International Journal of Innovative Research in Engineering
Volume 7, Issue 3 (May - June 2026), PP: 261-266.
https://www.doi.org/10.59256/ijire.20260703026
www.theijire.com
ISSN No: 2582-8746

Advance Safety Solutions for Boeing Aircraft's Using Artificial Intelligence and WSN

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How to cite this paper:
Chaithra S[1], Dheekshith N S[2], Jayashree B J[3], Divyashree R[4], Prabhavathi K[5], "Advance Safety Solutions for Boeing Aircraft's Using Artificial Intelligence and WSN", IJIRE-V7I3-261-266.

Abstract: *In current times, aircraft safety and reliability are important attributes aviation since minor flaws in the performance of any system can result in serious problems. The proposed system involves fault detection and preventive maintenance of the aircraft using IoT Machine Learning techniques. With this regard, temperature sensors, pH sensors, MQ sensors, and ADXL sensor play roles in the monitoring of temperature, contamination of fuel, leakage of gases, and vibration of an aircraft, respectively. Furthermore, sensors are linked with the ESP32 microcontroller to preprocess data. In the addition, data are transmitted to the cloudbased platform for analysis. Fault detection and classification are performed using Machine Learning through the application of random forest classifier method. This method achieved the accuracy classification of 93.8%. Firstly, the proposed framework ensures greater safety of flights through early fault detection, eliminates any unpredicted downtimes, and streamlines the process of maintenance. Furthermore, this framework is scalable and can be applied other use cases in the aviation industry. Through the application of this study in developing an intelligent predictive maintenance system, there has been a significant contribution to the advancement of predictive maintenance.*

Key Words: *Aircraft Fault Detection, Predictive Maintenance, Internet of Things (IoT), Machine Learning, Random Forest, ESP32 Microcontroller, Sensor Fusion, Edge Computing, Cloud Analytics, Condition Monitoring.*

I.INTRODUCTION

Engineering systems of planes belong to one of the most complicated and important branches because of the extreme harsh conditions of their work. Today, the planes should demonstrate stable work, high effectiveness very wide ranges of temperature, pressure, and vibration, as well as the maximal safety for the passengers. Any deviations from the norm of the temperature, vibrations, or contamination of the system offuelling might cause the malfunctioning of engines, which should be avoided. The traditional approach to the issue was connected with the regular checkups the malfunctions carried out by the specialists through different kinds of examinations. This way could be effective in some degree; however, the process had its reactive nature because it became obvious that there were faults after they have caused problems. Thus, such actions implied additional time repairs and increased risks for the passengers' safety. Besides, diagnostic procedures took more time and money than the current requirements in aviation require. As far as the discussion regarding the technological advancements in IoT solutions, embedded systems, and machine learning is concerned, it can be noted that the shift from the reactive to proactive and predictive approaches occurs due to the potential of gathering information about the condition the aircraft using IoT sensors installed in different parts of the aircraft. Also, due to machine learning used in processing massive datasets, predicting certainbehavioural patterns of the aircraft systems and the occurrence of their failures becomes possible. Given the above, the present paper intends to inform the reader about an intelligent system that is intended of monitoring aircraft defects, based on the usage of IoT sensors combined with machine learning, enabling analysing and predicting aircraft system defects. Speaking of how the objective will be achieved, it is important to note that the proposed system is going to employ temperature sensors for overheating detection, pH sensors for contaminant detection, MQ gas sensor for leakage detection, and ADXL accelerometers for vibration-based detection of mechanical failures.

Fuelling might cause the malfunctioning of engines, which should be avoided. The traditional approach to the issue was connected with the regular checkups the malfunctions carried out by the specialists through different kinds of examinations. This way could be effective in some degree; however, the process had its reactive nature because it became obvious that there were faults after they have caused problems. Thus, such actions implied additional time repairs and increased risks for the passengers' safety. Besides, diagnostic procedures took more time and money than the current requirements in aviation require. As far as the discussion regarding the technological advancements in IoT solutions, embedded systems, and machine learning is concerned, it can be noted that the shift from the reactive to proactive and predictive approaches occurs due to the potential of gathering information about the condition the aircraft using IoT sensors installed in different parts of the aircraft. Also, due to machine learning used in processing massive datasets, predicting certain behavioural patterns of the aircraft systems and the occurrence of their failures becomes possible. Given the above, the present paper intends to inform the reader about an intelligent system that is intended of monitoring aircraft defects, based on the usage of IoT sensors combined with machine learning, enabling analysing and predicting aircraft system defects. Speaking of how the objective will be achieved, it is important to note that the proposed system is going to employ temperature sensors for overheating detection, pH sensors for contaminant detection, MQ gas sensor for leakage detection, and ADXL accelerometers for vibration-based detection of mechanical failures.

