GAIAthon

AFRIBOT Fire Patrol

Fire Detection and Monitoring System

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ABSTRACT

Through this project we aim to establish and build an autonomous vehicle that constantly monitors and record data to estimate potential risks relating to forest and agricultural fires. Battling potential wildfires, before they could occur by constantly monitoring and determining locations that are high risk, using sensors that constantly record and send their data to the cloud.

Afribot aims to achieve its goal by Recording temperature, humidity and gas trends in the area to accurately predict potential fires in the designated area of surveillance covered by Afribot. The vehicle will act as an authority alerting device that sends the exact location of the fires using GPS or if there is any other irregular phenomenon occurring in the monitored area.

The main aim is to create a safe environment for nature reserves, agricultural lands and forests by constantly monitoring and sending the data to the party responsible and immediately alerting the authorities to any possible dangers.

INTRODUCTION

Wildfire poses a significant threat to the environment, agriculture, and nature reserves particularly in agricultural areas where losses could be exponential. Seasonal droughts, extreme weather and climate change are the major causes for wildfire outbreaks in Africa. Which pose huge risks to the livelihood of farmers and caretakers of natural reserves.

Traditional methods of fire monitoring, such as watchtowers and foot patrols, are slow, time-consuming, and ineffective in guarding extensive, inaccessible regions. To combat this issue and to reach the root location of the fires we need fast and constant monitoring of high-risk areas. And to have areas of high importance under surveillance that is automated and eliminates possible human errors.

Figure.1- photo of recent wildfire, that could have been reduced by early detection

There is a need for early warning and rapid response to minimize environmental effects, protect wildfire, and prevent loss of life and property. Therefore, creating an autonomous vehicle that constantly monitors the area and gives constant wireless feedback to measure and record the data history of the area predicting and alerting the authorities if potential fires will occur in the designated area.

The system consists of a team of autonomous, mobile sensor nodes with flame, smoke, temperature, and humidity sensors. Information is transmitted through the ESP32 microcontroller, with visual feedback on fire occurrences given by the ESP32-CAM. A GPS module gives location tracking accurately, and an onboard sprinkler system gives preliminary extinguishing of fires while the authorities are notified. By combining real-time monitoring with automated response, this solution aims to improve wildfire prevention and management efforts across Africa's wildlife and agricultural ecosystems.

CASE STUDIES

Egypt

Fire destroys 10 acres of farmland in Egypt's Siwa Oasis

A fire at Egypt's Siwa Oasis destroyed 10 acres of agricultural land, damaging farmers in the region. The cause is under investigation, but high heat and poor control of blazes are potential factors. *https://english.ahram.org.eg/News/99751.aspx*

Massive Fire Destroys 5 Acres of Farmland in Egypt

Another report on agricultural fires in Egypt, where 5 acres of crops were lost. Such incidents highlight growing fire risks in arid regions due to climate change and human activities.*https://waradana.com/english/article/151885-massive-fire-destroys-5-acres-of-farmland-in-egypt-video*

The Rest of Africa

1) *Madagascar on Fire: Climate Change the Arsonist*

- This article discusses the devastating wildfires in Madagascar, exacerbated by climate change and human activities. Fires have threatened biodiversity hotspots like Ranomafana National Park, raising concerns about long-term ecological damage.

2) UNESCO Reports on Central Africa’s Peatlands at Risk

- UNESCO highlights the threats to the Congo Basin’s peatlands, one of the world’s largest carbon sinks. Increased fires and deforestation endanger these vital ecosystems, which play a crucial role in global climate regulation.

3) BBC: Congo Basin Rainforest Fires Surge

- The BBC reports a sharp increase in wildfires in the Congo Basin rainforest, driven by land clearing and climate change. Scientists warn of severe consequences for biodiversity and carbon storage if the trend continues.

3.2.4 Libya

The 2023 fire season in Libya was quiet. 11 fires were mapped, resulting in a total burnt area of 417 ha between April and August. Table 88 presents the distribution of the mapped burnt area by land cover type using the Globcover land cover map, harmonised with CLC.

Table 88. Distribution of burnt area (ha) in Libya by land cover types in 2023.

Land cover	Area burned	% of total
Broadleaf forest	22	5.3
Mixed forest	222	53.1
Other Natural Land	147	35.2
Agriculture	27	6.4
TOTAL	**417**	**100**

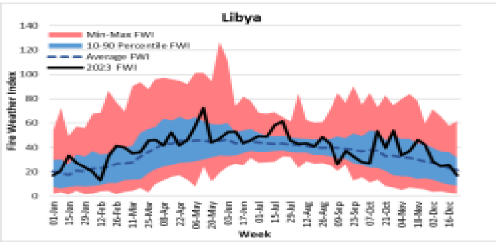


Figure 340. Fire weather Index information for Libya.

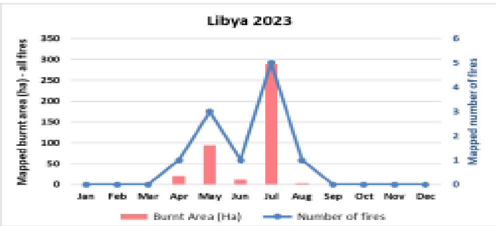


Figure 341. Monthly mapped burnt area and number of fires in Libya in 2023.

