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INTEGRATION OF AIR-QUALITY MONITORING SYSTEM INTO IOT

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Throughout its existence, humanity has constantly interacted with nature: both living and non-living. Before the first industrial revolution, the impact of human activity was apparently mostly not harmful. However, the invention of the steam engine and the subsequent development of heavy industry worldwide have led to a rapid increase in the concentration of toxic substances in the air, soil, and water. Nevertheless, with further technological advancement, researchers are intensifying their efforts to mitigate environmental contamination. For instance, statistics on emissions and pollutant concentrations were gathered from the major industrial hub of Ukraine - Kryvyi Rih [1]. These figures indicate that over the past decade, from 2009 to 2020, levels of various harmful emissions declined at different rates. Despite this, the situation with emission concentrations has remained unchanged and, in some instances, even deteriorated. Moreover, following the start of the full-scale invasion of Ukraine, the risk has escalated significantly, as attacks by missiles and strike drones could trigger a technogenic disaster at any moment. Thus, for the prevention of such events, continuous monitoring of toxic concentrations is required in the atmosphere, soil, and water.

To address this challenge, the optimal solution is the use of Unmanned Aerial Vehicles (UAV) equipped with the necessary sensor suite. The prototype of such a UAV-based air emission monitoring system (Fig. 1) consists of various gas analyzers, an ionizing radiation measurement module that measures both beta and gamma specters, a dust intensity sensor, as well as a module for pressure, temperature, and humidity. Additionally, auxiliary storage and Real-Time Clock (RTC) modules were installed. These components are used to log the acquired data in a .csv file onto a microSD card with timestamps. Information on temperature, pressure, and humidity can be used to facilitate comparison of results with state regulatory standards [2].

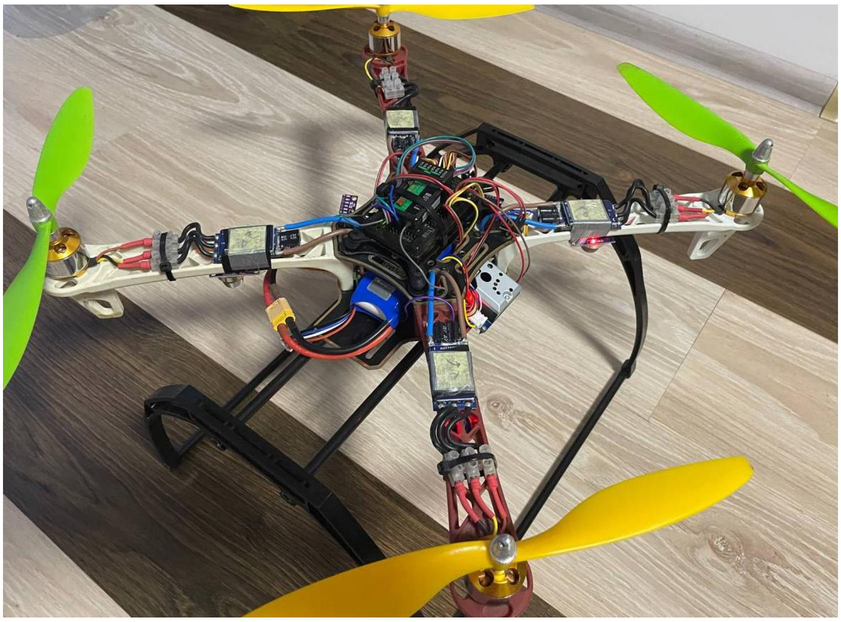

Fig. 1. **The prototype of UAV with sensors and auxiliary modules**

However, for such missions, real-time data acquisition is critical for accident prevention or, if an incident is inevitable, for ensuring the fastest possible response. However, for such missions, real-time data acquisition is critical for accident prevention or, if an incident is inevitable, for ensuring the fastest possible response. In this context, relying solely on recording sensor values to a file on a microSD card is insufficient; therefore, an additional, primary method for real-time monitoring is required. One of the most effective solutions is integrating the unmanned air quality monitoring system into an Internet-of-Things (IoT) ecosystem. In this scenario, the microcontroller responsible for data acquisition and processing must be equipped with wireless communication interfaces to transmit the gathered information to the receiver.

Firstly, it is necessary to select a suitable microcontroller capable of communicating with computer systems using wireless protocols such as Wi-Fi or Bluetooth. By utilizing these interfaces, the device can effectively establish connections with various computer systems. The optimal solution is a microcontroller manufactured by Espressif Systems. The ESP8266 series is not suitable due to the lack of a Bluetooth communication interface. In contrast, the ESP32 series supports the mentioned interfaces, as it was explicitly designed to interact with devices within a local network or with external hosts. Since it features both Wi-Fi and Bluetooth (including the Low Energy protocol), this series is the most optimal choice due to its affordability, technical performance, and IoT support. Consequently, the ESP32-S3 development board, based on the ESP32-S3-WROOM-1 module, was selected [3]. This board offers high performance, extensive GPIO capabilities, and full compatibility with the Arduino IDE.

Secondly, an appropriate IoT development tool must be selected. Among the various software options, Node-RED was chosen due to its flexibility, user-friendly interface, and broad compatibility with different microcontrollers and development boards. This tool enables the visualization of data from a wide range of connected sensors, indicators, and microcontrollers. The system architecture consists of 'flows' where individual objects – known as 'nodes' – are interconnected. Its versatility allows for the development of systems of varying complexity, ranging from simple home automation to advanced industrial control systems. Furthermore, the base functionality can be extended by installing additional custom libraries.

By programming the ESP32-S3-WROOM-1 using the Arduino IDE and both WiFi and uMQTTBroker libraries, the UAV-based air quality monitoring system establishes communication with the PC and Node-RED via the MQTT protocol. In this specific system, the development board, along with its connected modules and sensors, functions as the Publisher. Simultaneously, the microcontroller itself acts as the Broker, while the 'MQTT IN' node within the Node-RED palette – configured with the broker's IP address – serves as the Subscriber. Consequently, all received data is distributed among the nodes in real-time, in accordance with the logic defined in the code

Conclusion. As a result, a prototype of an IoT-based communication system between the UAV air-quality monitoring system's microcontroller and a computer was designed. Data from the UAV's microcontroller is transferred to the server via the MQTT protocol. The designed system provides a strong base for intellectual IoT systems because of its versatility and the accessibility of both hardware and software components. There is also great potential for modernization in several ways. The first is adding charts and plots for visualizing data received from sensors, covering both real-time values and past records. This will be helpful for analyzing data and managing critical situations. The second path for development is the integration of additional devices, such as upgraded wireless modules and standalone sensors. In this case, the UAV's operational radius can be extended, data precision can be improved, and mission time can be adjusted by charging stations. Lastly, cybersecurity measures are crucial and mandatory, as the system may operate in restricted or sensitive areas.

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