FMDB ***Transactions on Sustainable Environmental Sciences***

Realtime Air Traffic Monitoring System with Raspberry Pi Based Environmental Monitoring

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Abstract: Air traffic monitoring is an important part of aviation operations and plays a key role in ensuring the safety of aircraft, passengers, and personnel and maintaining efficient use of airspace. The need for increased air traffic and enhanced situational awareness has led to a growing demand for reliable, real-world monitoring solutions. This research introduces a real-time air traffic monitoring system developed with the Raspberry Pi. The system is designed to record, process, and display air traffic data efficiently. Various sensors are used to identify ambient conditions such as temperature, air humidity, air pressure, and even the proximity of aircraft and drones in limited airspace. If the sensor detects abnormal or critical conditions, such as extreme weather changes or unauthorized flight objects, the system immediately activates the alarm mechanism using a buzzer. At the same time, the collected data is transferred to the IoT platform, specifically ThingSpeak, allowing for remote time monitoring. The IoT platform enables certified users, including airport personnel and supervisory staff, to view live data from anywhere and receive immediate notifications about potential fraud and security concerns.

Keywords: Air Traffic; Raspberry Pi; Air Humidity; IoT Platform; Real-Time Air Ride Data; Air Traffic Surveillance; ADS-B Receiver; Visualisation and Analysis; Remote Access; Decision-Making.

Received on: 22/06/2024, **Revised on:** 28/08/2024, **Accepted on:** 11/09/2024, **Published on:** 12/12/2024

Journal Homepage: https://www.fmdbpub.com/user/journals/details/FTSESS

DOI: https://doi.org/10.69888/FTSESS.2024.000354

Cite as: R. Vani, K. Lalitha, S. B. V. J. Sara, V. Brindha, G. Gnanaguru, and D. Lale, "Realtime Air Traffic Monitoring System with Raspberry Pi Based Environmental Monitoring," *FMDB Transactions on Sustainable Environmental Sciences*., vol. 1, no. 4, pp. 211–220, 2024.

1. Introduction

The business Air Traffic Management (ATM) continues to be an important aspect of the aviation industry, focusing on safety, efficiency, and Sustainability. Environmental factors, such as gas emissions, temperature fluctuations, noise pollution, and

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vibration, can have a significant impact on flight operations, aircraft health, and passenger and crew safety. Aircraft tracking using OpenCV effectively utilises the power of this open-source computer vision library to monitor and track aircraft in real-time. By using high-resolution cameras, continuous video streams of air traffic are captured, and OpenCV's robust image processing [1]. But the process is complex. Naturally, increased air traffic must be met with the same level of appropriate air traffic surveillance to maintain safety, while also increasing the efficiency of the used airspace and possibly reducing separation distances to allow more aircraft to be safely routed through the same volume [5]. The remote monitoring using an Unmanned Aerial Vehicle is an alternative. However, it remains in the study stage, and the implementation process has not yet been initiated [6].

Processing tools are employed to analyse these streams [2]. The proposed system will implement real-time flight and environmental monitoring solutions based on the versatile Raspberry PI platform. This integrated approach uses the power of the Internet of Things (IoT) to improve aviation security and situational awareness by continuously monitoring the environment concerning airspace and landing routes [7]; [8]. A variety of sensors are strategically selected and integrated to recognize parameters such as air quality (CO, CO2, methane, ambient temperature, poisoning strength, and ground-level foundations. These factors can indicate potential threats such as gas leaks near the fuel station, exercise glare function, abnormal temperature conditions, excessive running noise, or structural problems with nearby infrastructure [9].

Early detection of such abnormalities plays a crucial role in preventing incidents and enhancing the overall reliability of airport operations. This is the first warning line for nearby soil or monitoring staff. At the same time, data is transferred to cloud-based IoT platforms such as Blynk, Thingspeak, and Firebase. This allows real-time monitoring, historical data protocols, and remote access via smartphones, tablets, or web dashboards. For data transfer to an IoT platform, Wi-Fi connections are utilized via the Raspberry Pi's on-board function or through external modules. The collected data is in a readable format and is periodically pushed into the cloud, along with a timestamp and a sensor ID for simple traceability. Promote proactive maintenance and environmental compliance by providing real warnings and long-term analysis for airport management [3].

For aviation authorities, centralized data views enable informed decisions to address sudden weather changes, environmental hazards, or mechanical irregularities. Researchers and developers in the aerospace field can also benefit from this setup as a testbed for simulation, innovation, and performance analysis. One of the system's great features is its cost-effectiveness [4]. Traditional air traffic monitoring and environmental control systems often feature inexpensive infrastructure, recurring maintenance, and proprietary software. However, the proposed solution was developed using open-source software, inexpensive hardware components, and modular integration technology [5]. This significantly reduces application costs, making it feasible for small regional airports, academic institutions, and government agencies in developing regions [15].