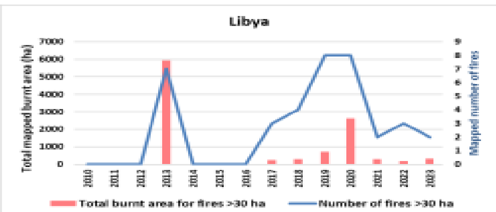


Figure 342. Annual mapped burnt area of fires ≥ 30 ha in Libya.

3.2.5 Morocco

After a hard season in 2022, the 2023 fire season was closer to average. 92 fires were mapped, resulting in a total of 8 127 ha burnt. Most of the fires occurred in July and August, including the largest of the year, over 2 500 ha in Aklim region. Three other fires exceeded 500 ha.

Table 89. Distribution of burnt area (ha) in Morocco by land cover types in 2023.

Land cover	Area burned	% of total
Broadleaf forest	3858	47.5
Coniferous forest	1508	18.6
Mixed forest	453	5.6
Other Natural Land	265	3.3
Transitional	1299	16.0
Agriculture	733	9.0
Other Land Cover	10	0.1
TOTAL	**8127**	**100**

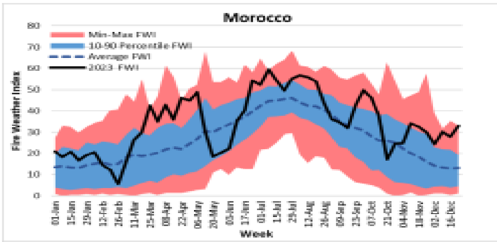


Figure 343. Fire weather Index information for Morocco.

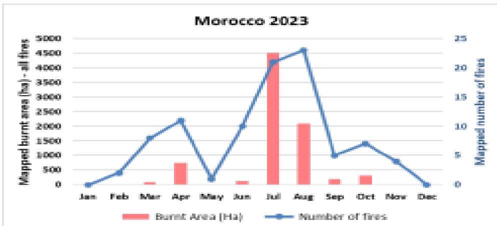


Figure 344. Monthly mapped burnt area and number of fires in Morocco in 2023.

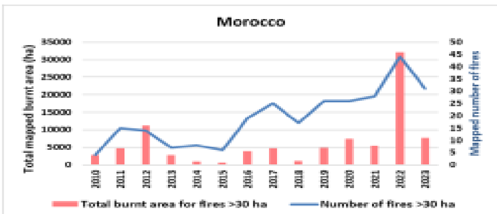


Figure 345. Annual mapped burnt area of fires ≥ 30 ha in Morocco.

Figure.2- statistics showing the increase in wildfires in Libya and Morocco

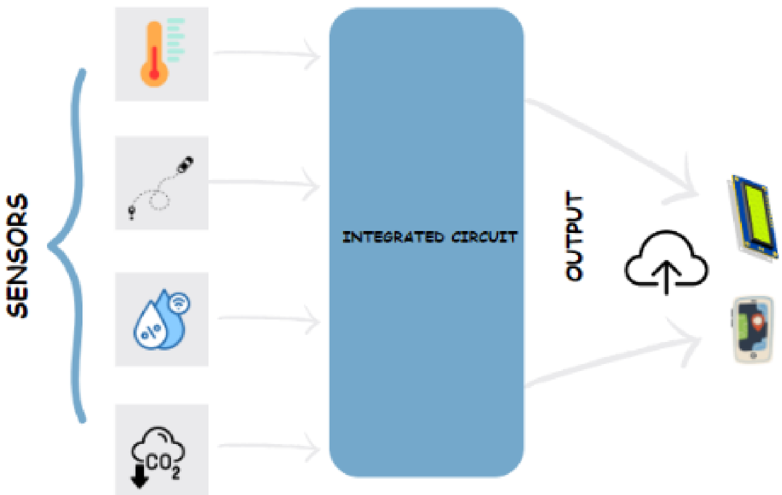
The massive increase in wildfires due to climate change and overall higher global temperatures need to be fought against. Therefore, a solution by providing a way to constantly monitor and assess the critical areas and the endangered areas of wildfire constantly and immediately alert the authorities and providing an initial solution before the wildfire increases in size and becomes an even bigger issue.

