SE4IoT - SOFTWARE ENGINEERING FOR INTERNET OF THINGS

Programme Name:
Erasmus Mundus M.Sc. Programme
Software Engineers For Green Deal (SE4GD)

WILDFIRE DETECTION AND MONITORING SYSTEM

Github Repository
https://github.com/nguyenvince/Wildfire-Air-Quality-IoT

SUBMITTED TO:
Prof. Davide Di Ruscio
Department of Information Engineering,
Computer Science and Mathematics,
University of L'Aquila

SUBMITTED BY:
Vidya Dhopate
vidya.dhopate@student.univaq.it
Salsabeel Husayn Hassan Tantoush
salsabeel.tantoush@student.univaq.it
Thanh Vinh Nguyen
thanhvinh.nguyen@student.univaq.it

SUBMITTED ON:
23rd January, 2024

TABLE OF CONTENTS

INTRODUCTION:

Wildfire detection and monitoring is an issue of paramount importance in the matters of public safety, air quality control, and environmental well-being. Using air-quality to detect wildfires is a reliable way to pinpoint anomalies in the air composition without risking human resources in wildfire detection. When wildfires occur, they release a plethora of pollutants into the atmosphere, including particulate matter, carbon dioxide, nitrogen dioxide, and increase the temperature of the surrounding air.

Monitoring and analysing air quality in real-time plays a critical role in early wildfire detection. This information is crucial to later efforts in controlling and mitigating the wildfire. Elevated levels of air pollutants released from wildfires can have detrimental effects on respiratory health, especially for vulnerable populations such as the elderly and those with pre-existing conditions. Hence, there is a need for a robust wildfire detection and monitoring system.

Moreover, the impact of wildfires extends beyond the human species: it is notorious for wreaking havoc on wildlife and the forest's natural ecosystems. In recent years, major wildfires across the world have resulted in devastating consequences for wild animals. Let us look at the example of the Australian bushfires [1] of 2019 - 2020. This calamity led to the loss of an estimated three billion vertebrates (including mammals, birds, reptiles). Koalas, the beloved animals in Australia, faced a severe decline in their populations due to habitat destruction and direct harm from the fires. The Australian wildfires resulted in more than 4000 people being admitted to the hospital, directly killed more than 30 people and was linked to 445 deaths. Another example is of the wildfires in the Amazon rainforest, one of the most important sites in the world from the perspective of oxygen regulation. In 2019, not only did wildfires worsen the air quality of the region but also posed a significant threat to insects, birds, and mammals endemic to Amazon.

These examples underscore the urgent need for effective wildfire detection systems not only for human safety but also for the protection of vulnerable wildlife populations and the preservation of the planet's biodiversity. Rapid response measures guided by accurate air quality monitoring can mitigate the impact on both human and animal communities. Wildfire detection systems must enable the identification of air quality anomalies to allow authorities to issue warnings and implement preventive measures. This ensures the safety of communities and facilitates effective firefighting strategies. Investing in robust air quality monitoring and detection systems contributes not only to public safety but also to the protection of ecosystems and wildlife affected by wildfires. Therefore, prioritising the development and implementation of advanced technologies for air quality anomaly detection is crucial for enhancing resilience in the face of wildfire events.

IoT IN WILDFIRE DETECTION BY AIR QUALITY MONITORING:

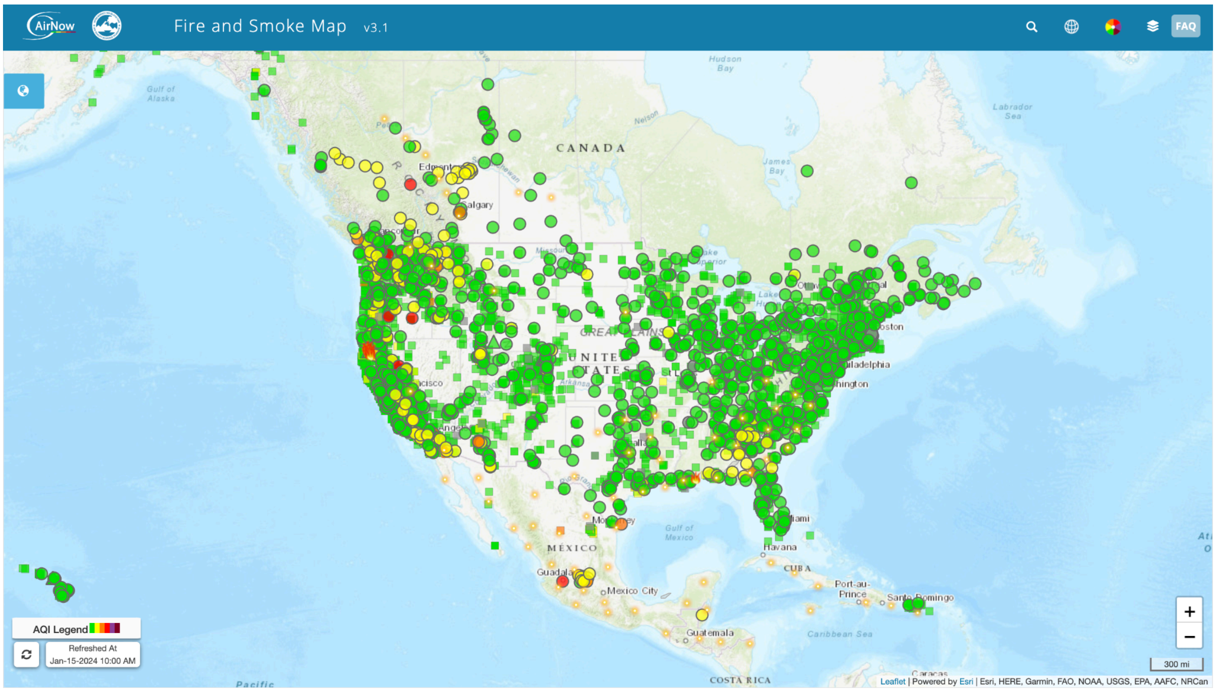
Traditional methods for detecting wildfires include Lookout Towers, Patrol Groups, and Community Reporting. However, employing an IoT-based air quality monitoring solution in wildfire detection revolutionises these traditional approaches and enhances our overall response strategies.

