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Data Logging and Analysis in an Unmanned Aerial Vehicle-Assisted Internet of Things Network

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Abstract: The world is moving towards ubiquitous connectivity, with many devices interconnected and transferring information across the Internet. However, providing Internet connectivity to every device remains challenging, especially in remote geographical areas. It is also difficult for humans to reach remote locations to collect data, hence edge devices need a source to transfer their data across the Internet. Unmanned Aerial Vehicles (UAVs) offer the perfect solution as they can reach remote locations while using lower resources to provide connectivity and collect data from remote devices. Following data collection, the next challenge is data processing. Most of the pre-existing networks process data on the edge device itself, which induces extra load and may lead to data loss from skipping of the data reading cycle. In this paper, various issues related to data logging and analysis in a UAV-assisted Internet of Things (IoT) network are discussed. Issues such as placement of sensor nodes, connectivity to the nodes, UAV platform and tools for the design and development of a UAV-assisted IoT network are presented.

Keywords: Wireless sensor network, unmanned aerial vehicles (UAV), data logging.

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1. Introduction

The Internet of Things (IoT) is expanding at a great pace and in the near future, almost every electronic device will be connected to the Internet and sharing data. IoT will significantly change both industrial manufacturing and our daily lives. There are a number of applications of IoT, such as smart homes, smart cities, smart agriculture, industrial IoT, etc. (Li et al., 2011; Xu et al., 2014). A detailed review of IoT technology can be found in Chhetri and Bera (2020), which covers trends, applications, challenges and future prospects. In the near future, 5G will be a key enabling technology for IoT. A detailed review of 5G IoT systems is provided by Chhetri and Bera (2020) and Shafiq et al. (2020).

Currently, there are millions of devices that are connected to the Internet and sharing data. These devices are known as edge devices. Use of edge devices and retrieval of data in locations where the Internet connectivity is low is a challenge (Wang et al., 2019). Many edge devices experience dropout which may be unnoticed by the user without directly checking the node. This can be more challenging if the nodes are installed in geographically adverse areas (Castellanos et al., 2020; Reddy et al., 2017; Mekonnen et al., 2018).

There are two main services provided by IoT networks, data collection and three-dimensional (3-D) positioning of IoT devices, provided via terrestrial Base Stations (BSs). Transmitting devices at the cell edge of the BS involves high energy consumption. Due to the low height of these BSs, the performance of devices in elevated areas is very poor. Unmanned Aerial Vehicles (UAVs) are used to overcome these disadvantages (Popescu et al., 2019; Wang et al., 2020). UAVs can be used to provide an air-ground integration network. A UAV furnished with communication equipment is used as a mobile BS for collecting data from IoT devices on the ground. UAV is proving to be an enabling technology for the IoT vision, as it can quickly provide communication and data collection services.

The present paper proposes a UAV-based data collection mechanism, where human presence is not required at the node installation location as inspection can be carried out by the UAV (Zhan et al., 2018; Saha et al., 2018). The Wireless Sensor Network (WSN) installed on the ground will collect data from various sensors connected to it. These sensor nodes only have to retrieve sensor data and transmit them, and do not need to conduct any further processing. The placement of the sensor nodes in the sensor network plays a crucial role in the whole functioning of the system, as battery life, connectivity and communication are highly dependent on this factor (Shi et al., 2011; Mohammad et al., 2014; Gapchup et al., 2017). There may be situations where 24/7 data transmission is not required by the WSN, hence for the desired spontaneous data transmission, this UAV system is introduced. A UAV will be deployed from the home location to the node installation location and will give an interrupt signal which will make the WSN nodes send data to the cloud for processing via the UAV (Sharma et al., 2017; Al-Azez et al., 2015). The UAV acts as an access point for the sensor nodes to send their data to the cloud. The cloud stores data continuously in a database and processes them as desired (Guth et al., 2016; Akherfi et al., 2016; Kosta et al., 2012; Chen et al., 2012; Aazam and Huh, 2014; Apostol et al., 2015). The cloud is a remote computer service that can be accessed from different locations across the Internet. This accomplishes two tasks: one is to provide computation ability for data processing, the other is to facilitate worldwide user access to the data (Benslimane et al., 2014; Nan et al., 2016; Aazam Eui-Nam, 2015).

The present paper is divided into the following sections: Section 2 summarizes related work; Section 3 describes the WSN network deployment and communication; Section 4 describes the UAV trajectory and data collection mechanism; Section 5 describes the cloud infrastructure and end delivery system to the user after data processing.

