RESEARCH ARTICLE

RSP Science Hub

International Research Journal on Advanced Science Hub
2582-4376
Vol. 06, Issue 03 March
www.rspsciencehub.com

http://dx.doi.org/10.47392/IRJASH.2024.007

Launch Vehicle Integrated Health Management System Model

Abhijith K[1], Jayaraj S[2], Yonadhan MM[3], Dr. Sreelal Pillai[4], Sajin S[5], Anu Assis[6], Vishnu Damodaran[7], Sajeena A[8]*
[1, 2, 3] UG - Electronics and Communication Engineering, TKM College of Engineering, Kollam, Kerala, India.
[4] Avionics Engineer, Vikram Sarabhai Space Centre, Thiruvananthapuram, Kerala, India.
[5]Scientist/Engineer-SD, Vikram Sarabhai Space Centre, Thiruvananthapuram, Kerala, India.
[6, 8] Associate Professor, Electronics and Communication Engineering, TKM College of Engineering, Kollam, Kerala, India.
[7] Assistant Professor, Electronics and Communication Engineering, TKM College of Engineering, India.
Emails: *abhijithraghavofficial@gmail.com[1], jayaraj.sreekumar@gmail.com[2], Yonadhanmm0@gmail.com[3], reelal_s@outlook.com[4], anuassis@tkmce.ac.in[6], vishnud2118@gmail.com[7], sajeena@tkmce.ac.in[8]*
****Orcid ID**: https://orcid.org/0009-0001-4919-1472*

Article history

Received: 26 January 2024
Accepted: 10 March 2024
Published: 25 March 2024

***Keywords**:*
Integrated Vehicle Health Management (IVHM),
Diagnosis,
Prognosis,
Limit checking

Abstract

Relying heavily on effective limit checking, Systems for integrated vehicle health management (IVHM) are essential for ensuring launch vehicles are dependable and safe. [1]. The temperature, pressure, and voltage are measured by sensors positioned strategically throughout the vehicle. The data is continuously compared in real time to predefined limitations set by the IVHM system developer. The main task of limit checking is to keep an eye on engine sensor data and spot possible problems when measured values go over or below predetermined boundaries. These problems could result in engine damage or decreased performance. The IVHM system is built to quickly initiate alarms or carry out corrective actions in response, such as modifying engine load, turning on cooling fans, or alerting the driver to fix the issue. Limit checking is optimized by statistical or machine learning algorithms that analyse past sensor readings and operational conditions. By considering variables like normal parameter ranges, the type of vehicle, and external circumstances, this analysis improves upon predefined limits. IVHM systems greatly enhance vehicle performance, reduce failure risk, and enable proactive maintenance interventions through continuous monitoring and analysis within acceptable bounds.

1. Introduction

For launch vehicles to be reliable and safe, an essential system for tracking, evaluating, and managing their state is called Integrated Vehicle Health Management, or IVHM. It is an online, in-flight analysis of the launch vehicle's multiple systems' performance. It foresees potential problems with medical diagnostic data. It also determines whether there was a failure. It assists in choosing the best course of action going forward, Including emergency measures like mission abort. By integrating modern monitoring technologies, operators will have a more timely and accurate view of the health of the system, which will enable them to identify sub-system problems and failures more quickly and increase their chances of successfully mitigating and preventing them. [4] For real-time monitoring and maintenance suggestions, IVHM integrates technology such as decision-making modules, diagnostic algorithms, and sensors. IVHM is primarily concerned with identifying anomalies and possible malfunctions in vital systems like navigation and propulsion when it comes to launch vehicles. [3] By gathering data from on-board sensors, processing it with sophisticated algorithms, and allowing early anomaly identification, it promotes proactive maintenance and lowers the likelihood of malfunctions. Limit checking in IVHM is used to detect anomalies, optimize maintenance, monitor performance, and improve safety and dependability. It also serves as an early warning system. Limit checking aids in data analytics, continuous improvement, problem identification, failure prognostics, and system health monitoring. It is important for maintaining safety, improving dependability, facilitating preventive maintenance, cutting expenses, and guaranteeing launch vehicle mission success. Integrated Vehicle Health Management (IVHM) uses technology from several channels, such as sensor data, fleet history, maintenance records, and design documents, to track and evaluate the state of the relevant asset. It aims to determine any problems with the resources and projects and how long it will remain functional. By providing Condition-Based Maintenance (CBM) for launch vehicles, this capability saves money and time [6]. All things considered, limit checking and IVHM are essential to preserving maximum efficiency and security during a launch vehicle's lifetime