Scalability is another important strength of this system. If airport requirements grow, you can add more sensors or network some Raspberry Pi units to cover a larger area. For example, using units near the runway, control towers near the terminal, or the strength station can provide a comprehensive environmental snapshot throughout the airport [13-15]. Each unit can be configured independently or as part of a distributed sensor network. To further improve functionality, machine learning models can be trained using collected data to identify patterns and predict anomalies. This predictive ability can help identify hazardous conditions, such as mist formation, excessive co-application, and even mechanical wear, via abnormal vibrational patterns [10].

The model can be used in the cloud for powerful processing or directly on the Raspberry Pi, utilizing optical libraries such as TensorFlow Lite. Harmful gases such as CO, CO2, NH3, and benzene. Level. Summer Module: Immediate local warning if an abnormality is recognised. Operating system. Python is the primary programming language used to equip sensors, manage data collection, and provide updates to the IoT platform [13]. The cloud page's dashboard interface enables stakeholders to view real-time diagrams, set threshold notifications, and download data records. Redundant checks and time intervals are embedded in the code to recover from failed transmissions and protocol errors, allowing for later diagnostics. Security is also taken into consideration in the design [14].

Data sent to the cloud is encrypted with standard HTTPS protocols, and access to the dashboard is controlled via login information and role-based permissions [11]. This ensures that sensitive airport data doesn't fall into the wrong hands. By implementing IoT and inexpensive hardware, advanced monitoring capabilities are brought to the fingertips of airport authorities, engineers, and researchers. It bridges the gap between technology and operational safety in a highly dynamic and sensitive area. Whether it's a large international airport or a remote landing rail, the adaptability, affordability, and efficiency of the system are valuable means of pursuing more intelligent and safe airspace management. The main findings indicate that the use of AI in trajectory prediction and air traffic management has significantly improved operational efficiency and safety.

However, the studies also point out limitations related to data variability and challenges in integrating multiple information sources. Air traffic surveillance and environmental surveillance are two important factors in the fields of aviation safety and airport management. Given the increased operating density of aircraft and growing concerns about climatic conditions around airports, a system that can monitor both air traffic and environmental parameters in real time is urgently needed [12]. The progress in embedded systems and the Internet of Things (IoT) has made it possible to implement such systems efficiently and at a low cost.

The Raspberry PI acts as a core processing device and collects data from a variety of sensors, such as temperature, humidity, gas, and motion detectors. These sensors are strategically located to monitor environmental conditions around the airport and to recognise the movement of aircraft or other objects within the airspace. These systems significantly improve the accuracy of aircraft tracking, allowing for the identification of plane location, speed, and transients in near real-time. Despite technical excellence, such systems focus solely on the movement and position of aircraft within a particular airspace. They do not provide insight into limited or dynamic environmental factors that influence or threaten flight operations. At the same time, environmental monitoring is treated as a separate domain. As a rule, it is carried out through fixed, independent weather stations and air quality monitoring units that are installed near the airport or distributed to the city for regional ratings. These systems measure parameters such as temperature, air humidity, air pollutants, noise, and pressure, regardless of real-time air ride data [5].

The power of the aircraft, flight safety, and even the feasibility of starting and landing are closely influenced by the surrounding conditions. An increase in carbon monoxide or methane near the runway can indicate gas leaks. A sudden temperature or pressure shift can affect the aircraft or engine. Additionally, excessive noise and vibration levels can indicate machine errors and structural weaknesses. However, existing surveillance infrastructure rarely correlates such environmental data with aircraft behavior and airport operations in real-time. Air traffic control is equipped to process location data, but often unintentionally, due to the dangers of concurrent environments, unless another team or system uses a different alarm. As a rule, they require large-scale calibration, professional staff, and large-scale maintenance.

This is only suitable for international or highly budget airports. Small regional airports, helipads, remote landing routes, or research stations involved in aviation research often lack access to high-end surveillance facilities. This inequality limits security, situational awareness, and response efficiency in the less developed aviation sector. There are clear technical and financial gaps when it comes to scalable integrated systems that allow us to observe both aircraft movement and surrounding environmental conditions. Many airport authorities, aviation researchers, and educational institutions want to analyze local challenges, such as seasonal smog near hill stations, extreme heat at desert-based airfields, and noise levels near urban zones.

However, the stiffness of traditional systems involves custom sensors, custom alarm thresholds, or integration into academic platforms. This limits the system's adaptability and reduces the benefits of special environments or experimental research. For example, aircraft data deviating from the expected descent pattern could be more insightful if it correlates with severe neutralization or high ambient temperature detected on the runway. Similarly, consistent spikes in vibrations and noise during landing can help you determine the need to start or improve aircraft expectations. Without such correlation, authorities will not only be forced to introduce delays but also increase the risk of surveillance and rely on incompatible data flows, manual interpretations, and reactive decisions.

