochs	Range Accuracy (m)	Angular Accuracy (°)	Root Mean Squared Error	Latency (ms)
1	0.56	0.48	2.34	37
2	0.64	0.55	2.32	44
3	0.48	0.58	2.38	47
4	0.55	0.63	2.38	51
5	0.69	0.59	2.40	27
6	0.69	0.68	2.36	34
7	0.71	0.64	2.39	38
8	0.65	0.73	2.35	29
9	0.74	0.76	2.41	40
10	0.77	0.72	2.39	48

In the study, the authors utilized data from real-time object sources to ensure the accuracy and relevance of the findings. By leveraging live data streams, the model was able to capture dynamic and instantaneous information about the objects being tracked. This approach allowed the model to observe and analyze real-world behaviors and interactions, leading to more robust and applicable results. Real-time data collection provided a continuous flow of updated information, enhancing the study's ability to model and predict object movements accurately. To analyze the performance of the model, various performance metrics were employed and rigorously tested over multiple epochs. During each epoch, data was continuously transmitted via a UDP socket to the model in real time for 30 seconds, and the results were recorded. The evaluation metrics included Range Accuracy, Angular Accuracy, Signal-to-Noise Ratio (SNR), Root Mean Square Error (RMSE), and Latency [25]. These metrics were used to critically assess the model's performance, in accurately simulating the crucial parameters and ensuring a comprehensive evaluation of the model's effectiveness in real-world conditions. Table. 1 gives the results obtained by all the epochs run to examine the model.

The Range Accuracy measures the precision in determining the distance to a target, vital for accurate location. **Angular Accuracy,** expressed in degrees, assesses the accuracy of azimuth and elevation angles, critical for pinpointing the target direction. **Root Mean Squared Error (RMSE)** quantifies the average deviation between the predicted and actual positions, reflecting tracking accuracy. Lastly, **Latency,** measured in milliseconds, gauges the delay between real-time target movement and radar detection, with lower latency crucial for real-time applications. Equation (10), (11), and (12) gives the mathematical transformations for the evaluation metrics where N is the number of measurements, R_i, θ_i, and y_i are the actual values of the i-th target and $\hat{R}_i$, $\hat{\theta}_i$, $\hat{y}_i$ are the measured values of the i-th target.

$$Range\ Accuracy = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(R_i - \hat{R}_i)^2} \quad \text{.................. (10)}$$

$$Angular\ Accuracy = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\theta_i - \hat{\theta}_i)^2} \quad \text{..........(11)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2} \quad \text{............... (12)}$$

Latency in a system, particularly in radar and communication systems, refers to the time delay between the initiation of an operation and its completion [25]. Equation (13) followed by (14), (15), (16), and (17) calculates the latency on the specific context and components involved in the system.

$$Latency = T_{transmit} + T_{propagate} + T_{process} + T_{queue} \quad \text{.............. (13)}$$

$$T_{transmit} = \frac{Packet\ Size}{Transmission\ Rate} \quad \text{.............(14)}$$

$$T_{propagate} = \frac{Distance}{Propagation\ Speed} \quad \text{........... (15)}$$

$$T_{process} = \frac{Number\ of\ Operations}{Processing\ Speed} \quad \text{............(16)}$$

$$T_{queue} = \frac{\lambda}{\mu \times (\mu - \lambda)} \quad \text{..............(17)}$$

The performance of the proposed model has been meticulously compared with other state-of-the-art models and architectures. Table. 2 provides a comprehensive evaluation and thorough understanding of the proposed model's effectiveness with existing cutting-edge approaches in the field.

Table 2 Comparison of the Proposed Model Performance Metrics

Model	**Root Mean Square Error (°)**
Our Model	2.3720 (Avg)
ViRa [26]	2.2587
RadSimReal [27]	2.7384
3D – Sim [28]	1.7493
Missile Borne SAR Simulator [29]	2.1183
RT – Sim [30]	3.0482

Table. 2 compares the average RMSE of various radar simulation models. Our model achieves an RMSE of 2.3720, higher than ViRa (2.2587) and 3D – Sim (1.7493), indicating slightly less accuracy. However, it outperforms RadSimReal (2.7384), Missile Borne SAR Simulator (2.1183), and RT–Sim (3.0482), showcasing better accuracy than these models. This suggests our model is competitive, balancing accuracy effectively compared to other radar simulation tools.