2. Related Work

UAVs can be a helpful tool for providing services for IoT networks. They can be useful in increasing the coverage area of an IoT network by providing relay technologies and communication aids. A UAV swarm network architecture and low latency routing algorithm was proposed by Zhang et al. (2019) to address the challenges of low latency requirement and dynamic topology of UAV networks.

The collaborative aspect of UAV-assisted IoT system architecture was discussed by Wang et al. (2020). This work also reviews the intelligent data processing, computation, communication and control methods for carrying out specific monitoring and evaluation tasks.

Li et al. (2020) proposed a Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol for an air-ground network in which the UAV flying over the ground network can collect information from the IoT devices. A new analysis model was also presented to analyze throughput performance of the protocol. This addresses the communication heterogeneity of the network.

In paper by Feng et al. (2019), UAV-aided data collection is presented and analyzed using a composite channel model. Both large- and small-scale fading effects are used to depict typical propagation environments. Energy constraints are also considered to characterize a practical IoT scenario. Multiple antennas are used in UAVs to communicate with IoT devices which have a single antenna.

Castellanos et al. (2020) showed that a UAV-assisted network can be used for collecting underground soil parameters, with a NarrowBand (NB)-IoT system proposed for collecting data. This tool uses a gateway mounted on a UAV using an NB-IoT-based access network and Long-Term Evolution (LTE)-based backhaul network to evaluate the performance of a realistic scenario in a field.

Alsamhi et al. (2019) discussed recent smart city applications of drones that can collaborate with each other. Their work provides a comprehensive survey of real-time application of smart cities. It includes a detailed discussion on data collection and other important aspects such as privacy, security and energy consumption.

3. Remote Sensor Nodes

Sensor nodes have limited battery and computation power resources. They are small and inexpensive devices deployed in a particular place/region to monitor the surroundings. Major components of a sensor node are the microcontroller, transceiver, external memory, power source and one or more sensors. Fig. 1. shows components of sensor node.

3.1. Wireless Sensor Network

The WSN acts as a self-configured and infrastructure-less wireless network used to monitor physical or environmental parameters, such as temperature, moisture, pressure or pollutants and to cooperatively pass their data across the network to a BS where the data can be observed and analyzed. A BS acts like an interface between users and the network (Wang et al., 2019). One can retrieve required information from this network by inputting queries. Typically, a WSN contains hundreds or thousands of sensor nodes.

3.2. Sensor Nodes Communication Medium

The sensor nodes can communicate among themselves using radio signals. A wireless sensor node is equipped with sensing and computing devices, radio transceivers and power components (Castellanos et al., 2020). The radio transceiver at the sensor node sends data to the drone transceiver. This uses the NRF24L01, which is a single chip radio transceiver that operates in an Industrial, Scientific and Medical (ISM) band and uses Gaussian Frequency Shift Keying (GFSK) modulation. The transceiver consists of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator, a demodulator, a modulator and an Enhanced ShockBurst protocol engine. The transceiver module can communicate at a rate of up to 10 Mbps over a four-pin Serial Peripheral Interface (SPI). All the parameters such as frequency channel, output power and data rate can be configured through the SPI interface. The complete specifications are shown in Table 1.

Table 1. WSN Specifications

Type of Specification	Specification Values
Frequency Range	2.4 GHz ISM Band
Maximum Air Data Rate	2 Mb/s
Modulation Format	GFSK
Max. Output Power	0 dBm
Operating Supply Voltage	1.9 V to 3.6 V
Max. Operating Current	13.5mA
Min. Current (Standby Mode)	26µA
Logic Inputs	5V Tolerant
Communication Range	800+ m (line of sight)

3.3. Positioning of Wireless Sensor Nodes

Information about the location of sensors in the WSN needs to be obtained, either by recording positions manually or by using a Global Positioning System (GPS) chip. However, neither of these options are feasible for sensor networks. A new localization protocol for sensor networks is proposed. In this technique, the area in which the anchor node is placed is designated using hexagons. These hexagons are of same size. The closest sensor node to the center of each of these hypothetical hexagons is determined. These nodes are called backbone sensors. The positions of backbone sensors are estimated geometrically. They are then treated as beacons and the positions of all non-backbone sensors are estimated using the centroid approach. Simulation results under noise-free and noisy conditions show that this protocol achieves a localization accuracy that makes it useful for most WSN applications (Reddy et al., 2017).

The WSN is a hexagonal design because this shape provides the minimum transmission path among the multiple hexagonal networks. The Euclidean distance between lattice points is much lower compared to any other shape, as shown in Fig. 2.

