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Monitoring and Safety of Aircraft using Wireless Technology

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Abstract

Traditional aircraft sensor networks, burdened by wire complexity and high-power demands, struggle with scalability and real-time data acquisition. This paper proposes Bluetooth Low Energy advertising as a transformative solution, leveraging its lightweight, energy-efficient, and secure nature within tree network architecture. Sensors broadcast data packets picked up by strategically placed gateways, enabling efficient data dissemination through multi-hop relaying. The approach boasts scalability due to minimal hardware and power requirements, leading to extended sensor battery life and reduced aircraft power consumption. Secure data transmission is ensured through encryption and redundancy. Real-time data analysis opens doors for applications like predictive maintenance, optimized flight paths, and enhanced passenger comfort. Challenges remain in standardization and potential interference, but BLE advertising presents a promising avenue for revolutionizing aircraft data communication, paving the way for a future of safer, more efficient, and intelligent flight operations.

Keywords*:* Aircraft, sensor, networks, bluetooth, predictive, maintenance, communication, avionics.

INTRODUCTION

An aircraft's monitoring system typically consists of two parts: non-safety critical systems (like the structural and engine health monitoring system, cabin environmental control system, and in-flight entertainment system) and safety-critical systems (like the engine control system and flight control system) [1]. The existing aviation monitoring system has historically been configured with a significant number of real-time sensors based on cable connections. 40,000 sensor connectors and 98,000 wires, for instance, are spread across more than 300 kilometres in the A380 aircraft [1]. The aviation monitoring system's wired system has the following issues:

- To avoid electromagnetic interference that could hinder airline customization during the manufacturing process, the power routing and the electrical signal routing should be physically isolated.
- Harsh environmental conditions and accessible sensor placements restrict the use of wire harness.
- Installing longer lines in huge structures requires a lot of labour and time.
- Wiring deterioration may result in incomplete or aborted flight missions, or possibly extremely catastrophic failures. A US Navy report states that roughly 78 aircraft are used for flight missions [1–6].

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The aviation sector has consistently been at the forefront of technical advancement, working to improve the dependability, efficiency, and safety of air travel [5]. Aircraft monitoring systems have been essential to guarantee the security of both passengers and crew in the pursuit of these advancements [2]. These systems have historically relied on wired connections, but in recent years, wireless technology has become more prevalent in the business. The swift rise of wireless communication and sensor technologies, which have the potential to change aircraft maintenance and monitoring completely, is driving this change.

This paper explores the design and development of wireless technology-based airplane monitoring systems. There is a growing need for cutting-edge monitoring solutions that can provide real-time data acquisition, predictive maintenance, and enhanced communication between ground control and airborne systems as aircraft have become more complex, with more electronic components and sensors than ever before [4].

Wireless technology has emerged as a possible alternative to address these difficulties due to its potential for more flexibility, less weight, and ease of installation [8]. This paper will examine the state of aircraft monitoring systems today and emphasize how important they are to the effectiveness and safety of aviation. Next, we will explore the realm of wireless technology, looking at its many uses in aviation and the possible advantages it presents, such as lower maintenance costs, more effective operations, and increased safety precautions. We will also go over the difficulties and restrictions involved in integrating wireless technology into aircraft monitoring systems, including topics like spectrum allotment, cybersecurity, and dependability issues [9]. This research study intends to provide insights into the ongoing evolution of wirelessly powered aircraft monitoring systems through a thorough review of current advances and case studies. Aviation stakeholders can ultimately contribute to safer and more efficient air travel for passengers worldwide by making informed judgments about the adoption and deployment of these systems by knowing their potential and limitation [6].

This research paper also delves into a cutting-edge solution that combines modern technology and aeronautical safety needs. This system is designed to offer real-time monitoring and visibility of maintenance personnel while they perform their tasks on or around aircraft. By utilizing Bluetooth technology, we aim to address a long-standing issue in the industry [10]. The system will efficiently track and locate maintenance personnel in the vast, complex environment of an aircraft maintenance facility [7].

The objective of this research is to explore the feasibility, design, and potential advantages of implementing a Bluetooth based safety system tailored to the unique requirements of aircraft maintenance. This system will empower maintenance crews to advertise their precise location to designated personnel, supervisors, and even the aircraft itself, hence improving the communication, accountability, and, most importantly, safety [8].