2. Experimental Methods or Methodology

The proposed methodology involves establishing threshold values for sensor readings, defining upper and lower limits to monitor acceptable ranges. Leveraging EDA Playground functions, the sensor input is read from randomly generated test bench data. Through mathematical comparisons or conditional statements, the readings are compared against defined thresholds, triggering a high output if anomalies are detected. [8] This output signifies actions such as alert generation, warning indicators, data storage for analysis, or corrective measures. The iterative monitoring process, implemented through a loop structure, ensures continuous real-time or near-real-time anomaly detection in the sensor readings.

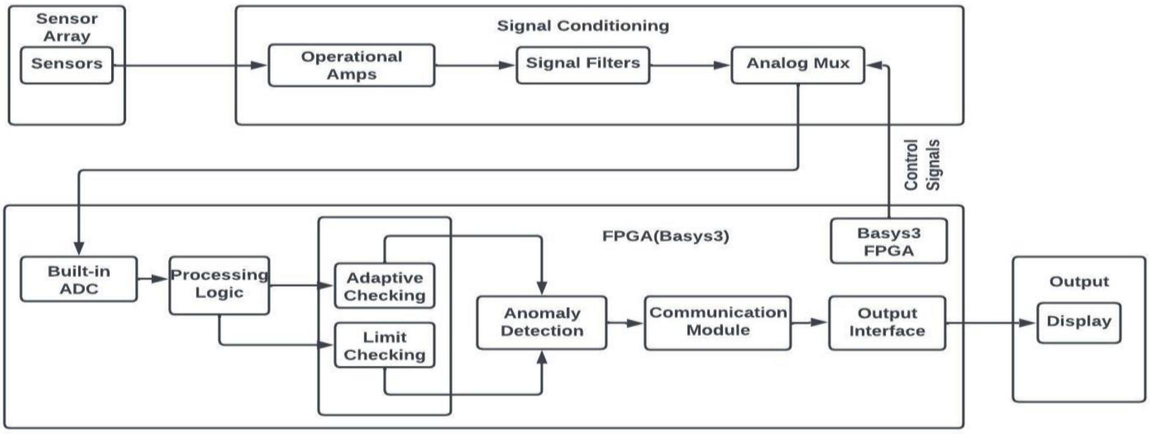

Figure 1 **Internal Block Diagram of IVHM**

Figure 1shows the sensor array comprises 32 sensors measuring parameters such as temperature, pressure, and vibration. These raw analog signals undergo signal conditioning using operational amplifiers and filters to prepare them for further processing. The conditioned analog signals are then converted into digital format using an Analog-to-Digital Converter (ADC) for processing on the Xilinx Artix-7 FPGA (Digilent Basys3). [5] Within the FPGA, algorithms including limit checking and adaptive limit checking are implemented simultaneously on different channels. Anomaly detection algorithms are employed within the FPGA to detect anomalies based on processed data and predefined limits. Pertinent information about anomalies, including the time of occurrence and corresponding channel number, is captured using event logging and report generation logic. An Ethernet and wireless communication module is utilized to transmit anomaly information to external systems. Display interfaces such as LCD or OLED are implemented to present anomaly data in a user-friendly manner. [9]

3. Results and Discussion

3.1 Static Limit Checking

One commonly used technique in Integrated Vehicle Health Management (IVHM) systems is fixed threshold-based limit checking. It makes implementation and result interpretation simpler by comparing measured data using predefined criteria.

These hard limits are established by engineering requirements, past performance, safety guidelines, or professional judgment. The procedure entails comparing sensor data in real-time or on a regular basis to predefined criteria, promptly identifying anomalous events to enable effective vehicle or system health monitoring. [10]