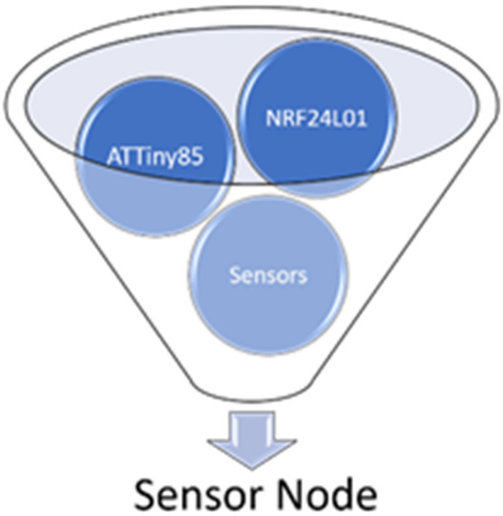

Fig. 1. Components of sensor node

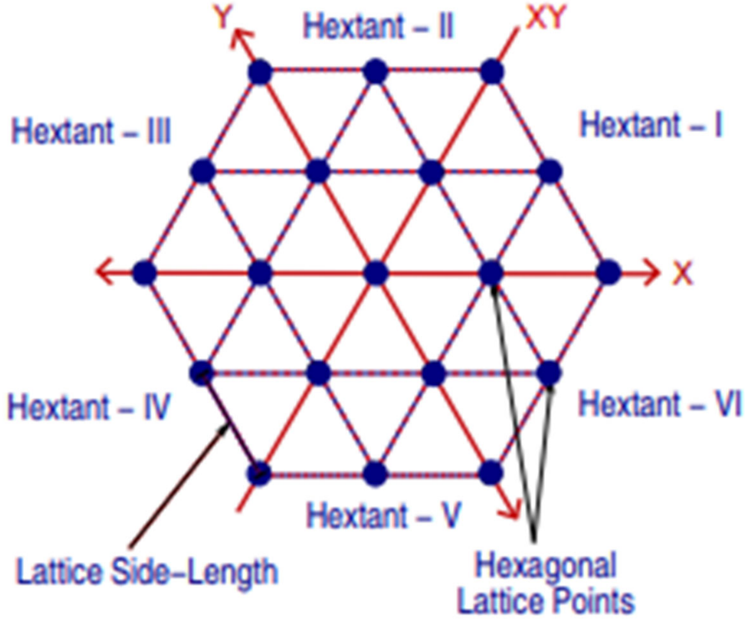

Fig. 2. Positioning of sensor node

4. UAV-Based Data Logging

It is difficult for a human to visit a place regularly and gather sensor data, especially when the place is located in a geographically adverse area, as this increases time and cost. These two factors can be reduced by the use of UAVs for data logging. A UAV can be used as an aerial anchor node (Mekonnen et al., 2018; Jhan et al., 2018) and can collect real-time data from a large area in a very short time with less energy consumption. A UAV should be designed and programmed in the most stable and efficient way to be able to get into range of each of the sensor nodes and collect data.

4.1. UAV Trajectory and Autopilot System

Manually flying a UAV takes a lot of training, time and effort. These can be reduced by operating the UAV in autopilot mode. By just inputting the waypoints and goals, the UAV will compute and follow the most efficient trajectory. There are many ways to accomplish this task, one of which is to use Mission Planner Simulation Software, which can configure or dynamically control the autonomous UAV (Saha et al., 2018; Shi et al., 2011). Fig. 3 shows the tracing of waypoints by the UAV using Mission Planner software.

Using this software, we can configure and tune the UAV, plan, save and load an autonomous mission, and monitor the UAV's status while in operation. We can obtain a satellite view of the map for marking waypoints and goals.

4.2. UAV- Assisted IoT Network Components

Apart from the basic requirements of a UAV, like flight controller and navigation equipment, there are some additional IoT devices which need to be interfaced with the UAV in order to receive data from sensor nodes and send them to cloud for further analysis (Mohammad et al., 2014). Fig. 4 shows some of these main components of a UAV platform for a UAV-assisted IoT network and are described below.