Environmental data from traditional weather stations is often updated every few minutes, with some systems updating every hour or less. In critical aviation environments, this delay can be hazardous, especially in situations involving chemical leaks, fire hazards, or sudden temperature fluctuations. Thus, systems capable of providing real-time environments and reports offer the possibility of a more dynamic and nuanced approach to airspace management. For example, suppose an aircraft consistently reports engine loads during landing at a particular airfield. In that case, this anomaly remains unnoticed unless it is paired with actual data, unusually high levels of air pollution, or excessive soil vibrations in the area. Integrating these data records not only helps you understand causality but also improves the functionality of predictive analytics.

Maintenance plans, emergency protocols, and operational plans can be adapted to data-controlled knowledge rather than assumptions or isolated observations. The situation is further limited in academic and experimental aviation studies. Universities, technical institutions, and independent laboratories that require flexible and customizable platforms for data collection and analysis, by examining the development of air traffic behaviour and aviation innovations. Not only are existing commercial systems affordable, but they also close gaps that limit the scope of the experiment.

Therefore, there is a need for open and inexpensive solutions that bridge the gap between air traffic surveillance and environmental sensing. These systems can be adjusted to record a variety of ambient parameters. This allows the sensor to be connected to flight data either directly from the ADS-B receiver or by operating the existing infrastructure. Collected data can be uploaded in real-time to a cloud platform for visualization, analysis, and remote access. These platforms support module expansion, allowing users to add or remove sensors as needed and adapt the software's behaviour for research, monitoring, or educational purposes. This allows for a transition from reactive management to proactive decision-making.

1.2. Problem Statement

In modern aviation, ensuring the safety and efficiency of air traffic operations is a top priority. As the volume of air traffic continues to increase globally, especially around urban airports and military zones, the challenges associated with monitoring and managing airspace have become more complex. Traditional air traffic control systems rely heavily on radar, satellite tracking, and expensive infrastructure that may not be accessible to smaller airports, remote airfields, or research institutions. These conventional systems are often limited in their ability to provide real-time, localised environmental data, an aspect that is equally critical for safe takeoff, landing, and overall flight operations.

Environmental monitoring around airports plays a vital role in assessing weather conditions, detecting pollutants, and maintaining operational safety. Sudden changes in temperature, humidity, air pressure, or the presence of hazardous gases can affect aircraft performance and pose serious risks to flight safety. However, most airports lack integrated systems that combine both air traffic monitoring and environmental surveillance compactly and cost-effectively. The lack of real-time alert mechanisms further delays response times to emergencies or unexpected changes in the airspace environment.

There is a pressing need for a scalable, real-time system that can efficiently monitor both air traffic and environmental conditions. This system must be low-cost, easy to deploy, and capable of transmitting real-time data to remote users. The goal is to maintain constant situational awareness and provide timely alerts for anomalies, such as the detection of unknown objects, weather disturbances, or abnormal gas levels. This project addresses the problem by developing a real-time monitoring system using the Raspberry Pi. The system collects data from multiple sensors and transmits it to an IoT platform, where users can view live readings and receive alerts. By combining air traffic tracking and environmental monitoring in a single system, the solution supports enhanced safety, decision-making, and compliance with aviation regulations. It bridges the gap between technology accessibility and practical implementation for small- to medium-scale airspace management environments.

2. Methodology

The proposed system aims to ensure aviation safety by monitoring real-time environmental factors that may impact air traffic, as illustrated in Figure 1. Various environmental sensors are integrated into the Raspberry Pi to measure parameters such as gas concentration, temperature, sound level, and vibration. These measurements can help detect anomalies that threaten the aircraft during takeoff, landing, or in general airspace navigation. After recognising an abnormal measurement, the system triggers a buzzer and transfers the data to the IoT platform for remote analysis and alerting. Each sensor continuously monitors its parameters. For example, alleyways check for the presence of dangerous gases in the area, while temperature sensors monitor fluctuations in air temperature. Sound sensors detect high noise levels and can indicate abnormal events, while accelerometers measure patterns of vibration or abnormal movement in monitored airspace. Data from the sensor caused the summer near personnel to be in an abnormal condition when the Raspberry Pi triggered a predefined threshold. At the same time, data is transferred to the IoT platform in real time using network connections.