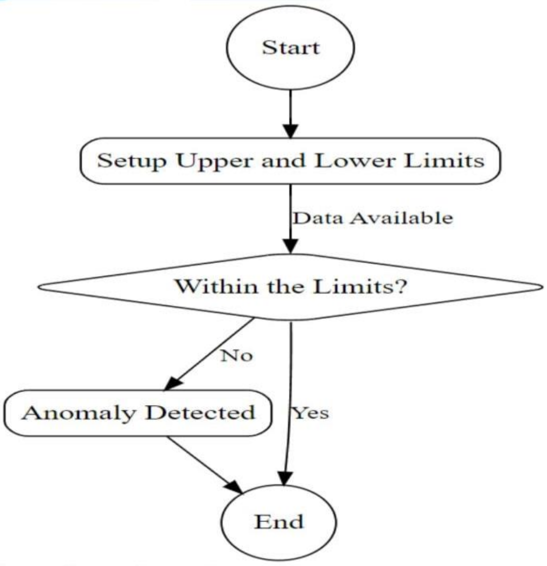

Figure 2 **Flowchart Representing Static Limit Checking**

Figure 2 shows the flowchart of static limit checking. The various steps in static limit checking are;

Define Threshold Values: Establish the precise boundaries or cut-off points. For instance, establish upper and lower bounds for the allowed temperature ranges in order to monitor the temperature.

Read Sensor Input: Utilize the relevant EDA Playground routines or libraries to read the test bench’s randomly generated input.

Compare Readings: Analyse the sensor's readings in relation to the established threshold values. To determine if the readings are above or below the predetermined limitations, use mathematical comparisons or conditional expressions. [11]

Handle Anomalies: A high value is set in the output register in the event that a sensor reading exceeds the predetermined threshold. This will indicate whether to send out an alert, turn on a warning light, save data for later examination, or initiate corrective action. [12]

Iterative Monitoring: Include a loop structure in your code so that it can regularly check the limit and continuously watch the sensor readings. This guarantees anomaly detection in real-time or almost in real-time.

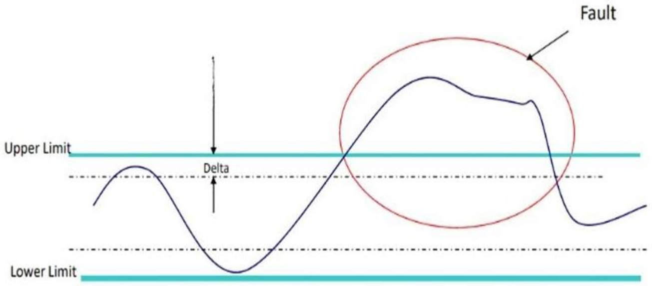

Figure 3 **Illustration of Static Limit Checking**

Figure 3 Shows static limit checking in which the horizontal lines stand for the upper and lower bounds, and a fault is seen when the random signal input crosses or passes over the horizontal line. When something goes beyond such bounds, it's labelled as a fault. [13]

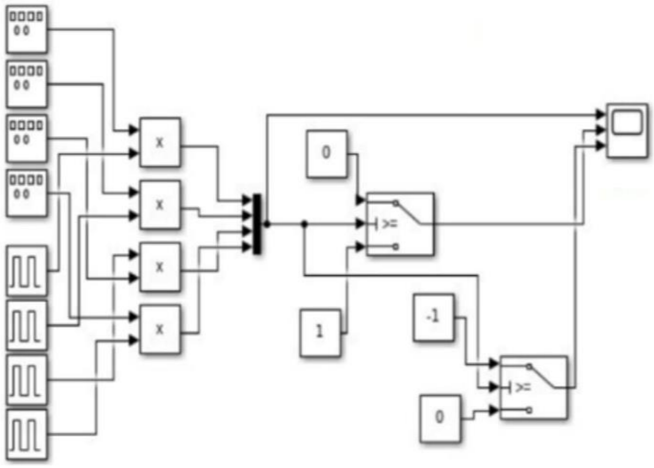

Figure 4 **Static Limit Checking in Mat Lab Simulink**

Figure 4 A pulse signal was used to sample a randomly produced signal. A multiplier was then used to multiply the pulse signal by the sampled signal that was produced. After that, at a given time, specifically 0.1 seconds, the combined signal was directed to a Multiplexer (MUX), so constructing the principal circuit as a type of time division multiplexing. Two threshold restrictions were enforced by a switch that processed the MUX's output further. The output was set to 0 in the event that the signal was greater than 0.5 and to 0 in the event that the signal was less than -0.5. Depending on the polarity of the signal, the output was assigned 1 or -1 for values between -0.5 and 0.5. The final product was produced by using this decision-making procedure. [14]