METHODOLOGY

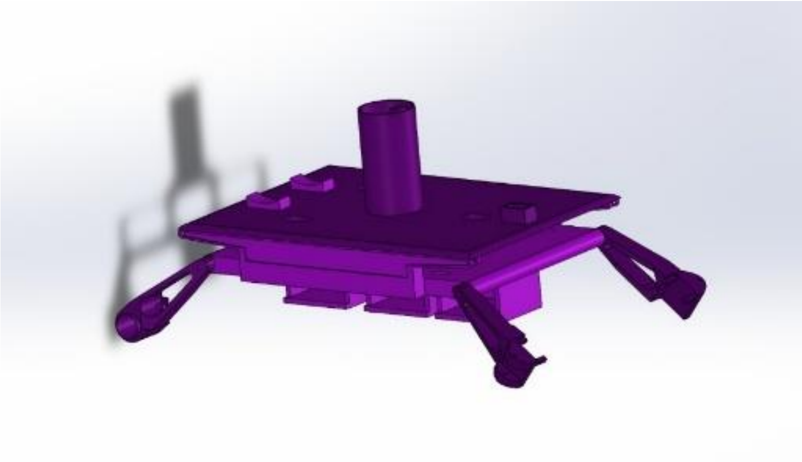
This section of the report outlines the development process of the project. A systemic approach was followed for this part. The first hurdle to overcome was to achieve high-end reliable output with minimalistic cost and accurate output from lower cost sensors and actuators. Secondly, to construct this project to be able to navigate complex agricultural and forest environments with many unexpected obstacles.

Achieving the intended goal of providing accurate and precise readings from the sensors, measuring the values for CO2 levels, temperature and humidity. While complying with the budget standard to accomplish our main objective. Operating with sensors such as MQ2, DHT11 which are multipurpose sensors that record multiple environmental parameters simultaneously.

For operating the sensors and the vehicle it is essential to have actuators that are used precisely to achieve their intended use. Pump, encoded motors, and servo motors operate synchronously to drive and operate the vehicle autonomously and simultaneously change their activation according to the sensor readings.



Using SolidWorks, a custom chassis was modeled to solve and overcome the unpredictable terrain of agricultural soil and forest environment. This would help since having a custom-built car will give us freedom and flexibility to place the components in the order and orientation that will be seen fit while allowing creative freedom for further improvements to the project.



TECHNICAL APPROACH

To have a continuous monitoring system that covers are large area and that sends the exact location where the fire started, we need to build a vehicle that travels and transmits its exact location, as well as constantly transmitting the sensor data to the cloud, where its accessible from anywhere in the world.

We need to know the logic of the system first to deploy it into real life sensors and actuators, to easily determine the logic of the system, we need to create a flowchart depicting the main flow of the system and what is the response for each circumstance.

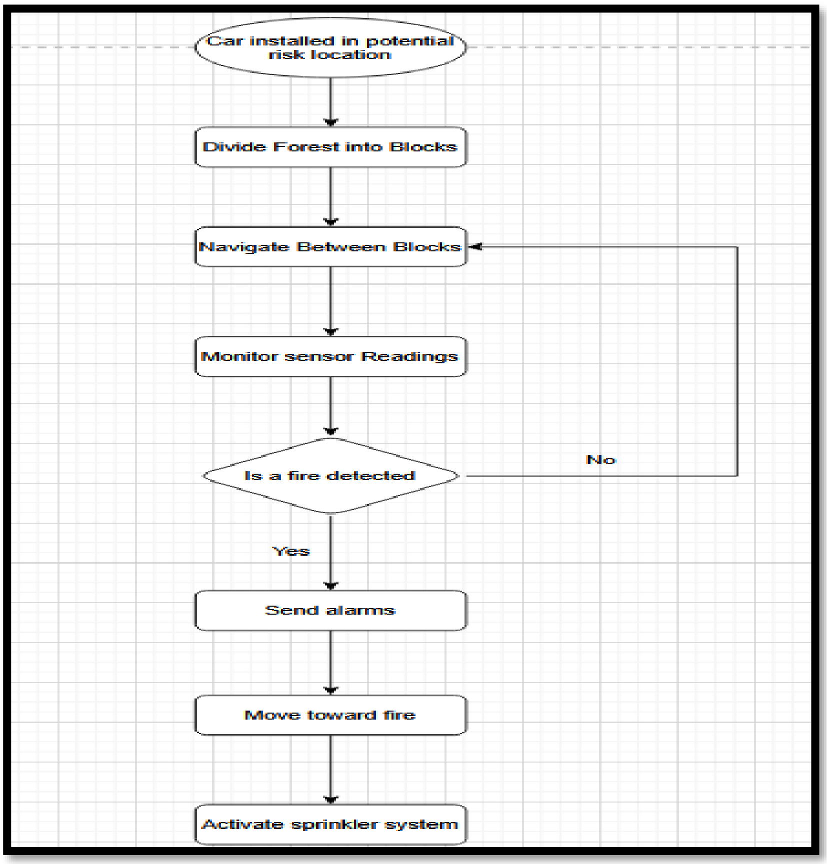


Figure.3- Flowchart of the logic

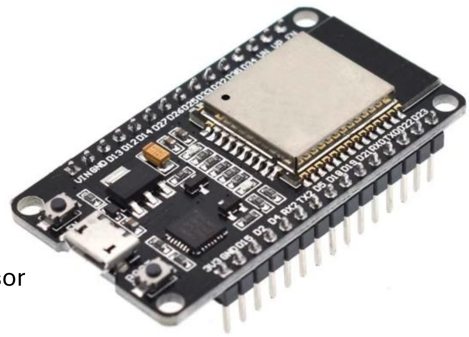
The BRITISH UNIVERSITY IN EGYPT

Following the logic of the flowchart we can determine the components, and the software needed to implement this project in real life.