The platform enables users, including airport authorities and researchers, to view live environmental data from afar, either via the web or a mobile interface. The combination of real-time alerts and remote monitoring enables faster responses, improved situational awareness, and precautions against surrounding risks near air traffic routes. The system begins by initializing the Raspberry Pi and configuring all connected sensors, including alleyways, temperature sensors, sound sensors, and accelerometers. These sensors collect actual data on environmental parameters such as dangerous gas concentrations, temperature fluctuations, ambient noise, and abnormal vibrations. The Raspberry Pi periodically collects measurements from each sensor and compares them with predefined threshold values to identify anomalies that may indicate potential hazards in the airspace. Suppose the sensor value exceeds a threshold, such as high gas levels or excessive vibration. In that case, the system immediately causes a buzzer to sound, alerting nearby staff and preparing the sensor data for transmission.

IoT platforms like Blynk and ThingSpeak offer live dashboards that enable users to monitor sensor values in real-time and receive instant alerts via mobile notifications or email. Additionally, the IoT platform can record this data and analyse it further, allowing authorities and researchers to visualise trends and make data-driven decisions. The system also features fault tolerance, ensuring that one or more sensors continue to function correctly even if they operate incorrectly. Additionally, the modular design of the system supports scalability, combining real-time data recording, automated notifications, IoT-based remote monitoring, and historical data analysis to enable the addition of more sensors or expansions to various applications, including runway monitoring and drone recognition. It not only reduces reliance on costly infrastructure-based systems but also improves situational awareness of aviation stakeholders through remote platforms. Ensures better security for aviation companies by providing critical environmental information essential for aircraft performance and risk detection.

The Raspberry Pi acts as a central processing unit for the entire monitoring system, managing data collection, processing, and communication between the sensors and the IoT platform. It is a compact, inexpensive, energy-efficient microcomputer that can run a fully Linux-based operating system, making it ideal for embedded systems and real-time monitoring projects. This setup utilizes several sensors, including gas, temperature, acoustics, and acceleration modules, via GPIO to interface with the interface (all-purpose/output). Reads sensor data periodically and processes it using Python scripts to determine whether the value has exceeded the critical threshold. Once anomalies are identified, the Raspberry Pi will quickly activate Summer for local warnings, loading data into the IoT platform simultaneously with integrated Wi-Fi functions. This way, users can remotely monitor environmental conditions in real time. Its versatility, ability to support a variety of sensor modules, and compatibility with cloud platforms make the Raspberry Pi a powerful and scalable solution for air traffic systems. Areas near airports and runways are often prone to gas leaks due to their proximity to fuel emissions and industrial activities.

The alley is confident that the airspace does not have hazardous gases that could affect both the health of ground staff and the safety of aircraft operations. Continuously monitors air quality and immediately recognises abnormalities in the gas mirror. When the concentration of harmful gas exceeds the preset limit, the system triggers warnings from the buzzer and transfers data to the IoT platform for remote monitoring and evaluation. Alleyways not only ensure immediate detection of dangerous gases but also serve as a long-term data protocol for air quality trend analysis at airports. Temperature sensors play a crucial role in measuring atmospheric temperature in real-time. Very high or low temperatures can also affect fuel combustion or cause structural problems. By integrating temperature sensors such as the DHT11 and DHT22, the system can monitor temperature fluctuations and provide timely updates. This is useful for aviation authorities in extreme weather conditions. Sensor data is sent to an IoT platform where users can view measurements and identify important changes that may affect flight operations.

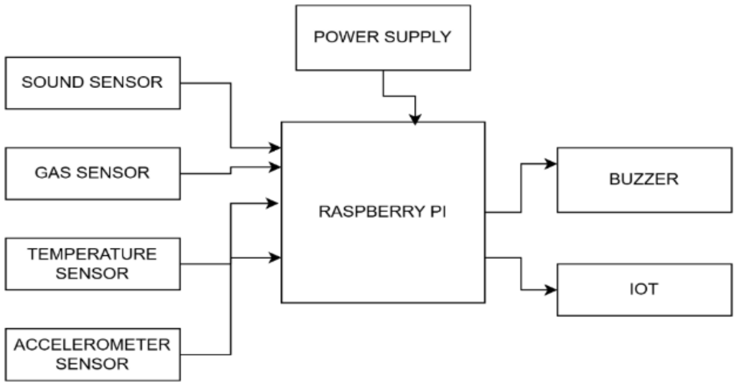

Figure 1: Block diagram of air traffic monitoring

A comprehensive performance evaluation was conducted on three core features of the system—Real-Time Tracking, Environmental Data Integration, and Interface Usability—to assess technical efficiency and user perception following recent updates. Each feature was analyzed using key performance indicators (KPIs), including accuracy, response time, error rate, and user satisfaction scores. The analysis reveals a nuanced picture of system performance, highlighting areas of strength as well as those that require further refinement. Real-Time Tracking displayed strong metrics across the board. With an accuracy of 85%, the system effectively tracked real-time data inputs with minimal discrepancies. A response time of 120 milliseconds places it within an acceptable range for most dynamic applications, ensuring users experience near-instantaneous feedback.