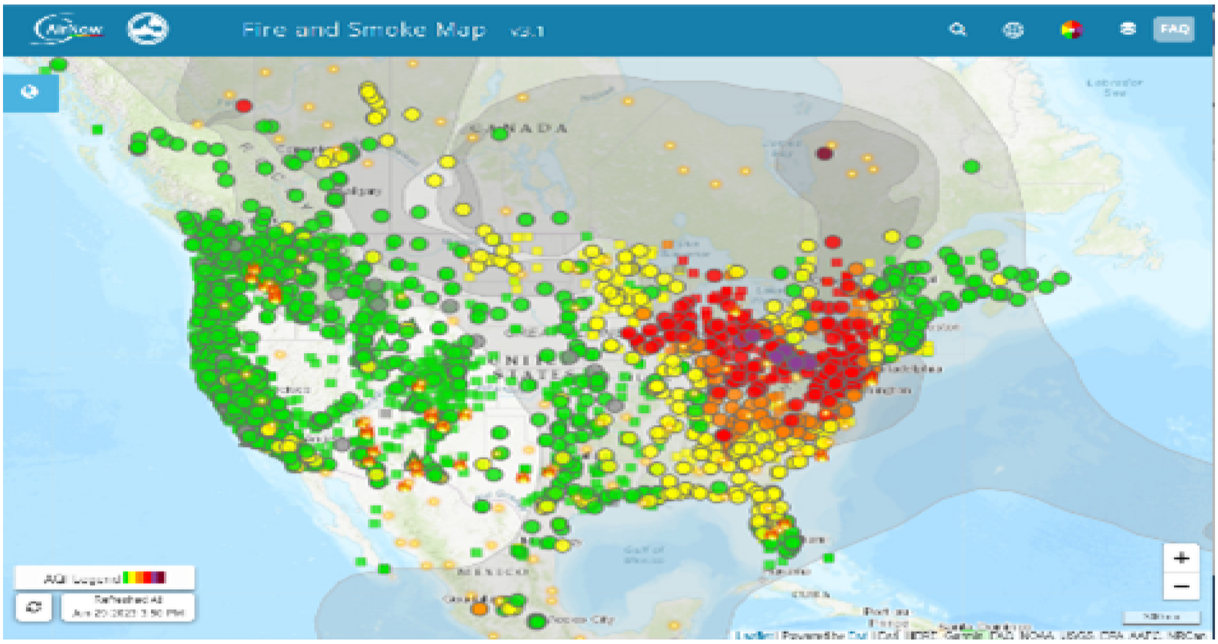
Real-time data from IoT devices allows for continuous tracking and monitoring of air quality parameters associated with wildfires, such as particulate matter, temperature and humidity, and nitrogen dioxide across a wide region. This instantaneous monitoring facilitates early detection and timely intervention, crucial for minimising its impact on public health and the environment. Secondly, the remote accessibility of data through IoT devices eliminates the need for manual monitoring present in the traditional methods. It enables efficient, automated systems that operate 24/7. This not only ensures a rapid response but also optimises resource allocation during wildfire events, so that more task forces can be dedicated to mitigation instead of monitoring. The data collected can be analysed to identify evolving patterns by scientists, aiding in predictive modelling for future incidents and improving overall wildfire management strategies in the scientific community.

Moreover, the transparency provided by IoT technology allows authorities, animal-rescue communities, and environmental agencies to access real-time information. This reduces the need for continuous dissemination of official information from verified sources. It fosters collaborative efforts in wildfire prevention and response. This heightened transparency also plays a vital role in creating awareness and facilitating timely evacuations.

In conclusion, leveraging IoT in wildfire detection significantly improves early response mechanisms, enhances predictive capabilities, and promotes collaborative efforts. It advances overall effectiveness in mitigating the impact of wildfires on human as well as environmental well-being.

PROJECT SPECIFICATION:





The above figures [2] illustrate air quality data from a US government website. The figures capture a snapshot of the air quality metrics at a certain time and date in the United States. The legend for navigating the visualisation can be found on the bottom left. Since the air quality of different regions varies even without the presence of wildfires, using IoT for monitoring AQI levels for incidents of wildfires is a complex task. The figures displayed back-to-back shed light on visualising the difference in air quality during a wildfire versus when one is not happening. Referencing this for visualising real-time air quality, valuable information can be effectively disseminated to researchers, businesses, educators, and the public.

> Towards this goal, we propose an IoT-based monitoring and alerting aerial drone system which constantly monitors the air quality levels in order to analyse the monitored data. It also alerts the concerned authorities in case of any anomaly in the parameters recorded that may signify the likelihood of a wildfire at a particular location, conveyed through the location's latitude and longitude.