Components and Sensors

1) Esp32S

The ESP will be used as the main microcontroller and the brain of the project, all the sensors will connect to the ESP and the ESP will send the sensor data and information to the web(ubidots), to be displayed wirelessly.



- Supply Voltage: 2.2 V ~ 3.6 V
- Frequency: 2.4 GHz
- Ultra-low-power management
- 4 MB Flash
- Data Rate: 54 Mbps
- Processor — Tensilica Xtensa® Dual-Core 32-bit LX6 microprocessor
- Wi-Fi: 802.11 b/g/n (2.4GHz)
- Bluetooth: Bluetooth v4.2 and Bluetooth Low Energy (BLE)
- ADC Pins: 18 (Analog-to-Digital Converter)
- UART, SPI, I2C, I2S, CAN Interfaces: Available for communication with other devices

2) DC Motor GA25-370 with Encoder 4.4kg 130RPM 12V with Bracket

The motors will be the main driving force of the project, and they will control the speed of the vehicle, as well as send the encoder data to the ESP to be displayed on the dashboard.

- Nominal voltage: 12 V
- Free-run speed at (12 V): 130 RPM
- Free-run current at (12 V): 0.07A
- Rated speed at (12 V): 100 RPM
- Rated current at (12 V): 0.3A
- Rated load torque at 12 V: 0.9 kg.cm
- Stall current at 12 V: 1.8 A
- Stall torque at 12 V: 4.4 kg.cm
- Gear ratio: 1:(46.8)

3) ESPCAM

ESP32-CAM is a small, low power camera module from ESP32 WIFI development board. It supports OV2640 camera, that will capture the front of the vehicle and display live feed of what is always in front of the vehicle.

Features:

- Onboard ESP32-S module, supports Wi-Fi + Bluetooth
- OV2640 camera with built-in flash lamp
- Onboard microSD card slot, supports up to 4G TF card for data storage
- Supports Wi-Fi video monitoring and Wi-Fi image upload
- Supports multi sleep modes, deep sleep current as low as 6mA

4) 12VDC pump

The Pump will be used to pump the anti-fire liquid from the Tank and to through the sprinkler system.
Features:

- Working voltage: DC 12V
- Working current: 0.5-0.7A
- Maximum suck range of 2m.
- The maximum head range of 3m.
- Operating Temperature: 5ºC to 40ºC
- Operating Water Temperature: 5ºC to 45ºC
- The maximum flow rate of up to 1 – 3L/min.

5) *Flame Sensor 1 channel*

The flame sensor is essential in detecting if there is a flame in the area mentioned, this sensor will send the signal to esp32 if any flame is detected.

Features:

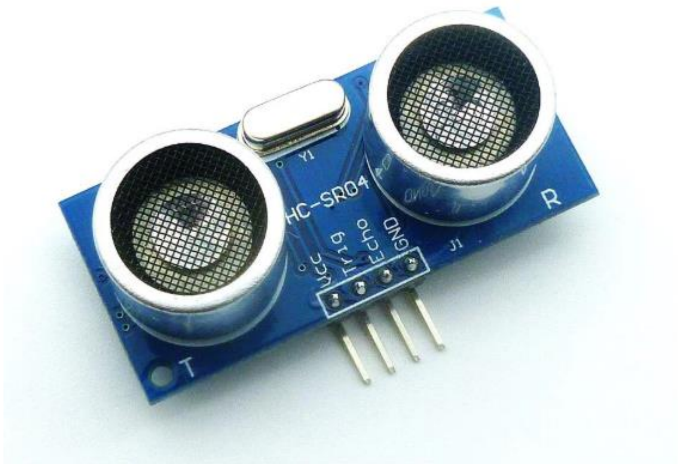
- Sensor for flame wavelengths between 760 nm to 1100 nm infrared is most sensitive
- **analog output**, real-time output voltage signal on the thermal resistance and D.
- **digital output** when the temperature reaches a certain threshold, the output high and low signal threshold adjustable via potentiometer.
- Detection Distance Up To 100 cm (indoor)
- Detection angle: About 60 degrees, particularly sensitive to the flame spectrum
- Adjustable sensitivity (potentiometer adjustment)

6) *Ultrasonic Sensor*

The ultrasonic sensor is used for obstacle avoidance, and to swerve if there is anything that is blocking the path of the vehicle.