The error rate of 5% is modest, indicating occasional lapses in tracking precision, but it does not significantly undermine user confidence. This is reflected in a user satisfaction score of 3.8, suggesting general approval with some room for optimisation, likely related to its response time and occasional inaccuracies. Environmental Data Integration emerged as the strongest performer in this evaluation. It achieved an impressive accuracy of 92%, the highest among the three features, pointing to a robust system for aggregating and interpreting environmental metrics. The response time was the fastest at just 95 milliseconds, supporting seamless data rendering for users. Additionally, it recorded the lowest error rate at 3%, which likely contributes to its leading user satisfaction score of 4.2. These metrics underscore the reliability and effectiveness of this feature, making it a standout element of the system.

Interface Usability, while improved, still lags in some performance aspects. It has the lowest accuracy at 78%, which may reflect inconsistent interface behaviours or functionality gaps that affect the user experience. Its response time of 150 milliseconds is also the slowest, suggesting delays in user interactions that could lead to frustration, particularly in real-time usage scenarios. With an error rate of 8%, the interface presents the most significant opportunity for improvement. Despite these issues, the user satisfaction score of 3.5 suggests that the changes have had a positive impact, although not enough to resolve existing usability concerns fully. Overall, the performance analysis paints a picture of a system that is advancing steadily, with significant improvements already implemented, especially in data integration and tracking. The primary bottleneck remains the user interface, which, despite notable progress, continues to pose challenges to users in terms of speed and reliability. This would ensure not only a smoother technical experience but also an increase in overall user satisfaction, as shown in Table 1.

Table 1: Performance metrics table

Feature	Accuracy (%)	Response Time (ms)	Error Rate (%)	User Satisfaction Score
Real-Time Tracking	85	120	5	3.8
Environmental Data Integration	92	95	3	4.2
Interface Usability	78	150	8	3.5

This table summarises the core performance metrics for each major feature of the system. Environmental Data Integration leads in accuracy, response time, and error reduction, making it the highest-rated in user satisfaction. Real-time tracking performs well, although with slightly lower precision and a slower response. Interface Usability trails in all technical metrics, which aligns with its lower satisfaction score. These results emphasize the need to prioritize further interface improvements to enhance the overall system experience. The data also suggests a strong correlation between technical performance and user satisfaction, particularly in error reduction and speed.

3. Results and Discussion

One of the primary challenges is integrating diverse sensors. Monitoring environmental parameters, such as temperature, gas levels, noise, and vibration, requires different sensors, each with its specific communication protocols (I2C, SPI, analog, digital). Managing these inputs through the Raspberry Pi's limited GPIO pins and ensuring synchronised data collection without conflict is a complex task. Another significant challenge is ensuring the real-time acquisition and transmission of data. The system is expected to collect, process, and transmit environmental and air traffic data continuously. Any delay in sensing or data transfer may lead to inaccurate or outdated information.

Hence, an efficient multithreading or parallel processing approach is required to maintain performance and responsiveness. Connectivity and IoT integration are also crucial challenges. The system depends on reliable internet connectivity to upload data to an IoT platform for remote monitoring. In areas with poor network coverage, data synchronisation issues and real-time access problems may arise. Solutions such as data buffering or offline data logging should be considered. Power management is a practical concern, especially if the system is to be deployed in remote or outdoor areas. The Raspberry Pi and connected sensors must be powered efficiently. Incorporating battery backups or solar-powered units may be necessary for uninterrupted operation. The data transmitted to the user end is shown in Figure 2. The real-time data recorded from various sensors is transmitted and conveyed to the user's panel for making necessary adjustments.