AIR QUALITY PARAMETERS FOR WILDFIRE DETECTION:

Temperature:
Temperature is used for early fire detection as wildfires generate heat. It helps assess environmental conditions, correlates with humidity, and, when integrated with other sensors, enhances predictive capabilities for effective wildfire prevention and response. [3, 4]

Dust (Particulate Matter):
Particulate matter (PM) in IoT-based wildfire detection systems is widely utilised as wildfires release smoke containing fine dust particles. Typically, the concentration of background PM2.5 (PM whose diameter is smaller than 2.5μm) is around 10-50 $\mu g/m^3$, but during wildfires, values can exceed 100-500 $\mu g/m^3$. Monitoring elevated PM levels helps in improving the accuracy of the wildfire monitoring system. [4,5]

Coordinates:
Coordinates (latitude and longitude) assist in detecting critical areas of the wildfire and/or a zone suspected to be susceptible to wildfire. The portability of the through aerial drones overcomes the challenges presented by stationary devices and allows for a wider coverage of the forests, enhanced mobility, reduced dependency on human intervention for detection, and reduced redundancy and duplication in data collection. These are set to hover around a fixed radius in areas susceptible to wildfire.

CO_2:
Typical ambient carbon dioxide (CO2) levels are around 400 parts per million (ppm), and specific values related to wildfires triggering events can vary based on the system's design and environmental factors. [5]

NO_2:
Nitrogen dioxide (NO2) is used in IoT-based wildfire detection systems as it can indicate combustion of wood. Typical ambient NO2 levels are around 10-20 parts per billion (ppb), but during wildfires, concentrations may increase significantly. [5]

FUNCTIONAL & NON FUNCTIONAL REQUIREMENTS:

Functional Requirements:

It is necessary for the Wildfire Monitoring System to perform the following functions:

Monitor and aggregate data from the sensors deployed in the forests:
Collecting real-time air quality data from various aerial drone sensors in the forests is crucial for effective and timely detection of forest wildfires. By monitoring and aggregating this data, it is possible to get a comprehensive overview of the entire zone at risk and identify dangerous areas.

Transform and store data received from the sensors:
The air quality data collected from the sensors must be transformed into a format that can be easily analysed and stored. This enables effective decision-making, wider dissemination of information to the public, and ensures that the data is available for future reference and scientific inquiry.

Visualising data from each sensor:
Visualising the data collected from the sensors can help to identify trends, patterns and areas for improvement. The data should be presented in an intuitive and accessible format – yet convey enough information – so that authorities can make informed decisions from it, take appropriate actions, and raise awareness among the public.

Sending alerts to the administrator of the wildfire detection system:
A key aspect of an IoT-based wildfire detection system is the ability to send alerts in real-time. This can include alerts related to anomalies in the air quality assessment or when any sensor stops sending real-time data. This helps to ensure that issues are addressed promptly to avoid the spread of the wildfire.

Controlling the drones in different zones and power saving:
The ability to control the wildfire detection system autonomously and remotely is crucial for detecting, mitigating, and raising awareness about wildfires. This is especially necessary because wildfires are located in remote zones which require significant manpower for physical presence which is fraught with risk.
Remote-control makes it possible to devote more human resources towards mitigation while also ensuring the safety of the human resources and the general public by close monitoring of the air quality levels.

Non-Functional Requirements:

Usability: The system should be configurable to be easy to use, analyse, and monitor.

Scalability: The system should be able to handle new sensors and keep track of individual sensor data without additional set-ups

Interoperability: The system should be compatible with various air quality monitoring devices and sensors for aggregating data across heterogeneous sources

Reliability: The system should always provide reliable, complete and accurate data.

Performance: The system should be capable of real-time monitoring and analysis with low latency in processing and reporting air quality data.

Transparency: The system should be understandable and accountable so that it is easier to adhere to relevant regulations and standards, such as Good Distribution Practices (GDP).

TECHNOLOGIES:

We used the following technologies to implement our system according to the project specifications.

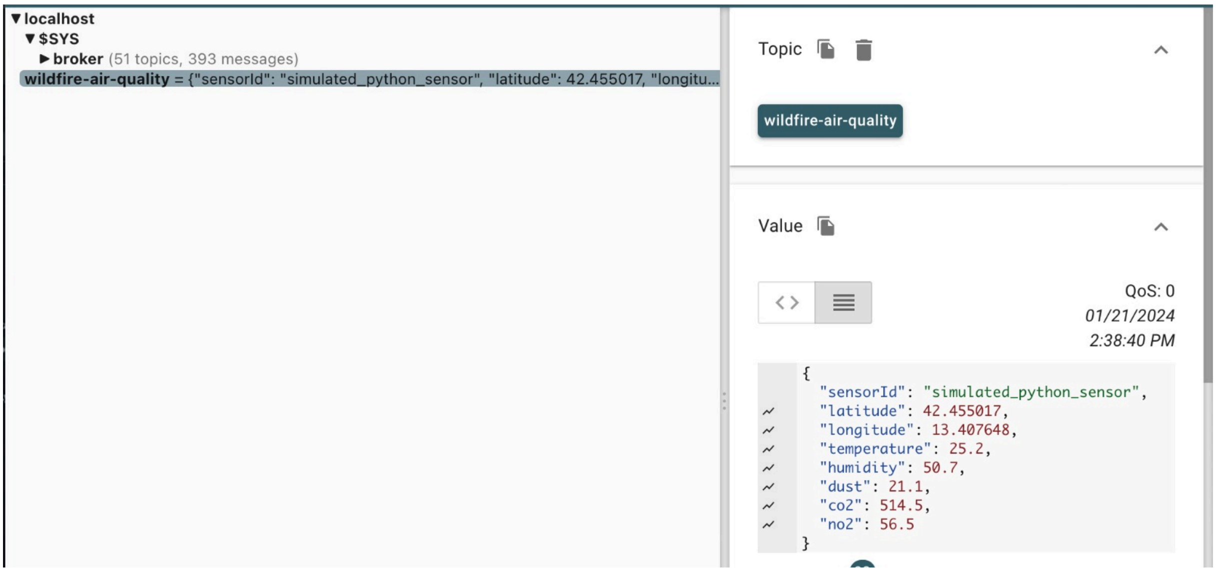
IoT Sensors: Data from sensors for Location Coordinates, Temperature, Humidity, CO_2, NO_2, and Dust (PM2.5) are simulated using:
- A dockerized Python script
- A Wokwi project simulating an ESP32 microcontroller device, with MicroPython

This is done in order to simulate heterogeneous sensor sources.