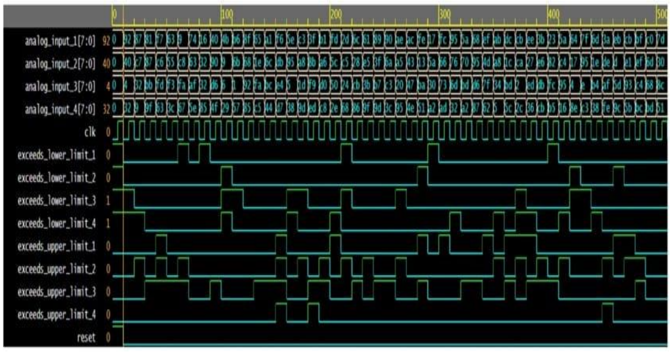

Figure 5 **Output Waveform of Static Limit Checking**

Figure 5 Symbolizes four randomly generated signals produced by the EDA playground simulator. Every one of the four analog signals is examined for irregularities. Error is detected if the signal crosses or falls below the threshold limits.

3.2 3.2 Dynamic Limit Checking

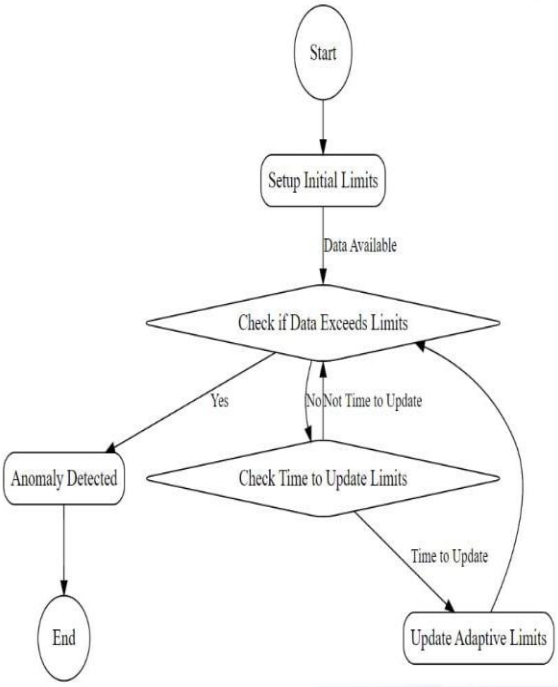

Figure 6 **Flowchart Representing Dynamic Limit Checking**

An enhanced technique for monitoring systems in real-time is dynamic threshold-based limit checking, which continuously modifies thresholds in response to changing operational conditions. Dynamic thresholds, as opposed to set thresholds, improve accuracy and lower false positives and negatives by taking into account variables like system deterioration and environmental changes. Because of its dynamic nature, it improves problem detection and provides more accurate identification, particularly in situations where fixed thresholds could malfunction. Figure 6 shows the flow chart of dynamic limit checking. The following are the main processes in dynamic limit checking; [15]

Dynamic Thresholds: Continuously analyse the incoming data or signals.

Adjust Limits: Dynamically update limit values based on the current characteristics of the data.

Real-Time Checks: Assess incoming values against the adaptive constraints to make precise, context-sensitive decisions.

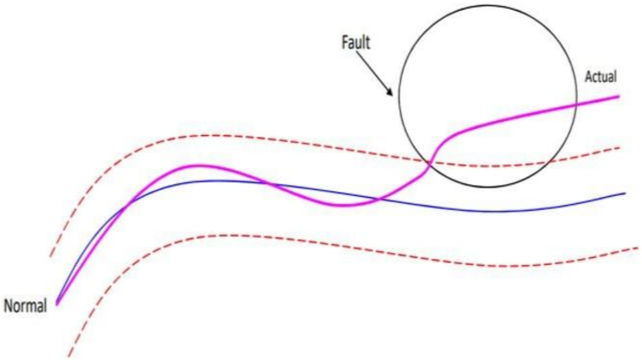

Figure 7 **Illustration of Dynamic Limit Checking**

Figure 7 Demonstrates dynamic limit checking, where the uniform curve in the centre represents the desired signal. Upon scrutinizing the input signal at every instant, the system detects an issue if it deviates much from the desired signal. Dynamic limit checking, with its adaptability and responsiveness, significantly contributes to the reliability and efficiency of IVHM systems by providing a more accurate and context-aware approach to anomaly detection and system monitoring. Four random signals are created by a design code that is implemented in the EDA Playground simulator. An algorithm built into the Verilog code dynamically modifies the upper and lower bound values according to predetermined criteria, allowing for flexibility in reaction to shifting simulation conditions.