In this introduction, we provide a glimpse of the critical importance of safety in aircraft maintenance, introduce the innovative Bluetooth based system and set the stage for the subsequent sections of the research paper. By addressing this pivotal aspect of aircraft maintenance, we take a significant step towards enhancing the security and efficiency of maintenance operations in the aviation industry. Thereby contributing to the overarching goal of ensuring safe and reliable air travel [9].

WHAT IS WIRELESS SENSOR NETWORK

A Wireless Sensor Network (WSN) typically comprises nodes that collaboratively sense and control the environment around them [7]. These nodes communicate wirelessly, forming a network. The standard WSN architecture includes three main components: sensor nodes, gateways, and observers (users). Sensor nodes and gateways constitute the sensor field, while gateways and observers connect via specialized networks or, more commonly, the internet [10].

Conceptually, a WSN operates based on a straightforward equation: Sensing + CPU + Radio = Lots of Potential. The sensing unit monitors environmental conditions such as humidity, pressure, and vibration. After collecting data through monitoring and sensing, necessary computations occur in the CPU [8]. Finally, the computed environmental data are transmitted via radio units across wireless communication channels among the nodes, ultimately reaching the gateway [11–13].

BLUETOOTH LOW ENERGY

While Classic Bluetooth reigns supreme for audio and data transfer, another whisperer emerged - Bluetooth Low Energy (BLE). Think of it as the minimalist of the bunch, designed for low-power applications where battery life is king. Think fitness trackers, smartwatches, and beacons whispering location updates. BLE operates in the same 2.4 GHz band but uses different radio modulation and coding, sipping from the power cup instead of guzzling [2]. This frugal approach grants BLE several advantages:

Extended Battery Life

BLE devices can run for months, even years, on a single charge, perfect for wearables and sensors that keep their ears to the ground.

Simplified Data Transfer

BLE focuses on small, quick data bursts, perfect for sensor readings and device control.

Enhanced Security

BLE's low power translates to lower vulnerability to hacking, making it a trusted partner for sensitive applications. But just like its Classic counterpart, BLE has its own modes for different modes:

Advertising Mode

It is the beacon in the darkness, broadcasting its presence to any BLE device within range. Imagine a sensor whispering its temperature reading for any passing smartwatch to hear.

Scanning Mode

It is the curious listener, actively searching for devices broadcasting in advertising mode. Think of your smartwatch hunting for nearby sensors or fitness trackers.

Directed Advertising and Directed Scanning

When whispers become targeted conversations. These modes allow devices to directly address specific others, streamlining communication and reducing energy waste.

Connection Mode

In this mode two devices establish a direct connection for data exchange. This is what happens when your smartwatch pairs with your headphones, whispering secrets only they can hear.

WORKING

Sensor Node Transmitter

The sensor node transmitter block diagram is shown in Figure 1. The sensor node transmitter is a crucial part of wireless sensor networks. It consists of several essential components that work together to monitor and collect data from the environment. Sensor is heart of sensor node which collects the status of different aircraft parameters and converts it to electric signals. In our prototype we have 4 different sensor nodes which collects following information’s:

1. Temperature inside the aircraft
2. Humidity inside the aircraft
3. Fuel temperature
4. Fuel level
5. Any worker is working on maintenance area

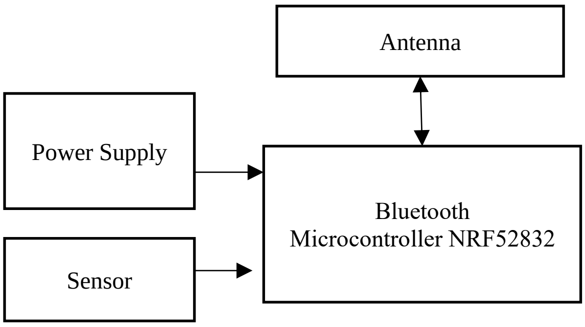

Figure 1. Sensor node transmitter.