Mosquitto MQTT Broker:

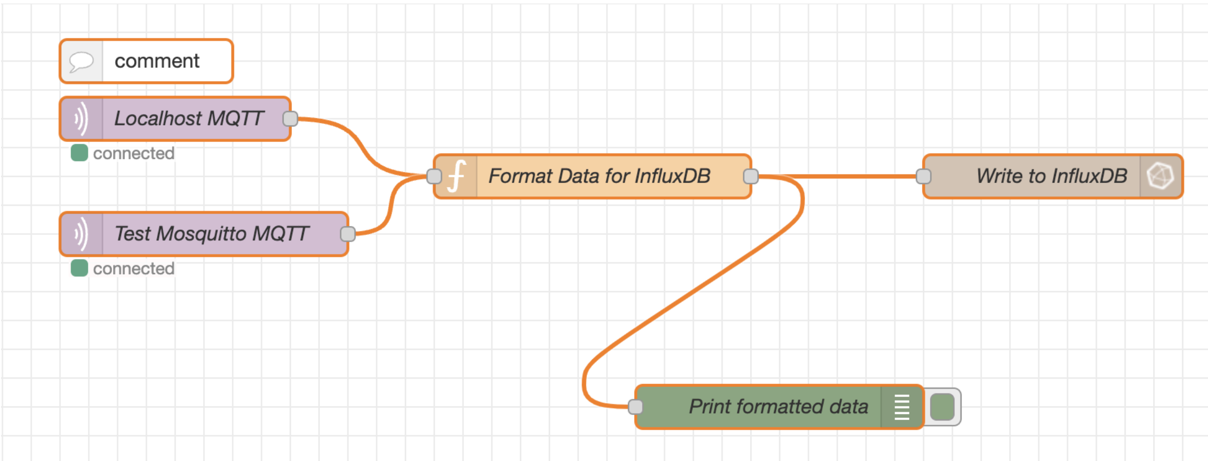
For seamless communication between the data from the heterogeneous sources and the database, we require a lightweight protocol providing a pub-sub mechanism that can be integrated with other technologies for flexibility and scalability purposes in the future, as and when necessary. Thus, our choice is the

MQTT protocol that is a viable option to get the (simulated) data from the sensors and to publish the data to the broker. For this, Mosquitto is an open-source message broker that we utilised. It implements the MQTT protocol. It acts as a central hub, facilitating communication between connected devices: the sensors and communicating this data further to node-red. Mosquitto has the ability to handle large numbers of simultaneous connections, making it ideal for IoT and machine-to-machine communication.



NodeRed:

NodeRed is used to subscribe to data from heterogeneous sensor sources via MQTT, format them, and write to InfluxDB, as outlined below:



In the above image, the wokwi_sensor connects to the 'Test Mosquitto MQTT' node while the simulated_python_sensor connects to the 'Localhost MQTT' node.

InfluxDB:

InfluxDB is a high-performance time-series database designed to handle large

amounts of time-stamped data. It provides real-time analysis and is optimised for handling metric and event data.
Since data being simulated by the different sensors in our solution needs to be stored in a highly scalable, time-series database with provisions for a variety of plugins, InfluxDB is a good choice. For our solution, we use the interactive UI of Influx which provides us with easy querying capabilities across specific timeframes.

Grafana:

Grafana is an open-source platform for visualising and analysing data. It provides a user-friendly interface for creating dynamic dashboards, allowing users to easily interact with their data. Grafana supports a range of data sources, including InfluxDB, and can visualise data in a variety of formats.

We use Grafana to visualise and analyse the data obtained from the InfluxDB Bucket. We utilised Grafana to create tailor-made dashboards of the sensor data received to provide better visualisation capability for the admin.

We also made use of the alerting features in Grafana to send email alerts through SMTP in case of any abnormalities in the parameter readings (Temperature, PM, CO_2, NO_2).

SMTP:

We use the SMTP functionality inbuilt in Grafana to send emails about anomalies in the parameters (Temperature, PM, NO_2, CO_2). We chose this method as email is a ubiquitous form of communication instead of favouring any specific messaging application. In addition, sending updates via email provides an official record of the information being sent/received.