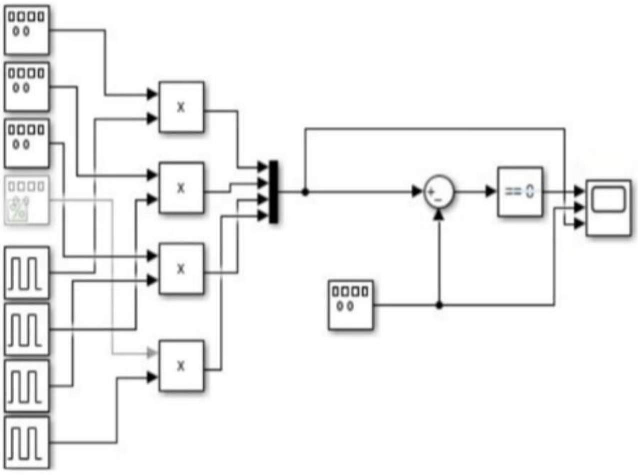

Figure 8 **Dynamic Limit Checking in Mat Lab Simulink**

Figure 8 demonstrates how the multiplexer chooses one signal at a time after multiplying the randomly generated signal by a pulse signal of predetermined durations (0.01s, 0.02s, 0.03s, and 0.04s). The selected signal is then passed into the "Sum" module, which subtracts the desired signal from the random signal sampled. Points in the random signal that line up with the intended signal value in the output produce zero in the sum module. If the Sum module provides zero, the output shows a logic high, telling the user that these random signal points match the intended signal.

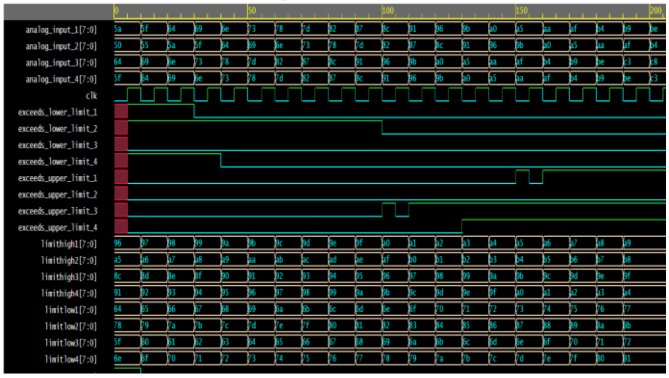

Figure 9 **Output Waveform of Dynamic Limit Checking**

Figure 9 shows four signals that were produced at random in the EDA Playground Simulator; this method is different from setting upper and lower bounds. Rather, the limitations are dynamically adjusted in response to past data, which reflects the typical behaviour profile of the signal. These continuously changing limitations are used in the analog signal comparison process. If the signals diverge from the threshold values, mistakes are detected and are subsequently detected as anomalies.

Conclusion

To sum up, the incorporation of vehicle health management (IVHM) into space shuttles is a significant development that guarantees the security, dependability, and effectiveness of space missions. The EDA Playground simulation demonstrates that the system can detect anomalies based on predefined limits and dynamically changing limits based on time. The MATLAB Simulink model illustrates that the system can be implemented using a MUX and signal-selecting mechanism to allocate time slots for each signal. This IVHM system can be directly implemented on FPGA boards using the HDL Coder in MATLAB Simulink. The later part of the project will focus on the real-time implementation of this system on FPGA. If the vehicles were mostly self-contained and had on-board IVHM capability, these would be a far cheaper operation compared to standard ground-based mission operations. [7]. The mission success rate is improved overall because of the extensive monitoring, diagnostics, and prognostics capabilities provided by IVHM, which greatly aid in the early identification and prevention of possible problems. The ultimate instantiation of IVHM is a vehicle that can adapt its controls to changing health statuses. Normally, this would be applied to unmanned vehicles, but it might also greatly improve the operational efficiency and survivability of manned ones. This will reduce attrition rates, increase safety margins, and enhance mission reliability and effectiveness even while it does not alter the underlying failure rate of vehicle components or systems. [2]. The application in maximizing mission performance, cutting operational costs, and guaranteeing the safety of both crew and spacecraft is becoming more and more important as space exploration progresses.