Specifications

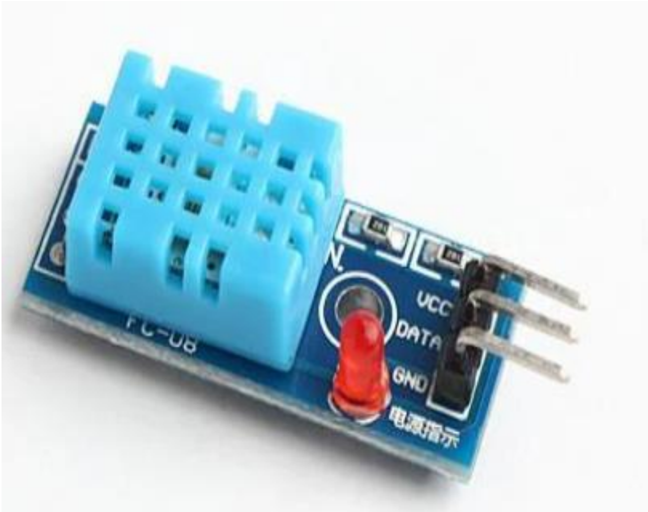
- Power supply: 5V DC
- Quiescent current: <2mA
- Effectual angle: <15°
- Ranging distance: 2cm – 400 cm
- Resolution: 1 cm
- Ultrasonic Frequency: 40k Hz



7) DHT11 (Temperature and Humidity Sensor)

DHT11 Temperature & Humidity Sensor. It features a temperature & humidity sensor complex with a calibrated digital signal output.

This will be used to send the temperature and humidity signal to the ESP32, to be displayed in real-time in the dashboard.



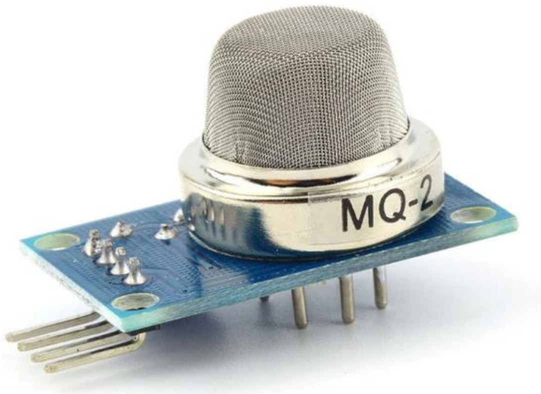
8) MQ-2

The MQ-2 sensor is a versatile gas sensor capable of detecting a wide range of gases including alcohol, carbon monoxide, hydrogen, isobutene, liquefied petroleum gas, methane, propane, and smoke.

Any increase in the following gases can result in a potential fire risk
Therefore, any increase will be met with warning signs in
The dashboard.

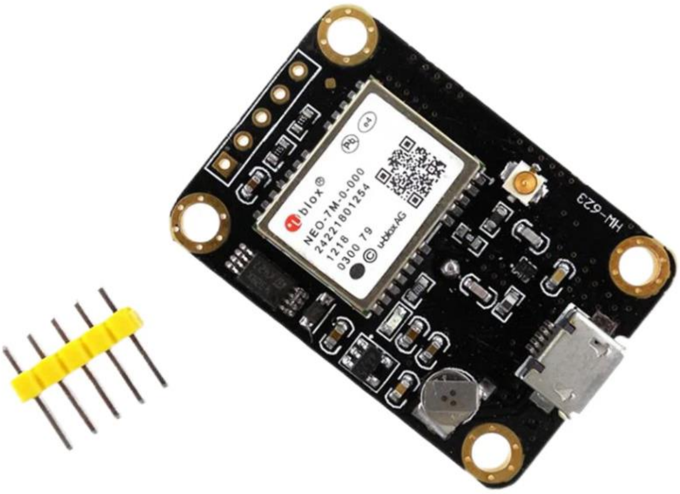
<u>4 pins as follows:</u>

- VCC (5 V)
- GND (ground)
- A_{out} (Analog output)
- D_{out} (Digital output)



9) GPS

The GPS module will be the base of the project as we will be able to locate the vehicles' location through the GPS module. The GPS module will send the vehicle's coordinate to the ESP which will in turn be sent to Ubidots to display the vehicles' location on a live map.



Connections

Main microcontroller (ESP32-S)

The ESP32 holds the connections for:

- 4 flame sensors: The 4 flame sensors are connected to detect flames (if any) and is stationed on a servo motor to rotate to make sure it reads in 360 degrees to check for fire in any direction.
- 2 Motor drivers (4 motors): The motor drivers are connected to the ESP (IN1 IN2) where making one pin high and the other low dictates the rotation direction and both low means stop (Note: Both cannot be high, or the motor would be damaged severely)
- PWM control for all wheels: The PWM pin for all wheels (from motor driver) are utilized to control the vehicle speed.
- An encoder: to tell the speed of the car as feedback to make sure the speed is the one required
- GPS module: To always have real time monitoring of the car's location at any time from any place by using ubidots.
- Relay EN (pump): 5V relay is used to control the pump as desired where the pump is connected to 12V, and the relay is enabled by 5V
- servo motors: the servo motor was already mentioned for the 4 flame sensors

Detection system microcontroller (ESP32-cam)

The ESP-cam holds:

- 3 IR sensors: Each IR is responsible for a side to read (Right, Left and middle)
- Ultrasonic sensor: Measures distance to make for an ideal obstacle avoidance

- Servo motor: to rotate the ultrasonic to scan for obstacles, it rotates from home position (0) to far left (+90) and then far right (-90). On code start it always goes back to home position
- Camera: Built into the ESP32-cam, it is used to get real time monitoring of what the car is doing. The video of the camera can be viewed by double clicking the ubidots map location to show you the footage of the camera live.