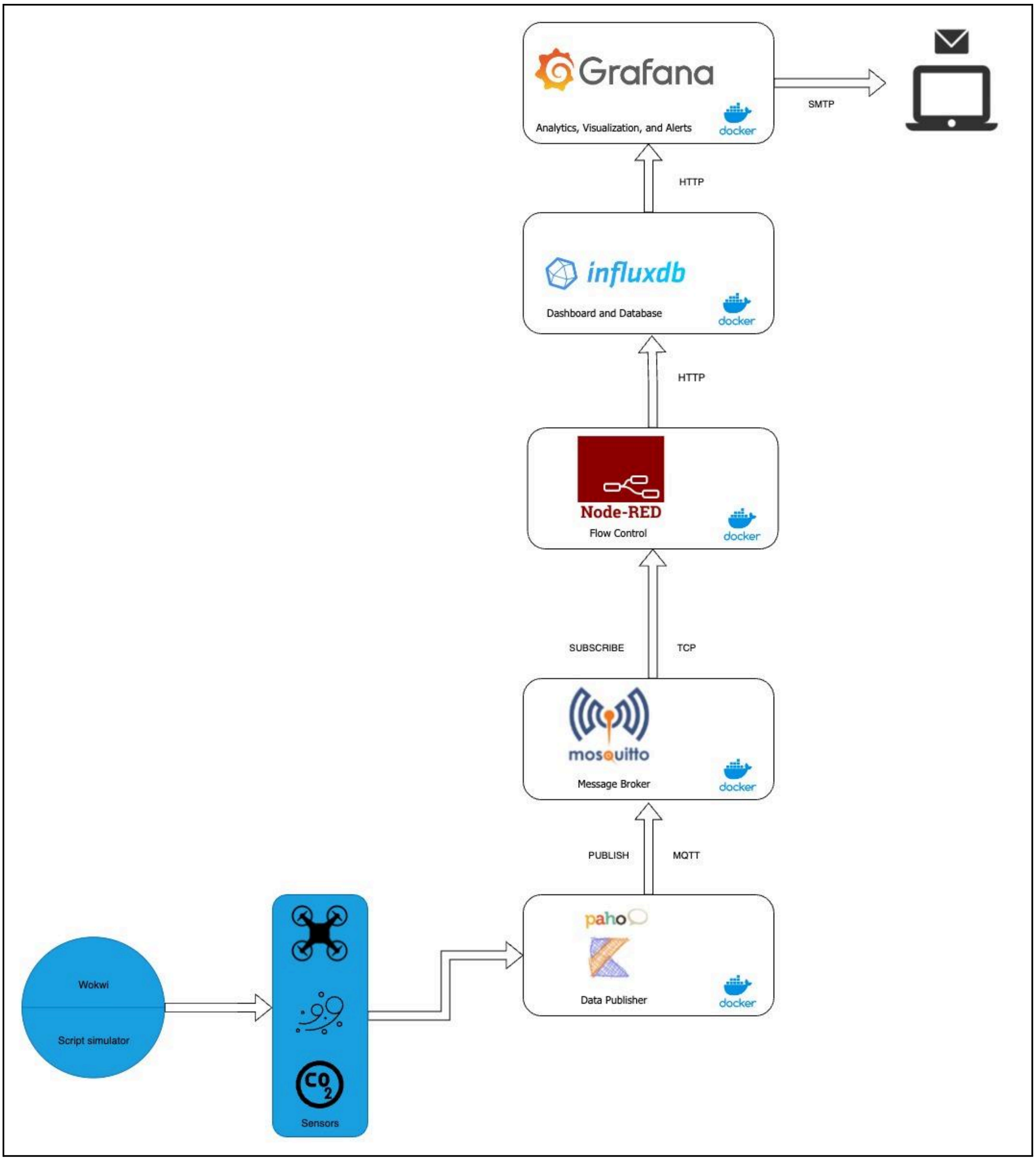
The SMTP Server configuration in Grafana (more details found [here]) allows for automation in the alert task, providing information, and interacting with end-users in a democratic and accessible manner. For our solution, we created a contact endpoint on Grafana which will enable us to receive notification on email. The alerts will 'fire' an email upon receiving data from the endpoint in case of abnormalities received from the sensors.

Docker:

Docker is a platform that enables the deployment of applications in containers. Containers provide isolation and reproducibility, allowing developers to build and deploy applications with confidence. The various components of our Wildfire Detection System are containerized using Docker and thus can be composed, replicated and deployed easily.

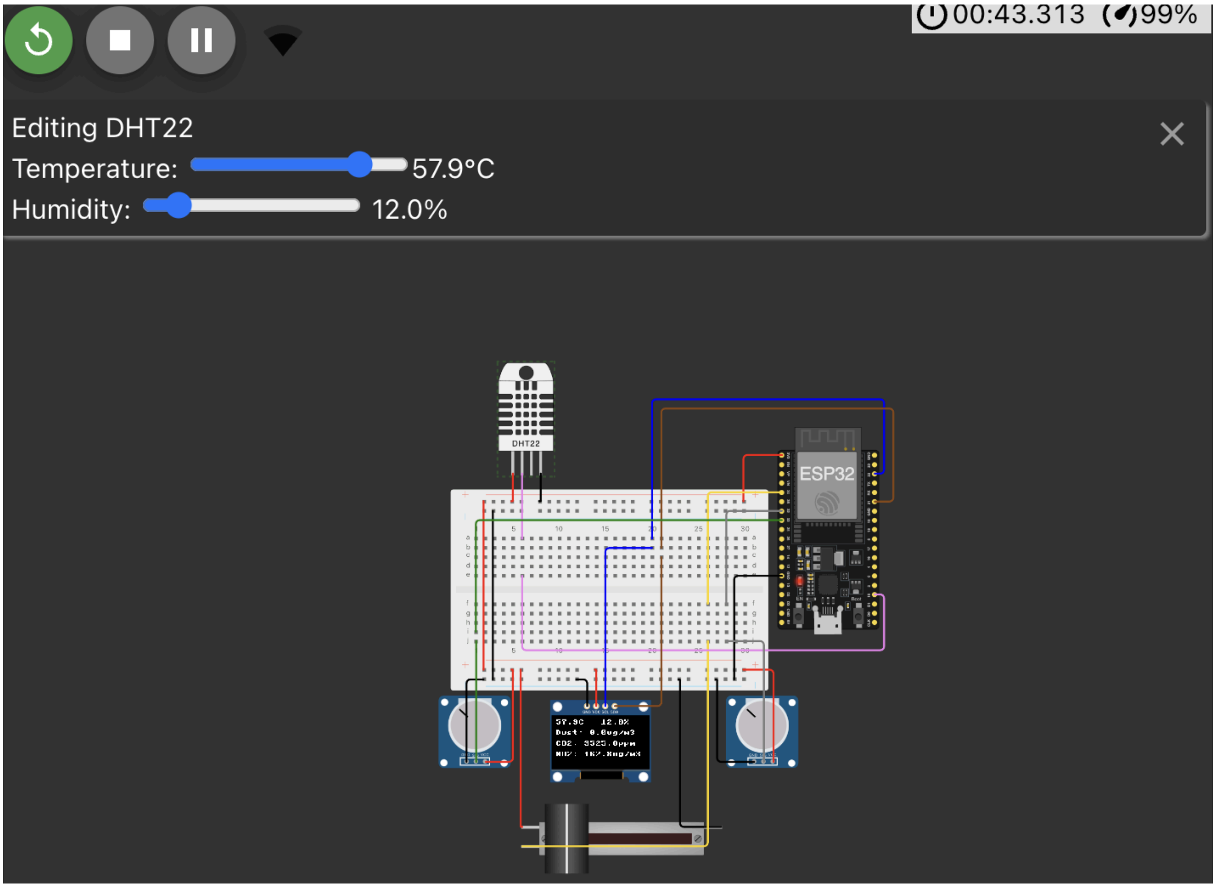
SYSTEM ARCHITECTURE:

The following diagram shows our wildfire detection IoT using AQ analysis system architecture and the technologies used.



ADDRESSING REQUIREMENTS:

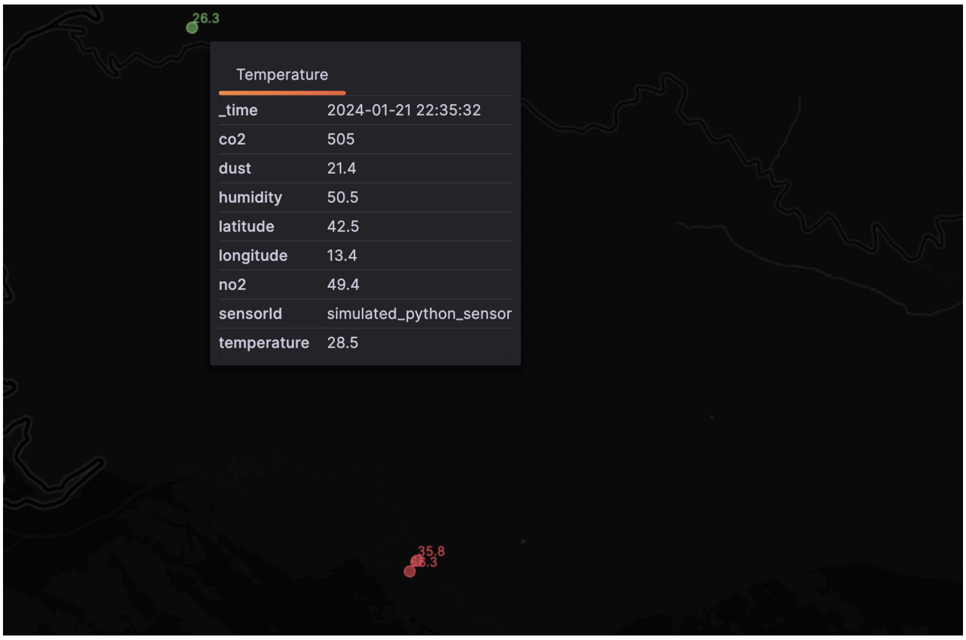
To illustrate how our solution addresses the functional requirements, air quality data from two different sensors, from two different data sources, are considered. They are named as follows: **simulated_python_sensor** and **wokwi_sensor**.



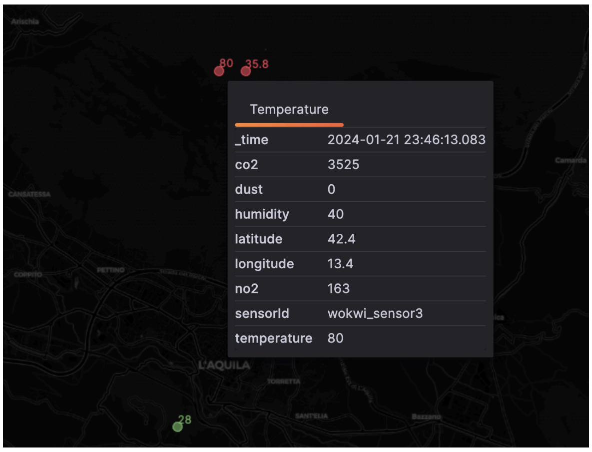
In the figure above, the Wokwi project simulates an ESP32 microcontroller that controls sensors and simulated sensors in real-time. Temperature and humidity sensor (DHT22) is on the top left. Potentiometers (simulated sensors) at the bottom can be used to adjust the simulated values of the CO2, NO2, and Dust that are sent to InfluxDB and visualised in Grafana.

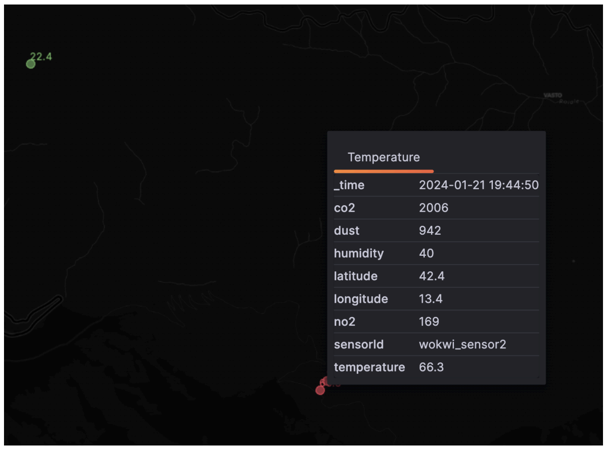
Monitor and aggregating the data from the simulated_python_sensor and wokwi_sensor sensors:

The figure below depicts the values of **parameters** from the data source 'simulated_python_sensor' on Grafana visualisation.