References

[1]. Jack J. Fox, Brian Jay Glass, “Impact of integrated vehicle health management (IVHM) technologies on ground operations for reusable launch vehicles (RLVs) and spacecraft", IEEE Aerospace Conference Proceedings, Volume: 2, February 2000.)

[2]. Williams Z," Benefits of IVHM", An analytical approach, IEEE Aerospace Conference, Big Sky, Montana, USA,(2006).

[3]. Zuniga F.A., Maclise D.C., Romano D.J.,

Jize N.N., Wysocki P.F. and Lawrence D.P, "Integrated systems health management for exploration systems". 1st Space Exploration Conference, Orlando, Florida, USA, 30 January – 1 February 2005.

[4]. Smith, J., & Askin, R. G, "Concept of Operations for a Multi-Level Integrated Vehicle Health Management System", Proceedings of the Annual Conference of the Prognostics and Health Management Society 2018.

[5]. Reichard K., Crow E. and Bair T, "Integrated management of system health in space applications". Reliability and Maintainability Symposium - RAMS 07, Orlando, Florida, USA, 22-25 January 2007.

[6]. Ezhilarasu, Cordelia Mattuvarkuzhali & Skaf, Zakwan & Jennions, I.K. (2021). "A Generalised Methodology for the Diagnosis of Aircraft Systems". IEEE Access. PP. 1-1. 10.1109/ACCESS.2021.3050877.

[7]. L. Zhang, J. Lin, B. Liu, Z. Zhang, X. Yan and M. Wei, "A Review on Deep Learning Applications in Prognostics and Health Management," in IEEE Access, vol. 7, pp. 162415-162438, 2019, doi: 10.1109/ACCESS.2019.2950985.

[8]. S. Ofsthun, "Integrated vehicle health management for aerospace platforms," in IEEE Instrumentation & Measurement Magazine, vol. 5, no. 3, pp. 21-24, Sept. 2002, doi: 10.1109/MIM.2002.1028368.

[9]. C. M. Ezhilarasu, Z. Skaf, and I. K. Jennions, "The application of reasoning to aerospace Integrated Vehicle Health Management (IVHM): Challenges and opportunities," in Progress in Aerospace Sciences, vol. 105, 2019, pp. 60-73, doi: 10.1016/j.paerosci.2019.01.001.

[10]. K. Jiang, Y. Zhou, Q. Chen and L. Han, "In Processing Fault Detection of Machinery Based on Instantaneous Phase Signal," in IEEE Access, vol. 7, pp. 123535-123543, 2019, doi: 10.1109/ACCESS.2019.2937225.

[11]. Gary W. Hunter, Richard W. Ross, Hampton, David E. Berger, David E. Berger"A Concept of operations for an Integrated Vehicle Health Assurance System". Journal of National Aeronautics and Space Administration Aeronautics and Space Administration, NASA/TM—2013-217825, 2013).

[12]. S. Chang, L. Gao and Y. Wang, "A Review of Integrated Vehicle Health Management and Prognostics and Health Management Standards," 2018 International Conference on Sensing, Diagnostics, Prognostics, and Control (SDPC), Xi'an, China, 2018, pp. 476-481, doi: 10.1109/SDPC.2018.8664882.

[13]. F. Elaldi, "An overview for structural health monitoring of composites in aerospace applications," Proceedings of 2nd International Conference on Recent Advances in Space Technologies, 2005. RAST 2005. Istanbul, Turkey, 2005, pp. 309-314, doi: 10.1109/RAST.2005.1512582.

[14]. Y. Tang, X. Yang and G. Wang, "A Framework for Health State Evaluation of the Complex Mechanical System With its Occurrence Probability of Failure Mode," in IEEE Access, vol. 8, pp. 73570-73587, 2020, doi: 10.1109/ACCESS.2020.2986791.

[15]. Z. Zhou, L. Huang and R. Lin, "Predictive Health Status Assessment of a Launch Vehicle Engine in an Ascending Flight Based on Vibration Signals," in IEEE Transactions on Aerospace and Electronic Systems, vol. 59, no. 6, pp. 7739-7749, Dec. 2023, doi: 10.1109/TAES.2023.3293457.