Power supply (Batteries)

The batteries used to power this system are 3 12V 3A batteries which are rechargeable and easy to disconnect since they are all placed externally and in a compartment under the car for easy access and simple removal.

Software Implementation and Data Flow

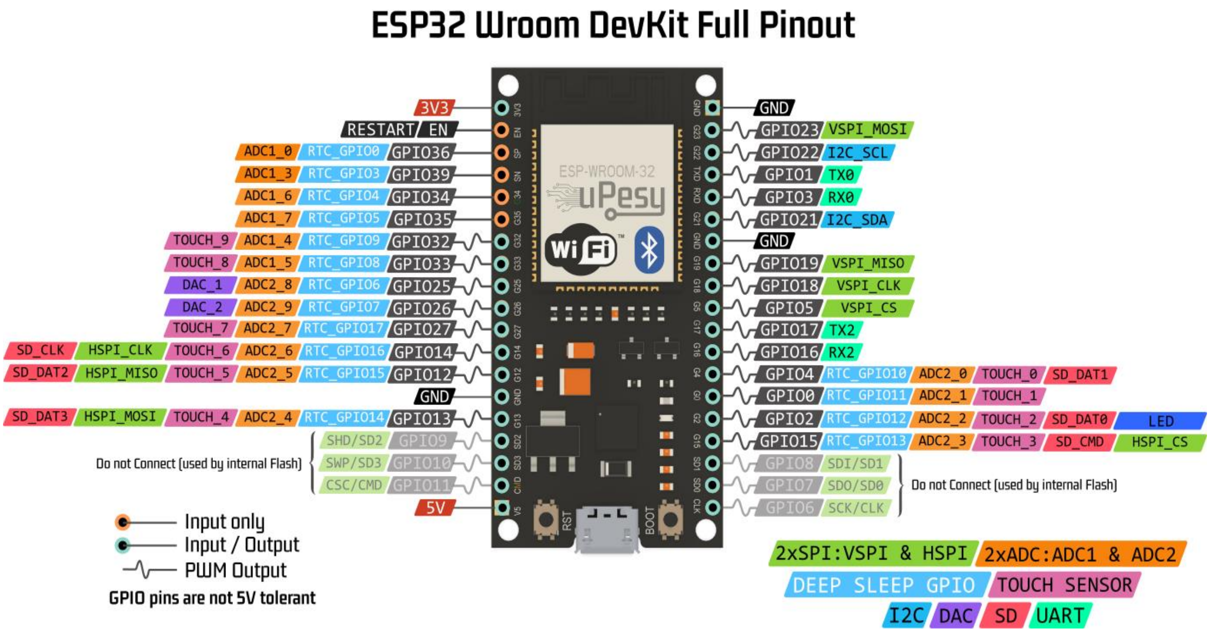
This section explains the overall structure of our IOT system, detailing how the software interacts with the hardware components. Exploring the connection between sensors and their collect data, and how that data is transmitted to Ubidots, platform for processing and actuation. The aim of the software system is to monitor temperature, humidity and flame detection which will allow for detection of fires and abnormal conditions. After that the sensor readings will be used to alert governments so they can take immediate actions and prevent casualties.

Data Collection

There are three ESPs: two ESP 32-s and the ESP32 with a camera. Each ESP is connected to sensors for collection of data. Analog sensors are connected to analog pins that have been built in ADC or Analog to Digital converter. This ADC converts the input continuous signal to a discrete signal which is better for accuracy and further processing of data because digital signals are less prone to noise and have higher precision and reproducibility.

Each ESP monitor different types of data, for example the ESP with a camera will be connected to a flame sensor that detects flame and fire in different directions. The other ESP is the main ESP which will be used for actuation and control of devices like pumps and motors. Also, it will be connected to other sensors like ultrasonic sensors which are used for the maneuvering of the car and obstacle detection. In addition to that This ESP will receive data from the other ESP and interface both its data and the received data on an external dashboard for visualization and decision making.The third

Esp will be connected to the ESP32-s through UART connection to send and receive data from the ESP32-s and update the corresponding variable in the dashboard.



Communication between ESPs

The system follows a bidirectional IoT communication system between two ESP32 boards and the Ubidots cloud platform with the help of MQTT for real-time communication and HTTP for supportive requests. The first ESP32-s (Robot Controller) sends the received signals to the other ESP32-s through UART communication. The received signal is then processed and sent to the dashboard using MQTT protocol. At the same time this ESP will receive signals like the flame condition signal from the other esp32 with camera and turn the pump on or off based on the received data. Also, this ESP is connected to a gps Module using UART communication, it sends the longitude and latitude values to the ESP and then pin the current location on a map on an external local server using a specific predefined IP address and the location is updated continuously. The ESP32 with camera is a publisher device, continuously publishing sensor data (temperature, humidity, flame detection) to Ubidots via MQTT protocol. It also uses HTTP GET requests to fetch the current IR sensor readings from Ubidots on demand for real-time obstacle avoidance. Both modules employ Ubidots as the main MQTT broker, allowing seamless cloud-based coordination—where the first device reacts to the second device's published sensor data, creating a closed-loop control system. The architecture allows for low-latency, real-time interaction between the robot and the environment while still providing remote monitoring via the cloud. Moreover, the third ESP receives a user-defined speed from Ubidots and sends the received data to the other ESP through UART and adjust the speed of the motors accordingly.