Using the Wokwi project as another data source, we can test the scalability of our system by adding 2 other drone sensors as depicted below, **wokwi_sensor2** and **wokwi_sensor3**.

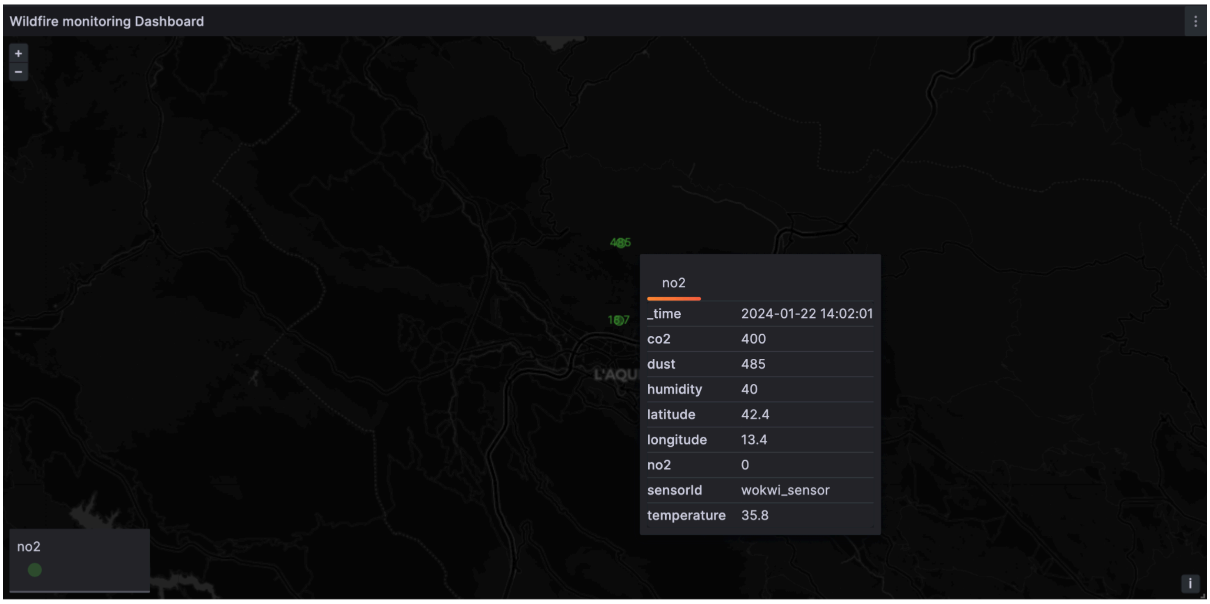




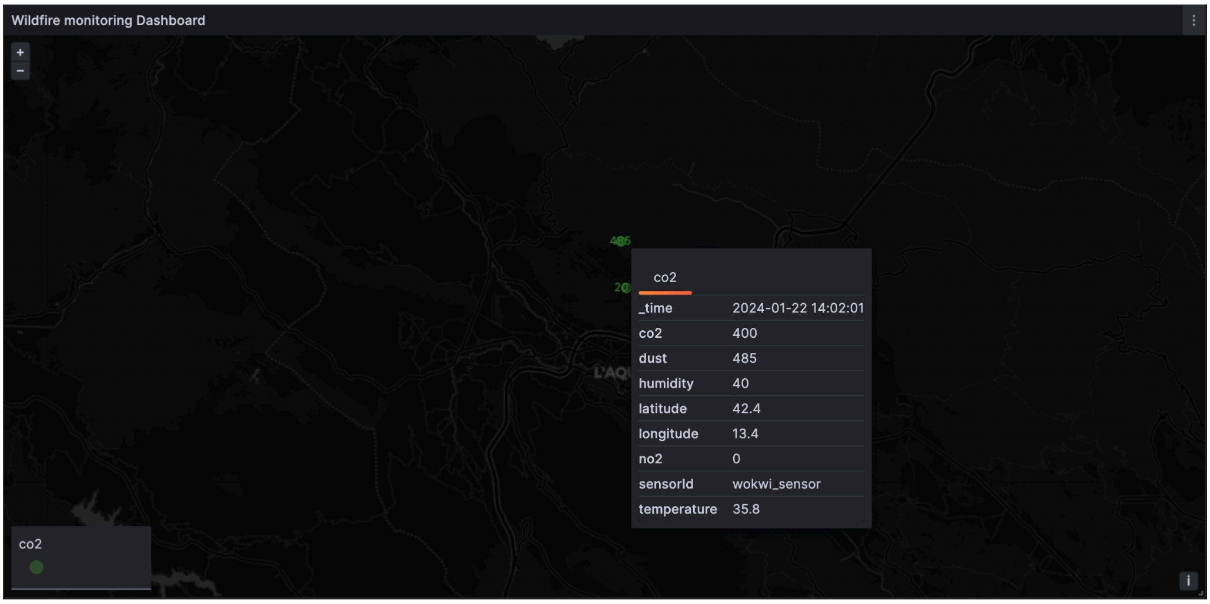
Visualise data from each source:

We use Grafana for creating Dashboards which enable the administrator to easily visualise the data which is being received from the sensors. Grafana uses InfluxDB as a datasource for obtaining temperature, CO2, NO2, coordinates, and PM data from the data sources and displays them as different forms of graphs.