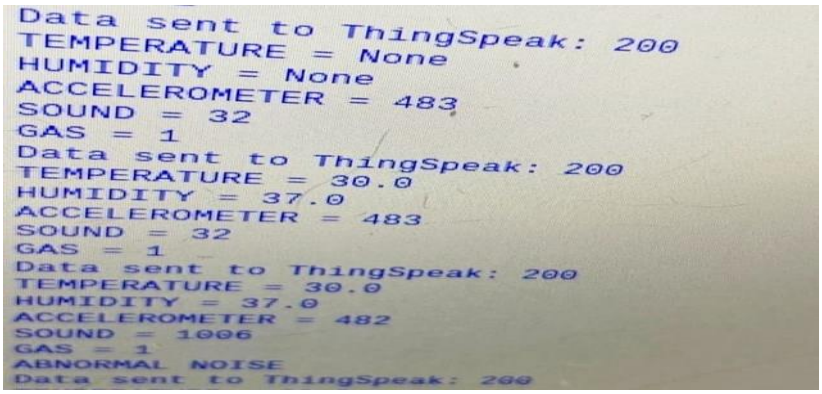

Figure 2: Information transmitted to the user's desk from the IOT platform

The temperature sensor plays a crucial role in measuring atmospheric temperature in real-time. Temperature changes can have a direct impact on aircraft performance, flight stability, and engine efficiency. Very high or low temperatures may also affect fuel combustion or cause structural issues. By integrating a temperature sensor, such as the DHT11, the system can monitor temperature fluctuations and provide timely updates. This helps aviation authorities take precautionary steps during extreme weather conditions. The sensor data is sent to the IoT platform, where users can view live temperature readings and identify any critical changes that could impact flight operations.

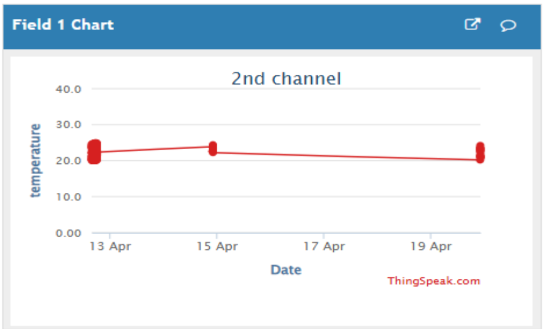

Figure 3: Temperature recorded using Thingspeak

The temperature readings over time are depicted in Figure 3. The results show that the sensors provided timely and accurate readings, and the Raspberry Pi successfully processed this data, taking the appropriate actions, such as activating the buzzer or transmitting data to the IoT platform. This confirms that the system can effectively detect potentially dangerous environmental conditions in real-time, an essential capability for improving aviation safety near airports or airstrips.

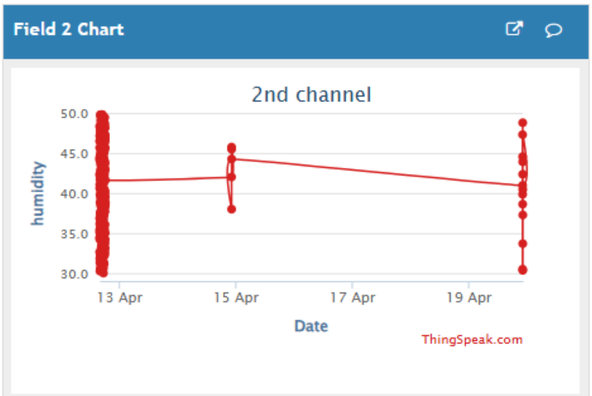

Figure 4: Humidity recorded using Thingspeak

The humidity value is illustrated in Figure 4 over time. The IoT integration also supports alert notifications via mobile apps, emails, or text messages, enhancing accessibility and enabling swift action. Minimising response times appears to be especially impactful, as even small delays affect the perceived efficiency of the system. Consistency across all features will be essential for scaling the system to broader usage without compromising the user experience. Continuous qualitative analysis helps refine the system over time, ensuring that it meets safety, efficiency, and environmental goals.

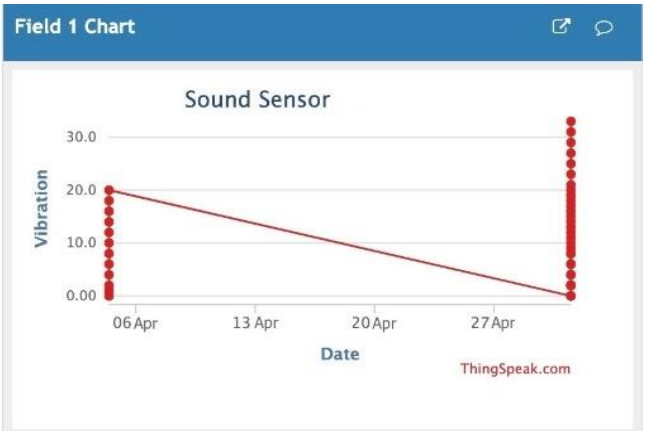

Figure 5: Sound sensor graph using Thingspeak

The sound sensor output is explored in Figure 5, and detects noise levels in the environment. High sound levels or sudden acoustic disturbances can indicate issues such as engine failure, nearby drone activity, or mechanical malfunctions. By analysing the intensity and pattern of noise, the system can identify unexpected or abnormal conditions in the airspace. Sound pollution around airports is also a concern, and this sensor helps maintain sound level records for regulatory compliance.