II.PROBLEM STATEMENT

The maintenance procedure is primary characterized by a reactive mode. The maintenance is done following the scheduled time for inspections, and the diagnostic procedure is done manually. Therefore, it means that the current condition of the aircraft is determined depending on the predetermined time schedule, ignoring the real state of the different aircraft part. There exist some hazards when the above methodology is used, such as breakdowns in the various aircraft components and unexpected stops, resulting in more expenses. Besides, times accidents take place. On the other hand, the manual inspection of the aircraft presents problem since it calls for substantial human efforts. Although modern technology has greatly enhanced the collection data from different aircraft components, it seems that the process of data handling is not adequate. Therefore, there is necessity for developing such a system, which would not only be smart but capable of monitoring continuously the vital parameters of the aircraft and evaluating them immediate. The basic purpose of the proposed system will be mainly dependent on the use of IoT-based sensors and machine learning algorithms, which would be responsible for the detection and prediction of potential faults the aircraft. Further, another issue concerning the non-permanent monitoring process might be associated with revealing an ongoing degradation of the aircraft's parts. In fact, variations in temperature, vibrations, andgas concentrations occurring before failure develop gradually, hence without monitoring system these factors remain unnoticed until a malfunction occur. What is more, it should be noted that currently is no use of all the received information through applying a special intelligent system analysing data provided by sensors. Although sensors are included into some subsystems, it cannot be stated for sure whether all data gathered by these sensors are analysed using some advanced algorithm able to discover failures. Moreover, it should be stressed that due to recent technological advancements aircraft have become more complex. Hence, the number of electronic devices installed on board increased, making a considerable number of generated data appear. As a consequence, monitoring these data manually turns out to be problematic. In order to overcome these challenges, it will be necessary to establish an information system using sensor data, as well as analysis of the acquired information by intelligent means. Using such a system would allow collecting analysing data and gaining additional information regarding the current state of the aircraft. It was expected that this system would be capable of detecting some patterns and making forecasts of failure probability.

III.LITERATURE SURVEY

Several developments have been made in areas of AI, IoT, and data analytics that have led to transforming aircraft maintenance practices from conventional methods to proactive and intelligent ones. Several approaches regarding fault detection, data fusion, and intelligent maintenance in aircraft have been proposed in several papers. Kabashkin et al. [1] have proposed a new approach of intelligent maintenance using a combination of hybrid AI models. The models developed relied on the use of ATSaaS (Aviation Technical Support as a Service). The intelligent approach used here is characterized by customized algorithm designs that are very efficient for the fault detection process. However, the work conducted these authors is characterized more by managementlevel optimization. Real-time sensors can play a key role in onboard fault detection systems, but they are not considered in the approach. In an interesting paper presented by Uzun et al. [2], they discuss the use of image data from borescope inspection in detecting faults using deep learning algorithms. Such algorithms have proven to be very efficient in terms of detecting small cracks and structural flaws airplanes. Despite the efficiency of the model, there is a failure to incorporate other data types like real-time sensor data. Another study published by Chen et al. [3] proposed a new technology called multi-rate sensor fusion method with a corresponding multi-task learning neural network algorithm to diagnose faults. This method is flexible in dealing with streams from different sources having different sampling rates, hence enhancing the fault diagnostic capabilities the designed system. Its feasibility, however, has been shown through simulated experiments rather than practical aircraft sensor data. Fan et al. [4] developed an intelligent machine learning approach to determine the maintenance requirements of an aircraft by employing condition-based maintenance through a combination of multiple types data, which include sensor data, logs, and flight data. Their approach outperformed any other prediction model built using a single type of data source; nevertheless, their model is only based on synthetic data without considering time restrictions. Plastropoulos et al. [5] conducted extensive research in the area of defect detection and severity assessment using machine learning techniques, which employed visual data extracted from the image of the defect obtained during the inspection phase. They were successful in promising results; nevertheless, owing to their dependence on visual information, their algorithms are limited to detecting visible defects. Specifically, Lee et al. [7] applied DRL algorithms to optimize predictive maintenance planning that maximizes the fleet's availability rate while reducing unexpected malfunctions. Despite the positive outcome of the study achieve through the simulation process, it relied purely on theoretical scenarios without real-time sensor anomaly detection. Further, Upadhyay et al. [8] created a model of defect detection in aircraft engines using deep learning methods and applying image processing techniques, such as U-Net and YOLO neural networks. It noteworthy that the effectiveness of the system can be guaranteed by implementing specific preprocessing steps. However, similarly to other computer vision models, this model ignores real-time sensor anomaly detection. Finally, Bisanti et al. [9] analysed digital twin technologies and provided suggestions on the possible application's digital twins within aircraft maintenance. Despite providing valuable information on future studies, no practical approach towards implementation was suggested in the study. In contrast, Patel et al. [10] examined different models of classification based on machine learning methods, such as Random Forest, Decision Trees, and SVMs. Consequently, it is important to highlight that the integration of models increases the accuracy prediction significantly. Notwithstanding the positive findings, the authors failed to incorporate real-time data into the analysis. The novelty of the paper [11], written by Sharma et al., is related to the literature review on various methods of Artificial Intelligence used for the detection of faults within aircrafts. In its turn, Kar et al. [12] studied the application of IoT technology for maintenance prediction of the systems of aircrafts. adequate architecture that includes sensors, communication module, and cloud analytics has been determined by the authors. As we can see from the review of the paper, machine learning has not been mentioned there. Taking into consideration all the above information, it should benoted that currently existing literature deals with either fault detection based on analysis images or with simulation and IoT architecture used for the purpose of maintenance prediction. The number of papers combining these three aspects is rather insignificant. That is why it seems appropriate to unite them in a single paper.