Fig. 3. Screenshot of mission planner

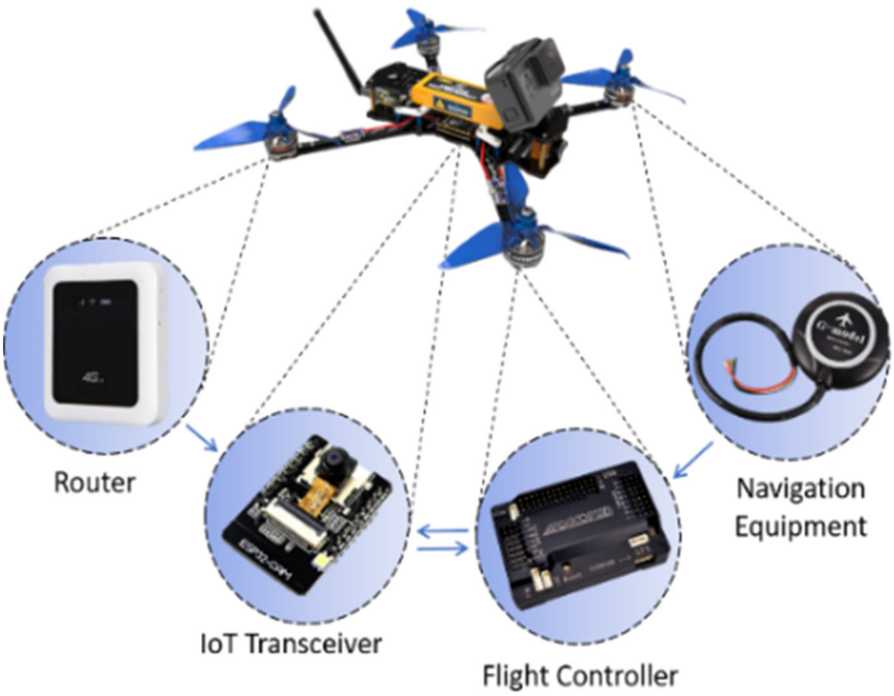

Fig. 4. UAV platform for UAV- assisted IoT network

i) GPS module : The GPS module is necessary for making an autopilot UAV. It provides the precise location in terms of latitude and longitude, and can be used for to track the UAV.

ii) IoT transceiver : An IoT transceiver is interfaced to communicate with the WSNs and collect the data. Devices such as the NRF24L01 are available for this purpose. The collected data will be passed to another module which will send them to cloud. Modules such as ESP32-CAM are available which can send the collected sensor node data to the cloud, and capture and send real-time images for object detection and recognition.

iii) Router: The router is a device that can connect multiple devices to Internet and can create local networks of devices such as an ad-hoc network. In this project, for data delivery to the cloud a router is attached to the UAV, which connects the ESP32 to the Internet for data delivery. When the drone moves from one area to another, the router switches between various cell towers and searches for the best available network that can connect to the Internet.

4.3. UAV to WSN communication

As soon as the UAV enters the range of sensor node, the node will be detected and the UAV will send an acknowledgement message to verify the connection. After verification, the WSN will start the data transmission through the NRF. Fig. 5 shows the algorithm followed by the sensor node (Gapchup et al., 2017; Sharma et al., 2017).

As soon as the UAV's NRF receives the data, it will pass them to the ESP32, which will be connected to the Internet through the router attached to the drone. The data will be uploaded to the cloud for further processing. Fig. 6 shows the connection diagram of the IoT network. The UAV will not just send real-time data if requested from the user; it can also collect and send previously recorded data.

In cases where more than one WSN is detected simultaneously, the data reception and transmission will be carried out one-by-one, with WSNs stored in a queue. To differentiate between the WSNs, the data to be sent will be preceded by a unique identification and the ESP32 will send the data accordingly (Al-Azez et al., 2015; Guth et al., 2016).

5. Data Analysis in the Cloud

After the data are collected by the UAV from the wireless sensor nodes, they are sent to the cloud for further processing and analysis. This reduces the processing load on the edge devices, hence they can work continuously on the data fetching process. The cloud here is a remote computer which is pre-configured to process and analyze the received data.

5.1. Cloud setup

The cloud is a remote compute service that can be accessed by users for various services such as Platform as a Service (PaaS), Infrastructure as a Service (IaaS), etc. (Akherfi et al., 2016; Kosta et al., 2012; Ngu et al., 2017). The functions of various components of this cloud setup are shown in Table 2.