5. Discussion

The results from the ten epochs provide a comprehensive overview of the radar simulation model's performance across key metrics: Range Accuracy, Angular Accuracy, Root Mean Squared Error (RMSE), and Latency. The Range Accuracy exhibits a fluctuating pattern, starting at 0.56 meters and peaking at 0.77 meters by the tenth epoch, indicating a steady improvement in range precision over time. Angular Accuracy follows a similar trend, beginning at 0.48 degrees and reaching 0.76 degrees, showcasing enhanced angular precision as the epochs progress. The RMSE, a critical measure of the model's overall prediction error, remains relatively stable around an average of 2.3720, with minor fluctuations between 2.32 and 2.41. This stability suggests consistent performance in error minimization across different epochs. Latency, which reflects the time delay in processing, shows variability, starting at 37 milliseconds and peaking at 51 milliseconds in the fourth epoch before dipping to 27 milliseconds in the fifth epoch. Despite these variations, latency maintains a range that balances responsiveness and accuracy. These findings indicate that while there are natural fluctuations in performance metrics due to varying conditions and model adjustments, the overall trend points to gradual improvements in accuracy and stability. The consistent RMSE values suggest reliable error handling, while the enhancements in range and angular accuracy demonstrate the model's capacity for precise target tracking. Latency variations highlight areas for further optimization to ensure timely data processing [31].

Future work should prioritize enhancing the model's responsiveness by reducing latency while maintaining high accuracy levels. Achieving this may involve optimizing the existing algorithms and improving hardware configurations to support faster data processing. Additionally, integrating more advanced algorithms, particularly for real-time data processing and noise reduction, could significantly elevate the model's performance. This could include machine learning techniques that adapt to varying environmental conditions and target behaviors, providing a more dynamic and accurate tracking capability. Moreover, exploring adaptive learning techniques will allow the radar system to self-improve over time, learning from past data to predict and adjust for future scenarios [32]. Incorporating a wider range of environmental scenarios into the simulation will also enhance its robustness, ensuring the model can handle diverse and challenging conditions encountered in real-world operations. Lastly, extensive testing in real-world conditions is crucial to validate the practical utility of the radar simulation model. This will ensure it meets operational requirements, performs reliably under various conditions, and can be effectively integrated into existing radar systems. Continued collaboration with industry and military stakeholders will help guide these developments to align with practical needs and technological advancements.

6. Conclusion

The study highlights significant improvements in range accuracy, angular accuracy, and overall prediction error stability (RMSE), with range accuracy improving from 0.56 to 0.77 meters and angular accuracy from 0.48 to 0.76 degrees. Despite fluctuations, RMSE remained stable around 2.3720, and latency, while variable, balanced responsiveness and accuracy. These results underscore the model's capacity for precise target tracking and reliable error handling. Future efforts should focus on reducing latency and integrating advanced algorithms for real-time data processing and adaptive learning, alongside extensive real-world testing. This study's outcomes will enhance radar system precision and responsiveness, benefiting society by improving radar-based applications in both civilian and defense sectors.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] M. Chiani, A. Giorgetti and E. Paolini, Sensor Radar for Object Tracking, in *Proceedings of the IEEE*, vol. 106, no. 6, pp. 1022-1041, June 2018.

[2] D. K. Barton, Low-angle radar tracking, in *Proceedings of the IEEE*, vol. 62, no. 6, pp. 687-704, June 1974.

[3] T. Kirubarajan, Y. Bar-Shalom, W. D. Blair and G. A. Watson, IMMPDAF for radar management and tracking benchmark with ECM, in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 34, no. 4, pp. 1115-1134, Oct. 1998.

[4] Seong-Taek Park and Jang Gyu Lee, Improved Kalman filter design for three-dimensional radar tracking, in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 37, no. 2, pp. 727-739, April 2001.

[5] X. Xiong, Z. Deng, W. Qi, H. Ou and Z. Cui, A Novel High-Precision Range Estimation Method Based on Phase of Wideband Radar Echo, in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 57, no. 6, pp. 3392-3403, June 2019.

[6] Y. Xu, W. Li, Y. Yang, H. Ji, B. Li and Y. Lang, Multiple Targets Echo Separation on Radar Range–Doppler Maps via Dual Decoupling Perception, in *IEEE Sensors Journal*, vol. 22, no. 21, pp. 20797-20804, 1 Nov.1, 2022.