NRF52832 is Bluetooth supported microcontroller which handles data processing and computation. It receives readings from the sensors and performs necessary calculations. The power supply section provides power to both microcontroller & sensor. It receives readings from the sensors and performs necessary calculations. The reading taken from sensor is processed by microcontroller. It compares the newly processed reading with the previously recorded reading. If the readings match, no action is taken. If the current reading is different, the data is added to a Bluetooth advertisement packet. This is how sensor node periodically reads the data from sensors and broadcast the reading over the air using Bluetooth technology. For a visual representation, refer to Figure 2, which illustrates the process of collecting sensor data and transmitting it via Bluetooth advertisement.

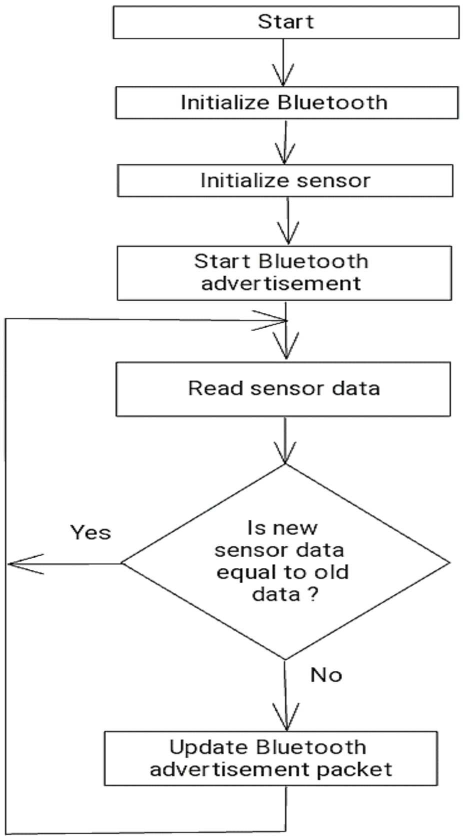

Figure 2. Process of collecting sensor data and transmitting it via Bluetooth advertisement.

Central Receiver

Figure 3 depicts the central receiver diagram. In this setup, the central Bluetooth receiver microcontroller assumes the role of a scanner. It scans the advertisement packets transmitted by Bluetooth devices in the vicinity and extracts sensor data from these packets. This wireless communication allows the central receiver to collect data from various sensor nodes. The power supply section ensures that the Bluetooth microcontroller receives adequate power and also controls the buzzer. Once the central microcontroller receives data from a sensor node, it forwards this information to a computer. The computer then represents the data graphically on the screen. An interesting feature is the alert mechanism: if any of the received sensor node data parameters exceed the predefined threshold limit, an alert sound is triggered using the buzzer. Figure 4 illustrates the process of gathering sensor data from known sensor nodes and displaying it on a graphical user interface (GUI) dashboard.

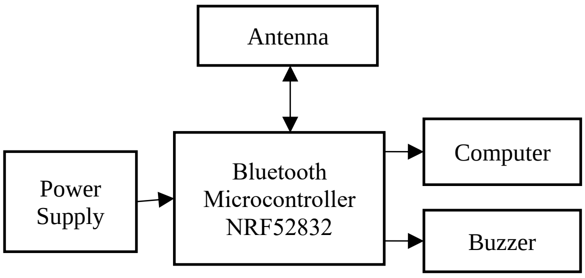

Figure 3. Central receiver.