Pager

Until now, the data has been sent and received via the dashboard and is available for anybody to monitor the area including governments and people. But in some areas , where cell phones or real-time online monitoring are not available, people need to be notified about the current condition in the area to react in case of emergencies. The basic working principle of the pager is that it receives sensor readings and flame condition from the dashboard and displays the received data on an LCD for visualization. Also, it is connected to buzzer to alert people or companies to start the evacuation immediately and act as soon as possible. Another advantage of the pager is that it is not fixed to a certain location and can be accessed or used from anywhere in the world.

Interfacing with Ubidots and data processing

Now ESP32-s has received data from the other ESP and collected some data and signals through sensors like ultrasonic and IR sensors. This data will be used for two purposes.

1. To visualize real-time sensor readings and the status of system components and actuators.

2. To use this data for control of devices like the pump and the motors.

For example, if a flame is detected by the ESP, it will send the signal to the ESP32-s. The ESP32-s will actuate the pump to try to suppress the fire through the activation of a sprinkler system. At the same time, the readings will be visualized on the Ubidots dashboard and will show the current condition of the area, and the color of the indicator will change from green to red, and a map will show the current location of the car. Finally, on the dashboard we will set an action to be taken after fire is detected, notifications will be sent to the governments and authorities to alert them about the fire and alert them of the fire and the location of the fire.

Location of the fire will be determined using the NEO-7m GPS module. The GPS module will send current coordinates of the car to the authorities which will help them in decision-making and evacuation of nearby populated areas.

In addition, the data captured by the system is stored on Ubidots for future analysis for experts and the system itself (if Ai is integrated) to study the data and learn from past events

Dashboard

The cloud-based IIOT platform that we used in this project is Ubidots. Ubidots will be the cloud in which our microcontrollers will send and receive real-time data from the sensors. The cloud platform is essential to visualize our sensors data and display the map and camera connected to the vehicle.

Ubidots was selected for its capability to integrate up to 10 variables.

Variables in Ubidots are the core elements used to store data from your IoT devices. A variable represents a specific piece of real-time sensor data, such as temperature, humidity, or GPS coordinates. These variables belong to a device and collect timestamped data points, known as "dots." By storing historical data, variables enable you to monitor, analyze, and visualize trends over time using Ubidots dashboards.

Ubidots being the main cloud of this project was a great choice as the data transmission to ubidots was implemented by MQTT communication, and Ubidots allows us to also use HTTP communication simultaneously through different ESPs.