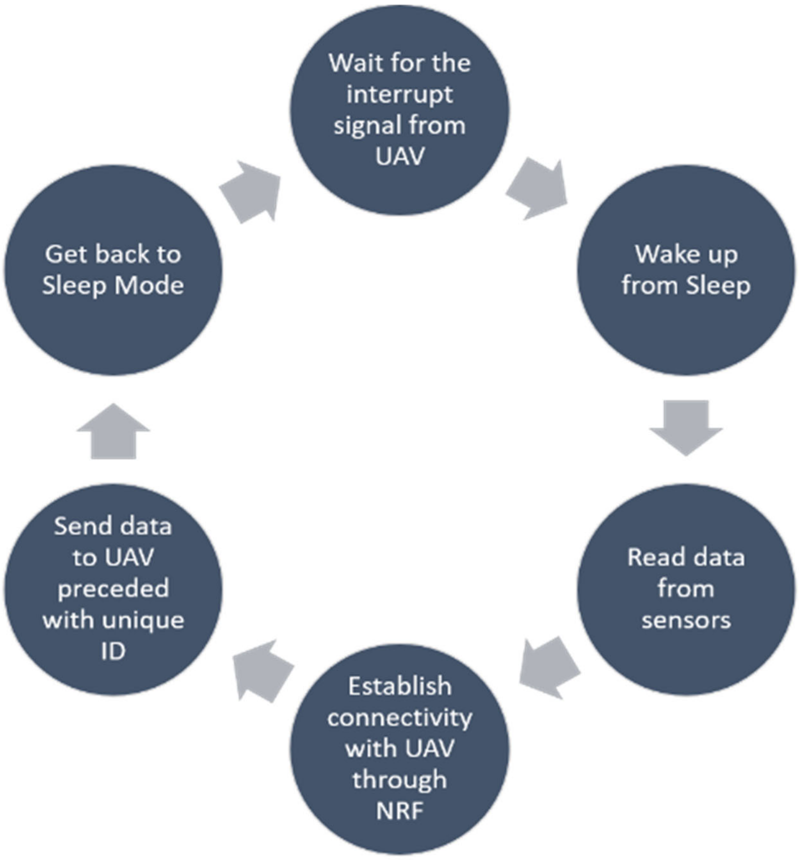

Fig. 5. Operation of sensor node

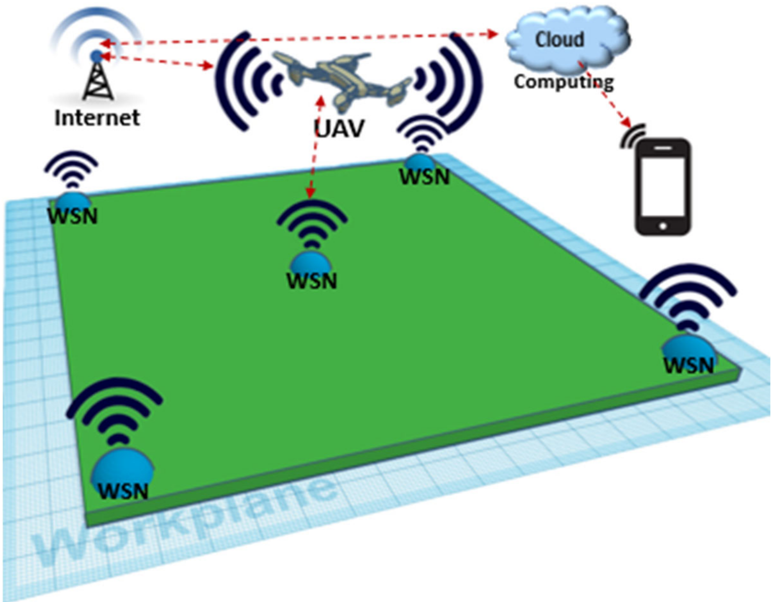

Fig. 6. IoT network configuration

Table 2. Cloud setup functionality

Components	Functions
Cloud Platform such as AWS, Google Cloud Platform, Microsoft Azure, etc.	Provide computing resources for deploying and operating applications on web
Node-RED	A flow control tool with processing ability for wiring together hardware devices
MQTT	A messaging protocol with publisher subscriber model; it works as a broker here
Grafana	A data visualization tool with data manipulation ability
MySQL	A database management system language widely used for data compilation and storage

5.2. Data collection and processing

The data will be continuously fetched from the wireless sensor nodes by the UAV. The UAV will have a Wi-Fi module, which will further transmit the data to the cloud via a Message Queuing Telemetry Transport (MQTT) broker. The architecture of data transmission is shown in Fig. 7.