The moment the noise exceeds the permissible range, the buzzer is activated to alert on-ground personnel. At the same time, the data is uploaded to the IoT platform for further review and logging. The sound sensor also helps in identifying noise pollution levels near airports, which is critical for maintaining compliance with noise regulation standards.

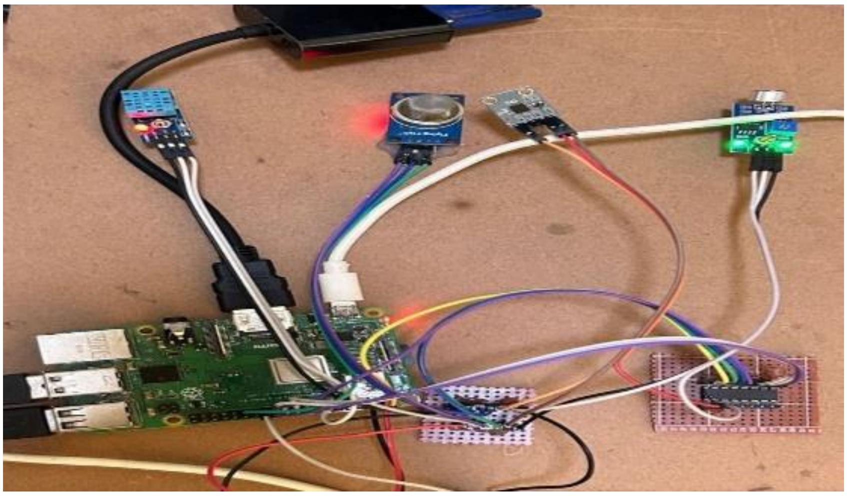

Figure 6: Hardware section of air traffic monitoring

The hardware section is described in Figure 6. If any sensor detects abnormal or critical conditions, such as extreme weather changes or unauthorized flying objects, the system immediately activates an alert mechanism using a buzzer. Simultaneously, the collected data is transmitted to an IoT platform, enabling remote real-time monitoring.

4. Future Enhancements

With the future in mind, the future of systems combining real tracking, environmental data integration, and improved user interfaces will not only revolutionise a wide range of industries. Additionally, one of the most promising implementations lies in the further development of autonomous airline systems, including drones and uncrewed aerial vehicles (UAVs), which heavily rely on integrated data to navigate complex airspaces autonomously. These systems make decisions in real-time using ambient inputs, such as wind patterns, pneumatic pressure, and dynamic weather forecasts. Meanwhile, technology tracking ensures safe coordination with human-crewed aerial vehicles and other drones.

At the same time, predictive analytics, which operates through AI and machine learning, is centrally important for future applications. These algorithms process historical and live environment data, as well as location data, to predict flight delays, recognize early signs of system errors, and recommend alternative routes or schedules with minimal human intervention. In space management, there is another important development that takes into account similar systems that track satellites and space carriers in Earth's orbit, predict potential collisions with solar radiation, magnetic fields, and atmospheric resistance, and optimise satellite paths. Additionally, Smart Urban Mobility Systems integrates these technologies not only to manage aircraft but also to utilize environmental data to set temperature-sensitive operations or monitor pollution in real-time.

The adaptive user interface, controlled by user behavior and preferences, is implemented on the surface to improve accessibility for a variety of operators in high-voltage environments, such as emergency responses and military operations. These interfaces are developed based on real-time conditions, as they emphasize important data while highlighting key information, and thus reduce cognitive load.

Finally, sustainability monitoring is deeply embedded in these systems, providing real-time insights into emissions, fuel efficiency, and environmental impacts, which help businesses meet further regulatory standards and environmental goals. As these technologies converge, they promise a highly intelligent, context-related system in the future. This not only improves operational efficiency and security, but it also dynamically adapts to changing requirements.

5. Conclusion

The actual tracking of the system's performance, integration of environmental data, and evaluation of the interface's ease of use provide an overall understanding of both user satisfaction and technical performance. While it is clear from a sample of 300 user responses and power metrics on accuracy, response times, and error rates that the system has made meaningful advances, the area of further improvement remains evident. Real-time tracking, which originally had moderate user permissions, increased from 3.2 to 3.8. This improvement addresses performance enhancements, including lower error rates and shorter response times. This function operates with 85% accuracy and a 120 ms metric response time, contributing to reliability by providing real-time data with minimal latency.

Despite the benefits, occasional mistakes and minor delays still indicate the need for fine-tuning options, especially in applications that require extremely high accuracy or speed. With accuracy levels of 92%, a minimum error rate of 3%, and a quick response time of 95ms, this function is an exemplary optimal technical function. User satisfaction reflects this excellence, increasing from 3.6 to 4.2. The data shows that, perhaps, optimised data fusion methods and improved display options enable users to find value in presenting environmental data in a way that the system can process and present effectively. Ultimately, the development of the system has been a clear success in many ways. Data demonstrate important advances in user and technical service satisfaction, particularly due to real-time pursuits and the deletion of environmental data. Nevertheless, the trip to a fully optimised system continues. Interfaces, as the main user interaction point, must be prioritized in future development cycles.