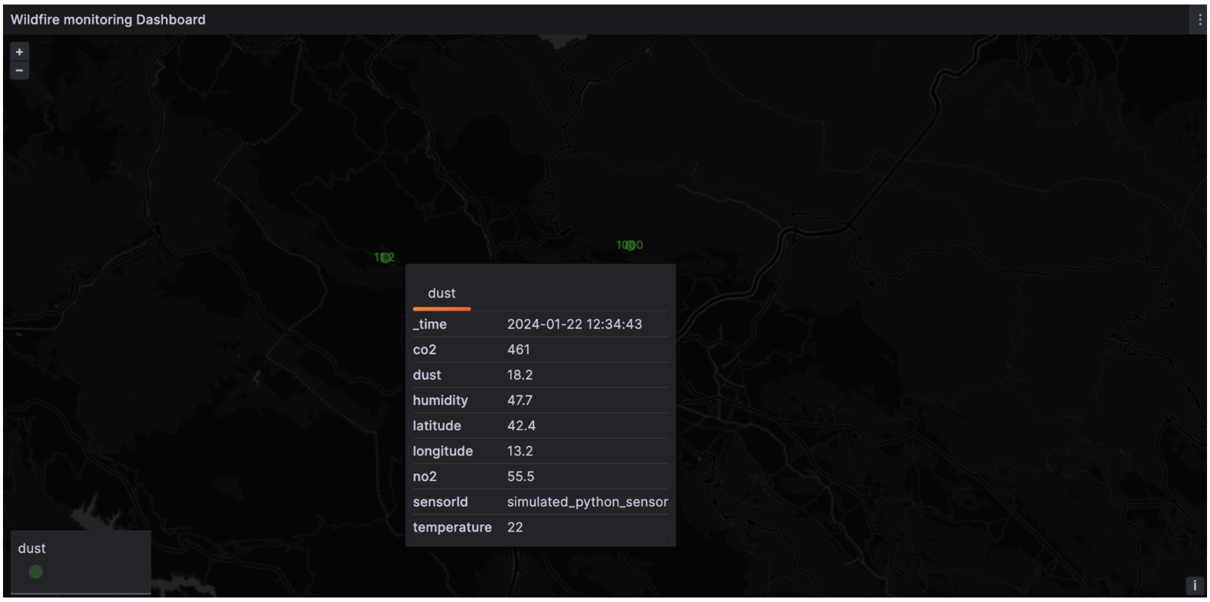
The figure below shows the NO2 Monitoring section of the dashboard and visualises the different temperature values in varied colours to be analysed by the admin:



The figure below shows the CO2 Monitoring section of the dashboard and visualises the different temperature values in varied colours to be analysed by the admin:



The figure below shows the PM Monitoring section of the dashboard and visualises the different temperature values in varied colours to be analysed by the admin:



Send alerts to the administrator of the IoT-based wildfire detection system using Air Quality analysis:

We also make use of Grafana's SMTP server configuration for alerting capabilities to inform the administrator in case of abnormal readings from the sensors in the monitoring data sources. We selected the SMTP functionality inbuilt in Grafana to send emails about anomalies in the parameters (Temperature, PM, NO2, CO2, Coordinates).

The below emails are received upon anomalies in the air quality and sudden stoppage of data from the sensors. The alerts are essentially rules for establishing thresholds to the system set in Grafana so that it can fire an alert to the Admin if the value of a parameter exceeds the set threshold.

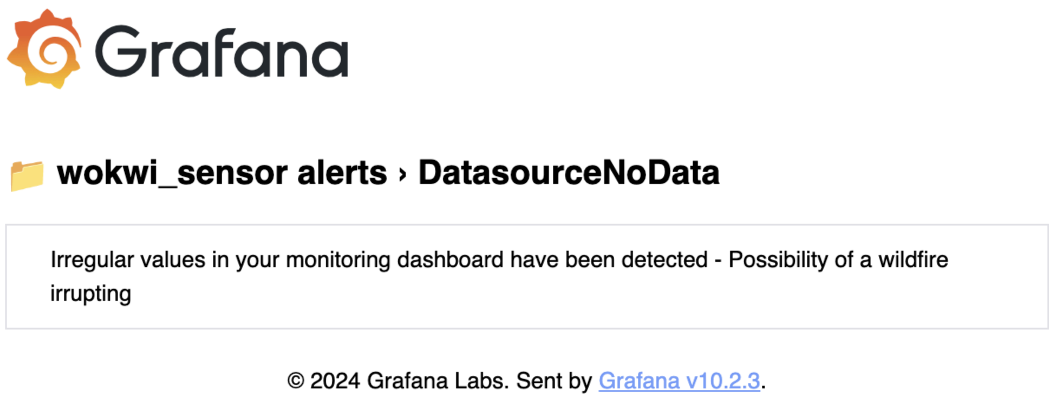
Grafana

📁 **Grouped by**

alertname=TestAlert instance=Grafana

Irregular values in your monitoring dashboard have been detected - Possibility of a wildfire irrupting

Above figure is an email alert from the anomalies in the air quality parameters, which signify potential eruption of a wildfire.


Grafana

wokwi_sensor alerts › DatasourceNoData

Irregular values in your monitoring dashboard have been detected - Possibility of a wildfire irrupting

© 2024 Grafana Labs. Sent by Grafana v10.2.3.

Above figure is an email alert from the stoppage of data from a sensor which either signifies serious wildfire causing damage to the IoT device or malfunction due to other factors.

REFERENCES:

1. https://www.bbc.com/news/world-australia-52804348

2.https://fire.airnow.gov/

3.https://blueskyhq.io/blog/predicting-wildfires-techniques-and-tools-for-monitoring-and-mitigating-risk

4. https://www.fs.usda.gov/research/treesearch/45727

5.https://www.carbonbrief.org/qa-how-scientists-tackle-the-challenges-of-estimating-wildfire-co2-emissions/