The data will be collected by the UAV via near radio frequency transmission protocol, which will in turn be delivered to the Wi-Fi module that will be present on the UAV by SPI communication between the NRF module and the Wi-Fi module. The Wi-Fi module will access the Internet from a modem attached to the UAV. The data then will be transferred to the cloud from the Wi-Fi module via the MQTT broker, which will be publishing these data to a specific topic. On the cloud there will be a Node-RED flow, as shown in Fig. 8, designed to receive the data from MQTT broker, which will be listening to the same topic as the Wi-Fi module is publishing. Node-RED will store the received data in the MySQL database (Aazam and Huh, 2014; Apostol et al., 2015).

The nodes used in Node-RED flows are MQTT-in, JavaScript Object Notation (JSON), template, MySQL and debug. These nodes create a flow that stores data in the MySQL database. These data will be further used for data visualization and analysis.

5.3. Data visualization and delivery

The data in the MySQL database table will be stored in an organized manner to facilitate analysis and further processing. The data are stored with a timestamp so that time of logging the data can be known. The sensors will be sending many heterogeneous data values, so storing different forms of data in different columns is necessary.

Grafana is a very effective tool for data visualization and presentation. It is already installed on the cloud, so it can begin fetching data from the MySQL table. The data can be visualized on any web browser across the globe by searching for the Internet Protocol (IP) address of the EC2 instance with port number 3000, for example, 192.48.62.3:3000. After logging into the Grafana, the user can navigate to the graph designated for the sensor data (Benslimane et al., 2014; Nan et al., 2016). The graph will be displaying the sensor data as shown in Fig. 9.