Acknowledgement: We are grateful to the faculty members for their guidance and encouragement throughout the study. Their contributions were instrumental in the successful completion of this work.

Data Availability Statement: All relevant data used in this study are available from the corresponding author upon reasonable request.

Funding Statement: The authors did not receive any financial support or funding for the conduct of this research.

Conflicts of Interest Statement: The authors declare that they have no conflicts of interest and that all sources have been properly acknowledged.

Ethics and Consent Statement: This research was conducted in accordance with ethical standards, and informed consent was obtained from all participants, with full confidentiality maintained.

References

1. X. Olive, L. Basora, J. Sun, E. Spinielli, M. Li, and C. Verdonk Gallego, “Reviews and responses for training a machine learning model to detect holding patterns in aircraft trajectories,” Journal of Open Aviation Science, Press.
2. M. Manideep, M. S. Naik, M. Bhanu, and P. Sunil, “Enhancing air traffic surveillance: Aircraft tracking via computer vision,” J. Emerg. Trends Novel Res., vol. 2, no. 12, pp. a272–a277, 2024.
3. D. V. Aditya, S. S. Aswin, S. Vanithadhaneesh, and M. B. S. Kumar, “A review on air traffic flow management optimization: trends, challenges, and future directions,” Discover Sustainability, vol. 5, no. 1, pp. 1–20, 2024.
4. J. Budroweit, F. Eichstaedt, and T. Delovski, “Aircraft surveillance from space: The future of air traffic control?: Space-based ADS-B, status, challenges and opportunities,” IEEE Microwave Magazine, vol. 25, no. 12, pp. 68-76, 2024.
5. Y. Chen, Y. Zhao, and Y. Wu, “Recent progress in air traffic flow management: A review,” J. Air Transp. Manage., vol. 116, no. 4, p. 103573, 2024.
6. E. V. Butilă and R. G. Boboc, “Urban traffic monitoring and analysis using unmanned aerial vehicles (UAVs): A systematic literature review,” Remote Sens., vol. 14, no. 3, p. 620, 2022.
7. D. N. Paithankar, A. R. Pabale, R. V. Kolhe, P. William, and P. M. Yawalkar, “Framework for implementing air quality monitoring system using LPWA-based IoT technique,” Measur. Sens., vol. 26, no. 4, pp. 1-6, 2023.
8. K. B. Shaban, A. Kadri, and E. Rezk, “Urban air pollution monitoring system with forecasting models,” IEEE Sens. J., vol. 16, no. 8, pp. 2598–2606, 2016.
9. L. Lalitha, R. Ramya, and S. Shunmugathammal, “AI-based safety helmet for mining workers using IoT technology and ARM cortex-M,” IEEE Sens. J., vol. 23, no. 18, pp. 21355–21362, 2023.
10. K. Lalitha, “IoT enabled pipeline leakage detection and real time alert system in oil and gas industry,” Int. J. Recent Technol. Eng., vol. 8, no. 6, pp. 2582–2586, 2020.

11. S. Manasa, R. Shobana, R. Srinath, V. A. Anand, K. Lalitha, and S. Maheswaran, “Smart protective vest for sanitary workers using internet of things,” in 2023 14th International Conference on Computing Communication and Networking Technologies (ICCCNT), IIT - Delhi, Delhi, India, 2023.
12. M. Lalitha, N. Meacher, and R. Nair, “Raspberry PI based cyber-defensive industrial control system with redundancy and intrusion detection,” Int. J. Pure Appl. Math., vol. 118, no. 18, pp. 4273–4278, 2018.
13. Environmental Protection Agency (EPA), “Review of the secondary national ambient air quality standards for oxides of nitrogen, oxides of sulfur, and particulate matter,” Federal Register, vol. 89, no. 248, pp. 105692–105788, 2024.
14. American Lung Association, “State of the Air 2020,” Policy Commons, Apr. 21, 2020. [Online]. Available: https://policycommons.net/artifacts/3675761/sota-2020/4481559/. [Accessed: Aug. 19, 2023].
15. C. A. Okigbo, A. Seeam, S. P. Guness, X. Bellekens, G. Bekaroo, and V. Ramsurrun, Eds., “Low cost air quality monitoring: comparing the energy consumption of an Arduino against a Raspberry Pi based system,” in Proc. 3rd Int. Conf. Smart and Sustainable Technologies (SpliTech), Split, Croatia, 2020.