[7] Y. H. Lee and T. E. Specht, Remote access multi-mission processing and analysis ground environment (RAMPAGE), *2000 IEEE Aerospace Conference. Proceedings (Cat. No.00TH8484)*, Big Sky, MT, USA, 2000, pp. 353-358.

[8] S. J. Cooke *et al*., CTLSS-an advanced electromagnetic simulation tool for designing high-power microwave sources, in *IEEE Transactions on Plasma Science*, vol. 28, no. 3, pp. 841-866, June 2000.

[9] L. Rai and S. J. Kang, Knowledge-Based Integration Between Virtual and Physical Prototyping for Identifying Behavioral Constraints of Embedded Real-Time Systems, in *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 39, no. 4, pp. 754-769, July 2009.

[10] Puñal, Elías & Garcia-Carballeira, Felix & Camarmas-Alonso, Diego. (2022). A Scalable Simulator for Cloud, Fog and Edge Computing Platforms with Mobility Support. SSRN Electronic Journal.

[11] S. Haykin, A. Zia, I. Arasaratnam and Y. Xue, Cognitive tracking radar, *2010 IEEE Radar Conference*, Arlington, VA, USA, 2010, pp. 1467-1470

[12] Ruixin Niu, P. Willett and Y. Bar-Shalom, Tracking considerations in selection of radar waveform for range and range-rate measurements, in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 38, no. 2, pp. 467-487, April 2002

[13] C. Capsoni and M. D'Amico, A Physically Based Radar Simulator, Journal of Atmospheric and Oceanic Technology, vol. 15, no. 2, pp. 593-601, Apr. 1998, doi: 10.1175/1520-0426(1998)015<0593:APBRS>2.0.CO;2.

[14] B. L. Cheong, R. D. Palmer, and M. Xue, A Time Series Weather Radar Simulation Based on High-Resolution Atmospheric Models, Journal of Atmospheric and Oceanic Technology, vol. 25, no. 2, pp. 313-329, Feb. 2008, doi: 10.1175/2007JTECHA923.1.

[15] S. Vishwakarma, W. Li, C. Tang, K. Woodbridge, R. Adve, and K. Chetty, SimHumalator: An Open-Source End-to-End Radar Simulator for Human Activity Recognition, IEEE Aerospace and Electronic Systems Magazine, vol. 37, no. 3, pp. 6-22, Mar. 1, 2022, doi: 10.1109/MAES.2021.3138948.

[16] T. Dallmann, J. -K. Mende, and S. Wald, ATRIUM: A Radar Target Simulator for Complex Traffic Scenarios, 2018 IEEE MTT-S International Conference on Microwaves for Intelligent Mobility (ICMIM), Munich, Germany, 2018, pp. 1-4, doi: 10.1109/ICMIM.2018.8443515.

[17] O. Caumont, V. Ducrocq, et al., A Radar Simulator for High-Resolution Nonhydrostatic Models, Journal of Atmospheric and Oceanic Technology, vol. 23, no. 8, pp. 1189-1204, Aug. 2006, doi: 10.1175/JTECH1905.1.

[18] C. C. Counselman and S. A. Gourevitch, Miniature Interferometer Terminals for Earth Surveying: Ambiguity And Multipath with Global Positioning System, in *IEEE Transactions on Geoscience and Remote Sensing*, vol. GE-19, no. 4, pp. 244-252, Oct. 1981.

[19] Ashby, N. Relativity in the Global Positioning System. Living Rev. Relativ. 6, 1 (2003).

[20] Colombo, Oscar. (1989). The dynamics of Global Positioning System orbits and the determination of precise ephemerides. Journal of Geophysical Research Atmospheres.

[21] Yifeng Zhou, H. Leung and M. Blanchette, Sensor alignment with Earth-centered Earth-fixed (ECEF) coordinate system, in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 35, no. 2, pp. 410-418, April 1999.

[22] Wampler, P.J., Rediske, R.R. & Molla, A.R. Using ArcMap, Google Earth, and Global Positioning Systems to select and locate random households in rural Haiti. Int J Health Geogr 12, 3 (2013).

[23] Church, Richard. (2002). Geographical Information Systems and Location Science. Computers & Operations Research.

[24] Y. Lee, J. Yang and K. H. Chang, Metrics and Evolution in Open Source Software, *Seventh International Conference on Quality Software (QSIC 2007)*, Portland, OR, USA, 2007, pp. 191-197.