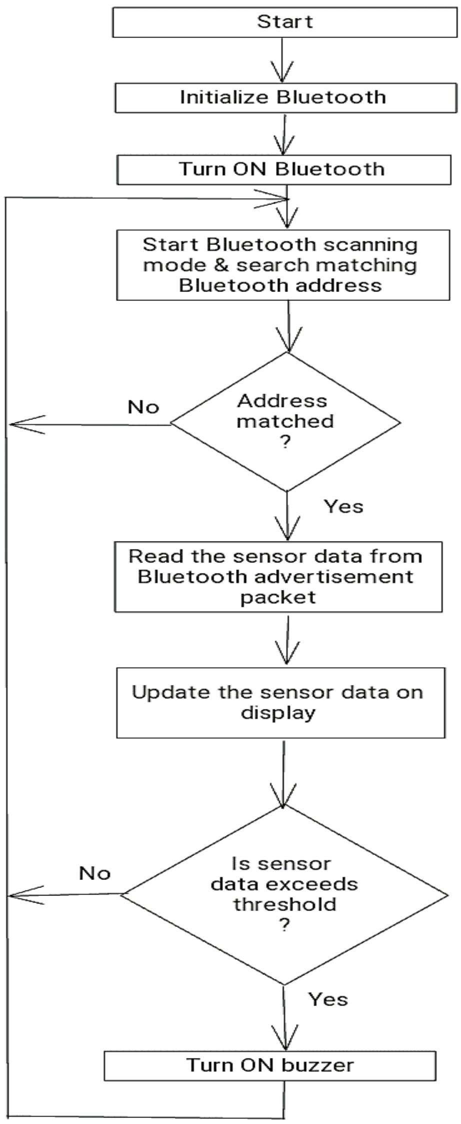

Figure 4. Process of gathering sensor data from known sensor nodes and displaying it on a graphical user interface (GUI) dashboard.

Our system includes a software feature that allows the crew to log detected faults into a database using a graphical user interface (GUI), as depicted in Figure 5. The maintenance personnel can access the fault list and take necessary actions to resolve issues. Once a problem is resolved, they update the status in the list to indicate completion of the maintenance task. Additionally, we have a sensor node known as a 'person beacon,' which is essentially an ID card worn by maintenance engineers. When a maintenance engineer is working in a critical zone, the main dashboard GUI displays a warning. This precaution ensures that no one starts any aircraft machinery during maintenance, thereby helping to prevent accidents.

RESULTS

The most interesting results in this our project correspond to the performance of Bluetooth data transmission. These project model gives satisfactory. Additionally, by assembling the entire prototype using our boards, we successfully validated the operating hardware. Figure 5 displays a screenshot of the GUI developed for graphical data representation, where all the data read from the sensor node is presented.

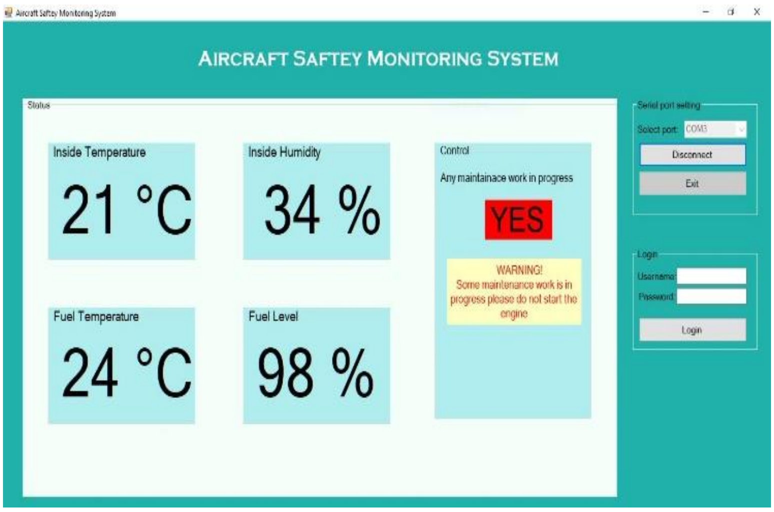

Figure 5. A screenshot of the graphical user interface showcases the data representation, including all the information retrieved from the sensor node.

In our research, we conducted experiments involving different input sensor parameters to simulate the internal conditions of an aircraft. These parameters included the internal temperature, humidity, fuel level, and fuel temperature. Our study utilized both sensor nodes and market-calibrated instruments to measure these parameters. Remarkably, the readings obtained from the sensor nodes closely matched the market calibrated instruments readings, demonstrating an impressive system accuracy of 95%. This alignment between simulated and actual data is crucial for ensuring the reliability and safety of aviation systems. Reading taken from sensor compared with reading taken from market calibrated measurement instruments is shown in table 1. Crew add detected fault details is shown in Figure 6 and the maintenance engineer resolves the raised issue & updates the issue status as completed is shown in Figure 7.

Table 1. Reading taken from sensor compared with reading taken from market calibrated measurement instruments.