IV.METHODOLOGY

The strategy of this particular study includes the construction of a live aircraft monitoring and fault detection framework that uses IoT sensors and machine learning techniques. In terms of the method applied this research project, it involves data acquisition, data preprocessing, transmission, data analysis, and alarms in a systematic fashion.

A. Data Acquisition

Data acquisition is the first step in which data are obtained from sensors mounted on different parts of the aircraft. These include temperature sensors, pH sensors, gas sensors, and accelerometer sensors that measure aircraft's temperature level, fluid condition, gas levels, and vibration frequency. To improve data accuracy, the readings from the sensors undergo signal conditioning where the signal is filtered and amplified. Once the signal is conditioned, it sent to the computer for processing.

B. Data Pre-processing.

Pre-processing of data follow after their acquisition from the sensors. Data preprocessing mainly entails data noise reduction, smoothing, and normalization of data for improved consistency. Additionally, feature extraction occurs during this phase where the significant features are extracted and recognized based on trends such as temperature, vibration, and deviation.

C. Edge-Level Processing

Edge-level processing involves the use of ESP32 microcontroller to undertake local processing. Local processing is mainly concerned with filtering the data collected by the various sensors. This helps in identifying important data while minimizing the amount of data that needs to be uploaded into the cloud. Data buffering is also considered in cases where there is a communication problem between the two processes.

D. Data Transmission

The process of data transition is carried out after the preprocessing process. The data that has been pre-processed is then transmitted to the cloud using the Internet. This is facilitated by the use of Wi-Fi protocol for communication and HTTP or MQTT protocols for data transmission.

E. Data Analysis Using Machine Learning Mode

Data analysis refers to the process of using machine learning models to analyse gathered data from the systems. The developed machine learning model makes use of the existing data, which includes the characteristics of both normal and abnormal systems. Using the continuous analysis of the data, it is possible to predict faults.

V.SYSTEM ARCHITECTURE

The architecture of the proposed system is developed in terms of hierarchy and consists of multiple layers which would ensure constant monitoring efficient processing information as well as detecting and addressing any possible issues arising with aircraft systems.

A. Sensor Layer

The sensor layer is aimed at collecting data associated with environment and mechanical factors regarding those aircraft subsystems which should be continuously monitor. For this purpose, special sensors capable of monitoring various fault indicators are used:

Temperature sensors for monitoring temperature anomalies in engines and other aircraft equipment pH sensor for monitoring properties of fluids and the contamination of aircraft fuel or hydraulic equipmentEach sensor generates either analog or digital signals depending on their type. Such signals have to be filtered and amplified using special modules and stabilizers.