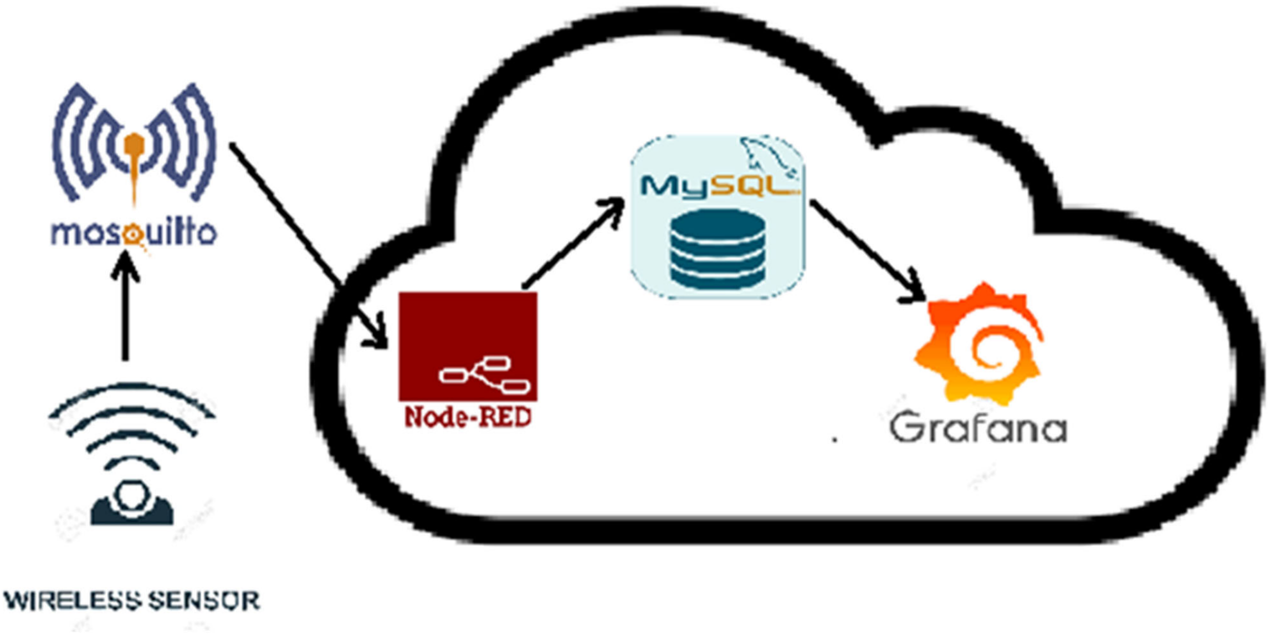

Fig. 7. Data transmission architecture

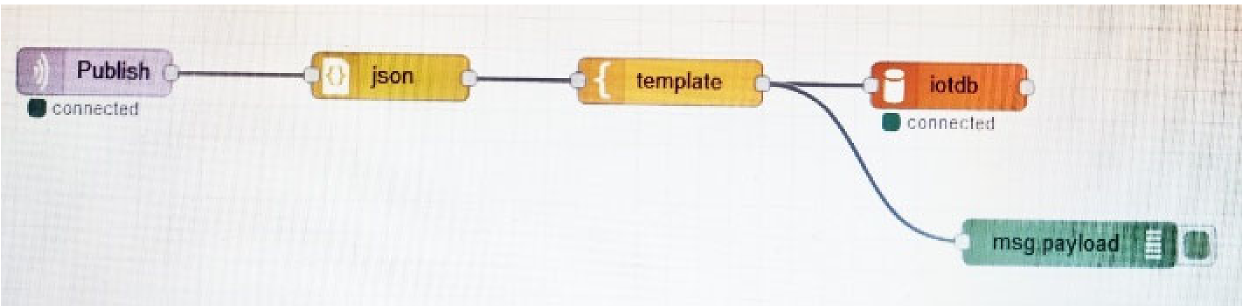

Fig. 8. Node-RED flows

Fig. 9. Graph visualization in Grafana

6. Object Detection and Classification

While moving, the UAV takes some random pictures of the surroundings to further classify and store the data if any relevant object is detected. The captured image is processed initially on the UAV before being sent to the cloud. The initial processing on the UAV includes image compression and conversion to Base64 encoding. To convert the image into Base64, the code is written in the Arduino Integrated Development Environment (IDE) software and uploaded to the ESP32-CAM along with the previous code. This converts the image into Base64 encoding so that it can be sent to the cloud via an MQTT channel. On the cloud (Node-RED) there is an MQTT receiver that receives the image data and decodes the Base64-encoded string to retrieve the image. This image is then sent to a visual recognition node that classifies the image into certain pretrained classes. This output of the visual recognition node is sent back to the user via an MQTT channel which the user can access from a mobile phone app (discussed below). The Node-RED flow for this image detection and classification is shown in Fig. 10.

The visual recognition node used here is connected to IBM cloud's Visual Recognition service which detects the images based on the training it received. This node can be customized by our own Computer Vision Node that can classify the image as defined by us. We also coded the computer vision model using YOLOv4 for classifying certain classes, however, converting into Node-RED node was a tedious task and the data set used for training were not standard, so for better and smooth processing we implemented IBM cloud's service.

7. Mobile App

To check the incoming sensor data or detected object, the user can use a dashboard via a mobile app. For this project we used the IoT MQTT Panel app, which is available in Google Play Store for anyone to download. After installing this app, the user needs to connect to the cloud via the IP address of the cloud. Under this connection the user can add multiple panels to send or receive data. A graph panel can be used to visualize sensor data; it also has an Input Text column where the user can send some text to MQTT Topic and the output of classified images can be displayed on text output panel. This makes it easier for the user to monitor and analyze the data, as shown in Fig. 11.