[25] W. Zhang, M. Feng, M. Krunz and H. Volos, Latency Prediction for Delay-sensitive V2X Applications in Mobile Cloud/Edge Computing Systems, *GLOBECOM 2020 - 2020 IEEE Global Communications Conference*, Taipei, Taiwan, 2020, pp. 1-6.

[26] C. Schöffmann, B. Ubezio, C. Böhm, S. Mühlbacher-Karrer and H. Zangl, Virtual Radar: Real-Time Millimeter-Wave Radar Sensor Simulation for Perception-Driven Robotics, in *IEEE Robotics and Automation Letters*, vol. 6, no. 3, pp. 4704-4711, July 2021.

[27] Oded Bialer, Yuval Haitman; Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), 2024, pp. 15407-15416

[28] D'Amato, Juan & García Bauza, Cristian & Boroni, Gustavo & Vénere, Marcelo. (2013). Real-Time Aircraft Radar Simulator for a Navy Training System. Computer Applications in Engineering Education. 21.

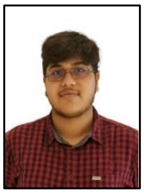
[29] T. Shu, B. Tang, K. Yin, Q. Sun, Y. Chen and W. Yu, Development of multichannel real-time Hardware-in-the-Loop radar environment simulator for missile-borne Synthetic Aperture Radar, *2015 IEEE Radar Conference (RadarCon)*, Arlington, VA, USA, 2015, pp. 0368-0373.

[30] H. Ergezer, M. F. Keskin and O. Gunay, Hardware-in-the-loop radar test simulator, *2014 4th International Conference On Simulation And Modeling Methodologies, Technologies And Applications (SIMULTECH)*, Vienna, Austria, 2014, pp. 666-673

[31] D. F. Külzer, F. Debbichi, S. Stańczak and M. Botsov, On Latency Prediction with Deep Learning and Passive Probing at High Mobility, *ICC 2021 - IEEE International Conference on Communications*, Montreal, QC, Canada, 2021, pp. 1-7.

[32] L. J. Porcello *et al.*, The Apollo lunar sounder radar system, in *Proceedings of the IEEE*, vol. 62, no. 6, pp. 769-783, June 1974.

Author’s Short Biography

<table>
<tr><td></td><td>Mitul Goswami was born in Balasore, Odisha, India on 9th May 2004. He completed his High School at B.D.M. International School, Kolkata, West Bengal, India in 2020 and is currently pursuing a B. Tech in Computer Science & Engineering from Kalinga Institute of Technology, Bhubaneshwar, Odisha, India. He has worked at the Indian Institute of Technology, Kharagpur, India as a Research Intern and has also worked at the Integrated Test Range, Defence Research and Development Organization (DRDO), Chandipur, Odisha as an Intern. He has published papers in reputed IEEE and Springer international conferences and journals and also has been granted a UK-registered patent, which adds to his academic expertise. Mr. Goswami’s research interests include Machine Learning, Deep Learning, Optimization Techniques, Remote Sensing, and Hyperspectral Image Classification.</td></tr>
<tr><td></td><td>Shashwat Kumar was born in Pune, Maharashtra, India on 23rd SEPTEMBER 2004. He completed his High School at Modern Public School, Balasore, Odisha, India in 2020. He is pursuing a B. Tech in Computer Science & Engineering from Kalinga Institute of Technology, Bhubaneshwar, Odisha, India. He has worked at the Integrated Test Range, Defence Research and Development Organization (DRDO), Chandipur, Odisha as an Intern. Shashwat's research interests include Machine Learning, Computer Networking, and Optimization Techniques.</td></tr>
<tr><td></td><td>Dr Sourav Kaity joined Defence Research and Development Organization, India as a Scientist and is currently posted to Integrated Test Range, Chandipur from 2003 just after his graduation. He graduated from Regional Engineering College, Durgapur, now known as NIT, Durgapur in Computer Science and Engineering with Honours in 2003. He completed his MTech in Computer Science and Engineering from the Indian Institute of Technology, Kharagpur in the year 2010. He was awarded the doctoral degree in 2021. He is working on Real-time systems for data processing for the last 19 years. Now he is heading the Real-time Data Processing (RTDP) department. His research area is focused on real-time systems, trajectory data processing and analysis, moving object and flight vehicle tracking systems, measurement and estimation of object location, improvement of accuracy and prioritization of tracking instruments, flying object visualization, and simulation of trajectory.</td></tr>
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