S.N.	Sensor node	Sensor	Parameter	Actual reading (Taken form Calibrated instrument)	Readings from sensor nodes
1	Sensor node 1	DHT22	Inside temperature	23°C	21°C
		DHT22	Inside humidity	32%	34%
2	Sensor node 3	DS18B20	Fuel temperature	24°C	24°C
3	Sensor node 4	Fuel level sensor	Fuel level	100%	98%

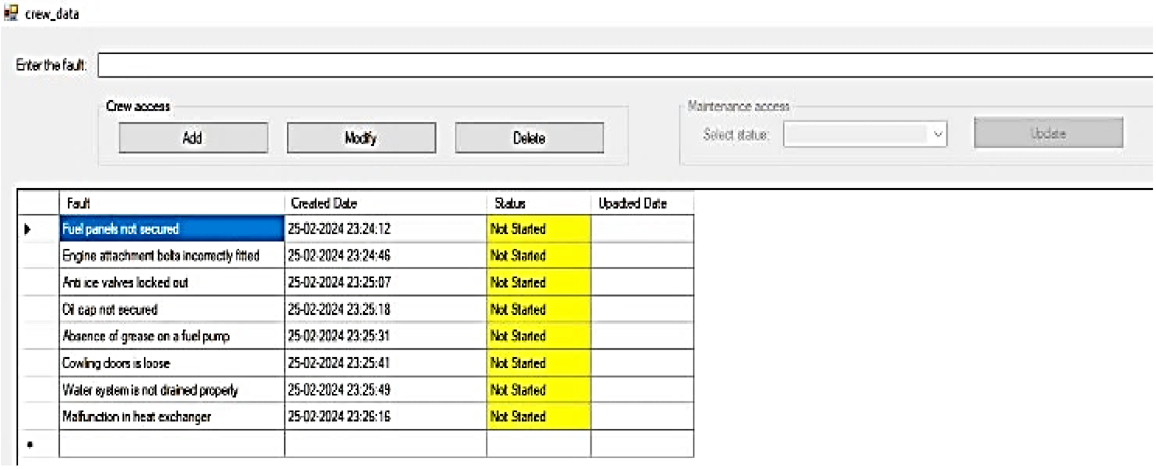

Figure 6. Crew add detected fault details.

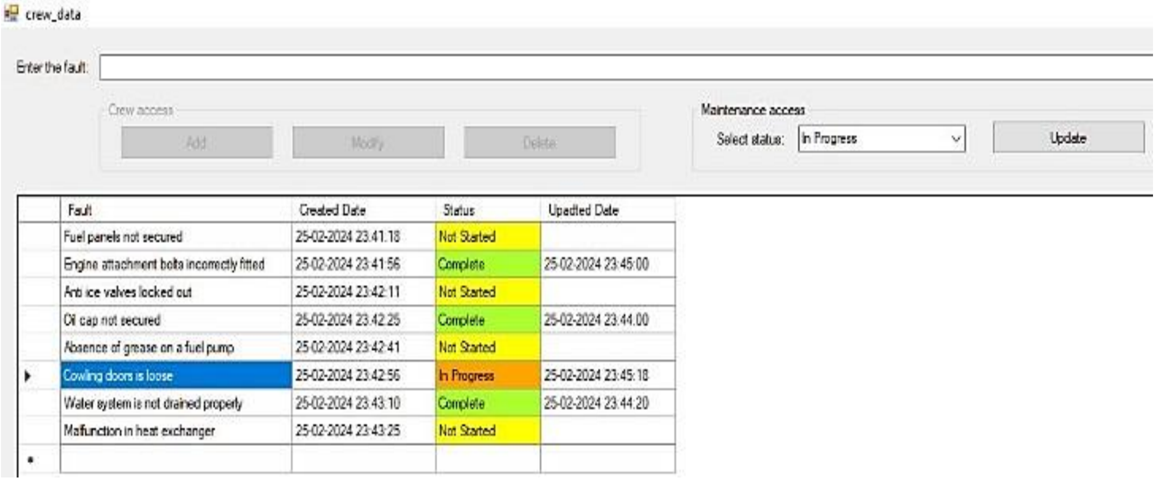

Figure 7. The maintenance engineer resolves the raised issue & updates the issue status as completed.

CONCLUSION

This research paper presents a wireless monitoring system designed for aircraft. It effectively showcases the wireless communication protocol's functionality, verifies the correct operation of buses (UART, SPI, and I2C), confirms sensor reliability, and validates the assembled prototype. Overall, the system concept, software, and debugging have been successfully implemented.

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