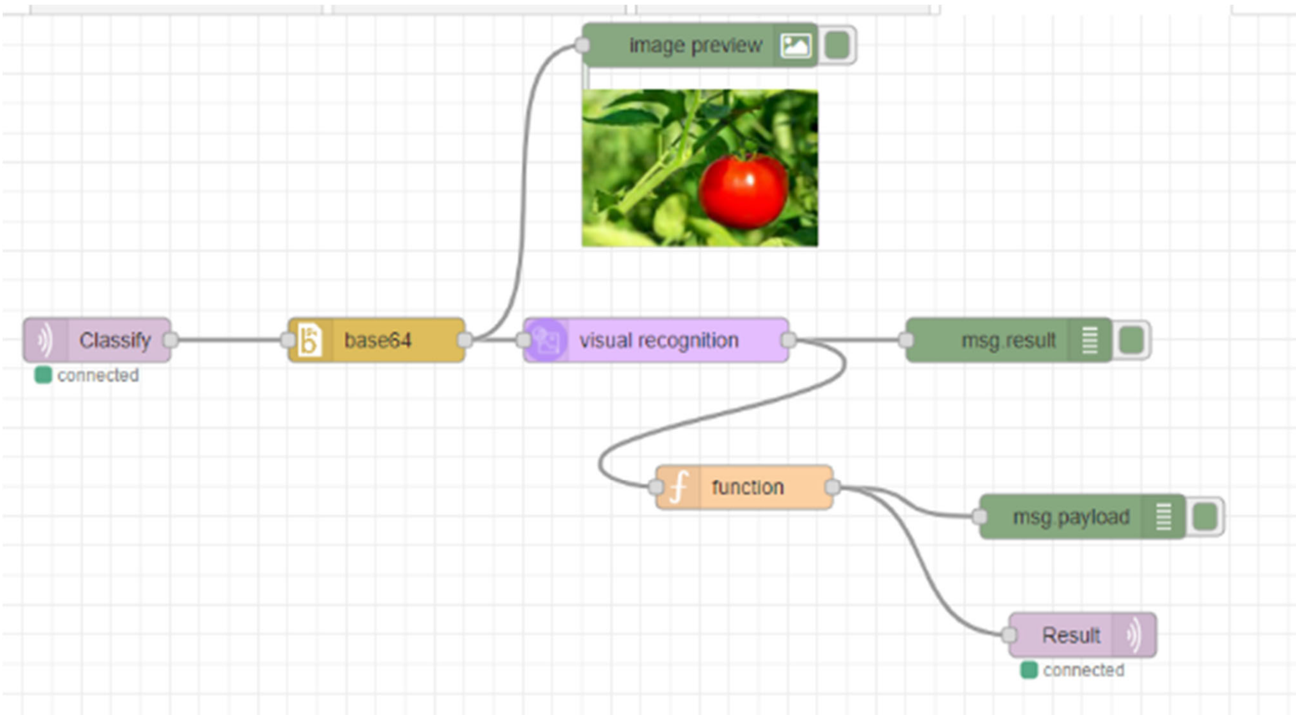

Fig. 10. Node-RED flow for image detection and classification

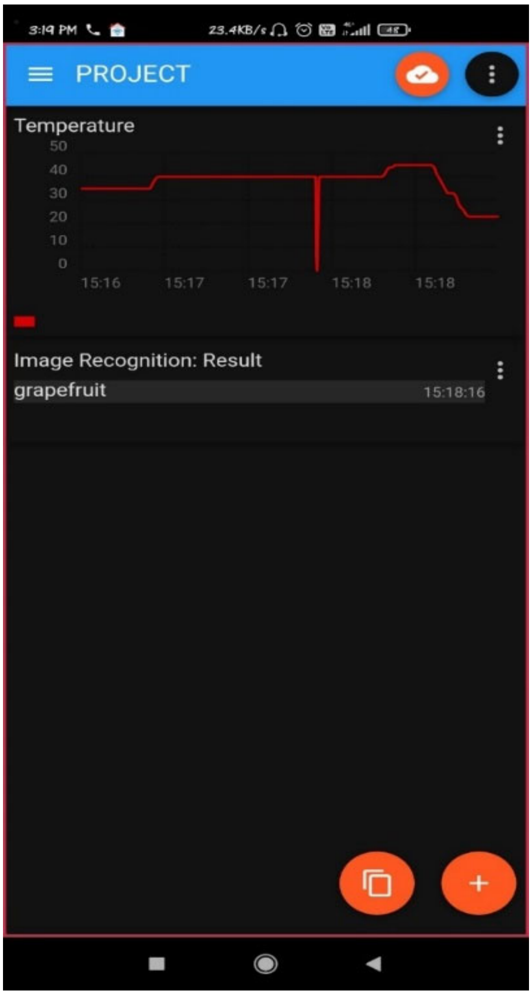

Fig. 11. Data visualization in mobile App

8. Future Work

With the evolution of the 5G network, the router can be removed from the UAV which will reduce its weight and energy consumption. Object avoidance can be implemented by adding some ultrasonic sensors on the UAV. Data security is a major priority to be implemented in future work.

9. Conclusion

A UAV-assisted IoT network for data logging consists of a transceiver and a gateway in addition to flight controller and navigation equipment. In this paper, various issues related to connectivity and data collection from the sensor nodes have been discussed. Available cost-effective solutions have been suggested for the design and development of a UAV-assisted IoT network. The data collection and transmission processes should be performed seamlessly to reduce workload on the WSN. Cloud computing is the best option for preprocessing. The tools used for this procedure are very reliable and open-source technologies, with a lot of available repositories. End data visualization is crucial for the client, managed remotely without any human intervention. The UAV can be autopiloted to the end point from where it needs to fetch data and will further transfer the data to the cloud for processing. It is straightforward for the end user to access the results across the Internet from anywhere in the world.

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Author Contributions

Mr. Amar Barik contributed to conceptualization and implementation of WSN, IoT and data collection. Mr. Saumykanta Khatua was involved in UAV platform hardware and software, data collection, processing and visualization. Mr. Abhishek Rana contributed to design and integration of various subsystems. Dr. Gajanan R Patil contributed to conceptualization, Literature survey, supervision, project administration and manuscript editing.

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