B. Edge Processing Layer

For the edge processing layer, ESP32 is employed. In essence, this is a controller that handles data collected from sensors and processes it for further transmission. Its primary functions include:

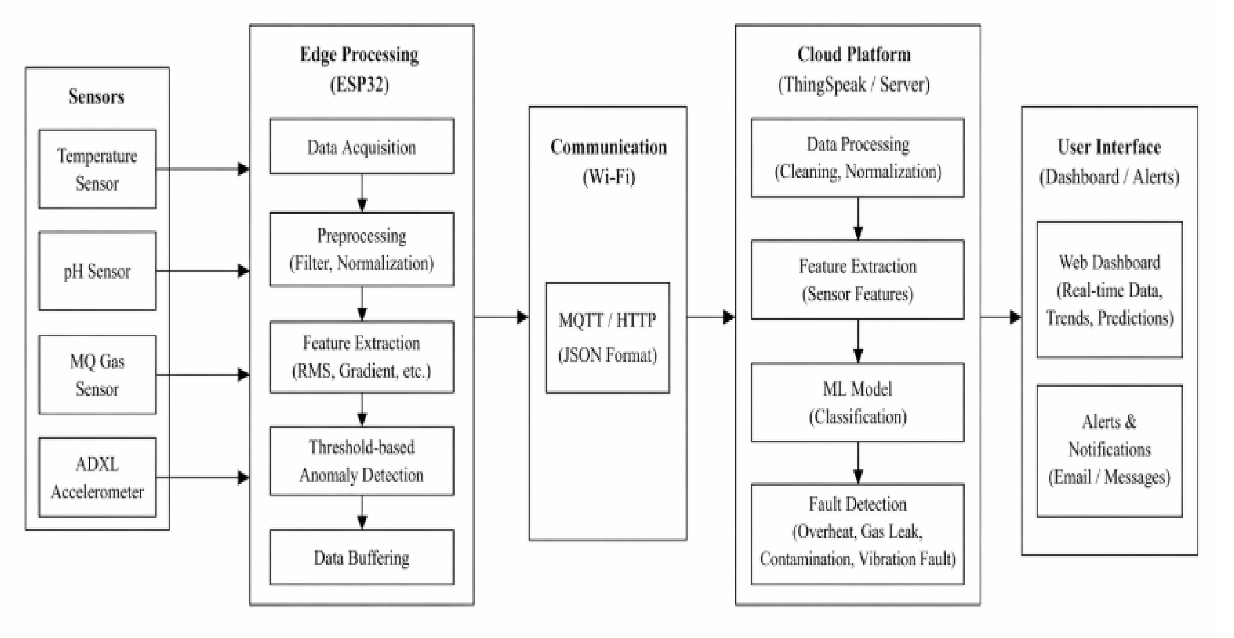

Fig. 1. System Architecture

VI.RESULTS AND DISCUSSION

To examine the efficiency of the proposed defect detection mechanism for aircraft, several test cases were conducted both in hardware as well software simulations. Test cases included varying the input values such as the quantity of gas and pH value with the help of sensors and data collection through the hardware platform. System shown in Fig. 2 reflects the possibility of designing an affordable platform for monitoring multiple parameters.

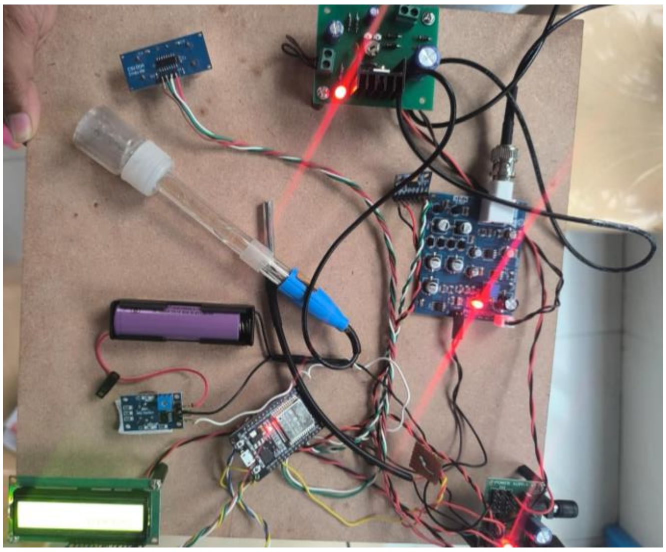

Fig 2. Hardware

The software component of the system is an application that allows for working with the system, entering parameters, and getting results. The use of the application interface allows us to get access to the system and to analyse the received data on the basis of information about readings of the sensors. It implies that the application will provide the opportunity to enter gas and pH values, which will help to find out the level of the fuel contamination by using the machine learning algorithm.

Figure 3 represents the interface of the application that was developed with the purpose of ensuring the ease of its work. In this regard, the proposed solution does not require special skills all processes will be performed through the clear interface with the necessary fields.

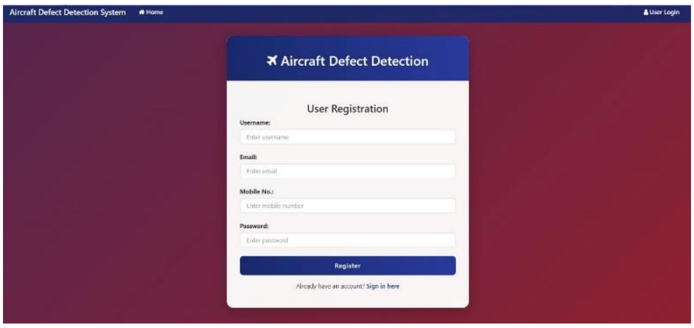

Fig. 3 Login and registration UI interface

In turn, Figure 4 provides an interface for entering the needed parameters, namely gas and pH values, to predict the fuel contamination level.

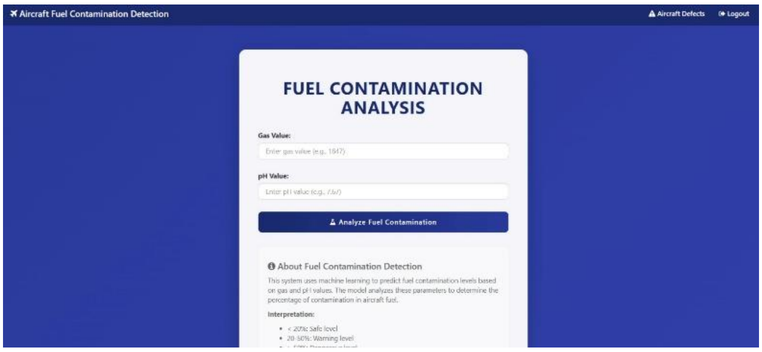

Fig 4. Parameter entry interface

The outputs generated by the system are shown in Figure 5, which shows the output regarding contamination analysis in percentage format. As per the analysis done by the system, an output value of 29.10% has been observed, which lies in the moderate contamination range.

The proposed model constantly analyses the inputs provided and provides the output on the screen of interface instantly. The process involved the application of machine learning techniques, thus making it easier to detect complex patterns in the inputs. Consequently, the model is able to analyse all the variables involved to improve fault detection.

The efficiency of the proposed model can be described as extremely high; it not only detects faults but also classifies them accurately. As per the findings obtained, the average accuracy rate of the model lies between 93.8%.

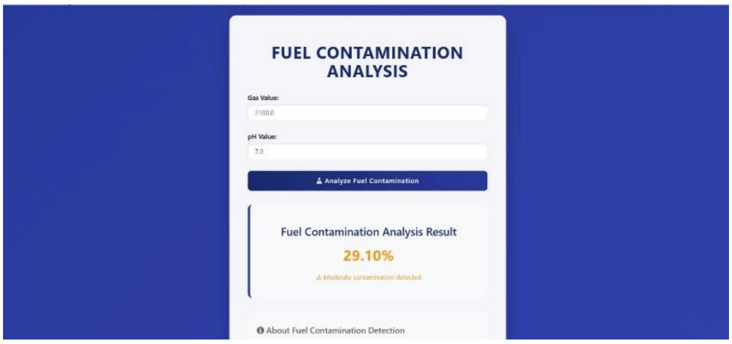

Fig 5. Result

VIII.CONCLUSION

In order to emphasize the fact that the suggested solution may become an efficient fault detector for the aviation system, it is necessary to pay attention to several factors. Firstly, one may claim that the usage of IoT sensors together with machine learning algorithms appeared to be very efficient for detecting the faults. This mean that the mentioned solution may become quite useful while monitoring the temperature level, gas concentration, vibration level, and other parameters related to the characteristics of liquids.

When it comes to the results gained while carrying out tests of this solution, it becomes clear that it works well while collecting and analysing the data and detecting faults. More specifically, the faults were detected with the help of the machine learning algorithm suggested in course of research. One should also mention the high accuracy level, which was determined to be 93.8%. Using a web-based platform also increased the efficiency of solution.

In addition to that, greatly decreases human inspection and supports preventive maintenance. This system ensures the detection of any fault or defect in time and, thus, allows us to guarantee the safe operation of the system. Besides, being relatively inexpensive and highly efficient, it could be used not only in the aviation industry but also in other industries as well as it is necessary to monitor some particular processes.

As for further development of the topic, one might consider improving the described approach through the use of better approaches to deep learning and different kinds of sensors to detect more complicated faults. Moreover, one could conduct tests the system in real aviation practice.

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