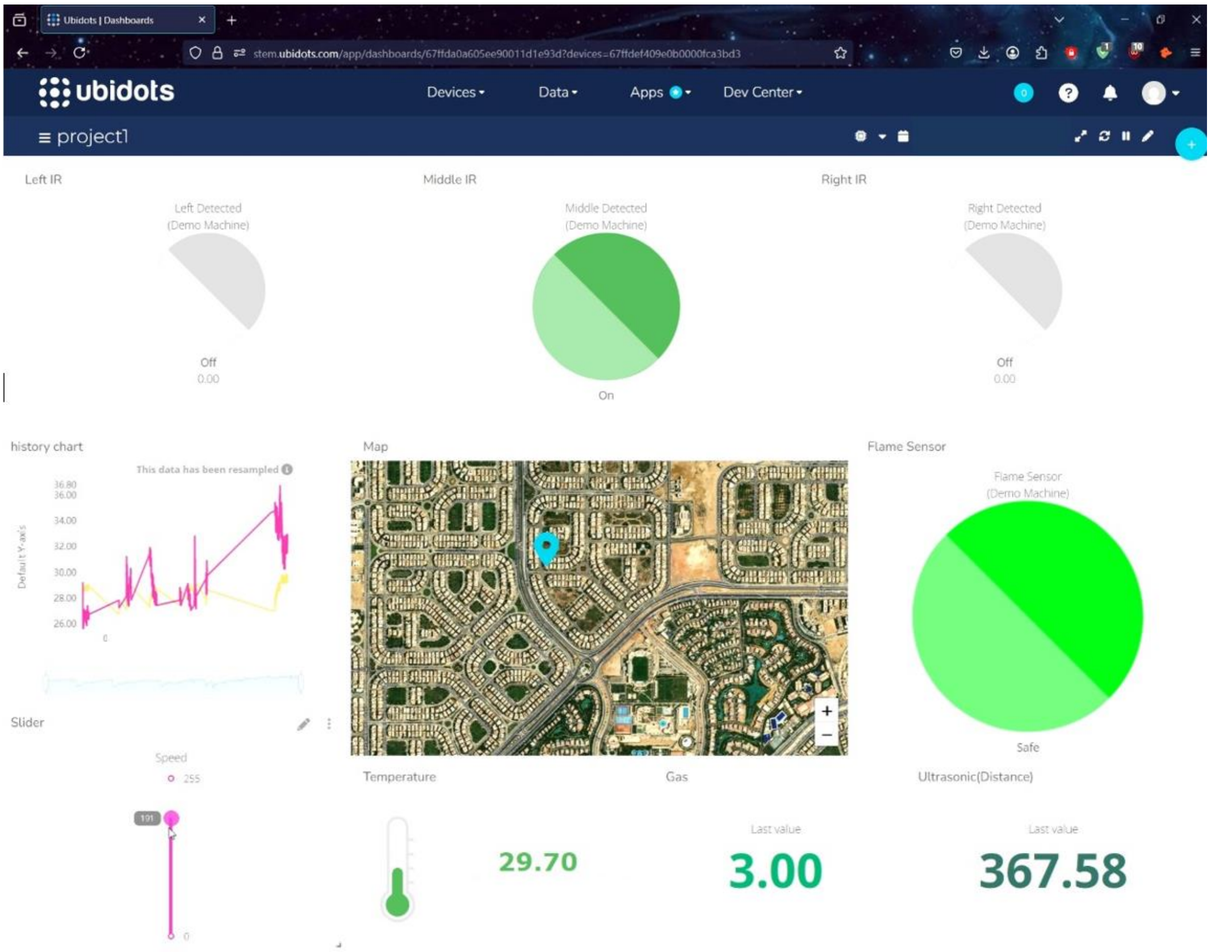
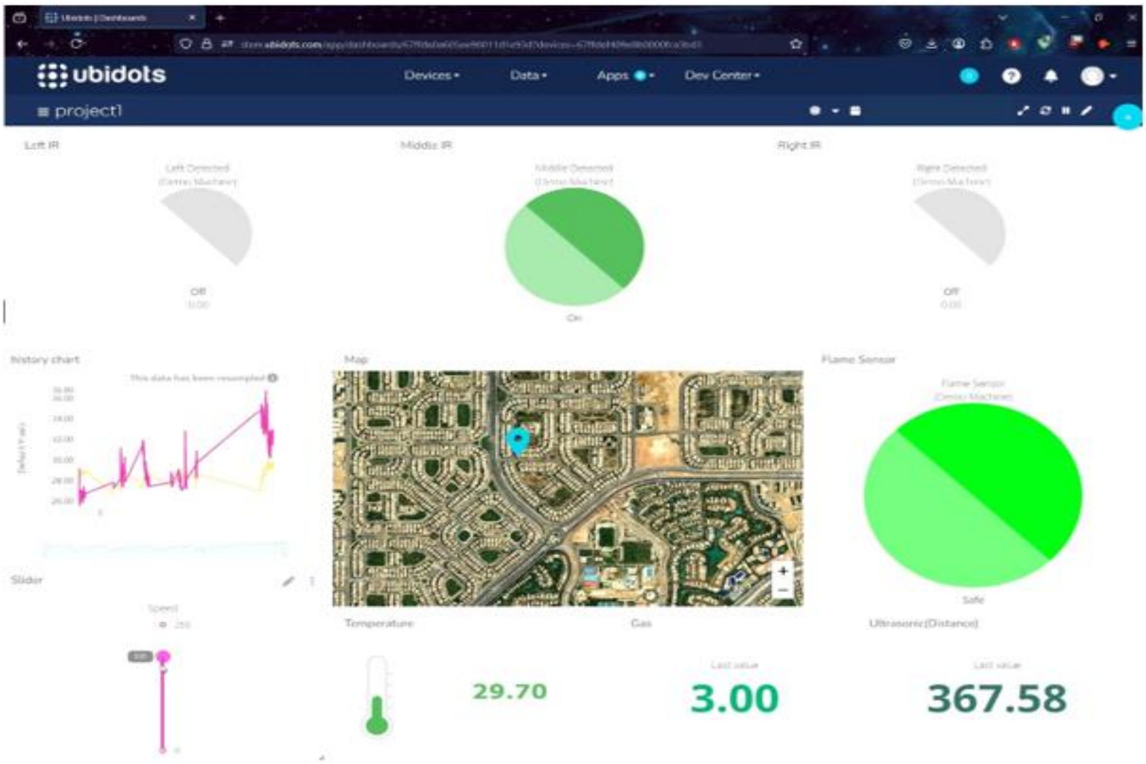


Figure.6: Dashboard for the project

RESULTS

In this project, the cloud-based IIOT platform used is Ubidots which was successfully implemented to facilitate real-time data transmission between the microcontrollers and the cloud. Ubidots served as the central system for receiving sensor data, displaying system status, and enabling responsive control of actuators. The platform also provided a user-friendly dashboard for data visualization, a live vehicle map, and camera integration.



The obstacle avoidance system is equipped with multiple components that support its functionality within the system. It includes three infrared (IR) sensors, each positioned to monitor a specific direction—right, left, and center—to aid in environmental awareness and decision-making. This is presented on the dashboard where each of the three sides is presented by green or grey indicator. An ultrasonic sensor is also integrated to measure distances, enabling effective obstacle avoidance. The value of the ultrasonic sensor reading is then displayed on the dashboard to be viewed. The dashboard is also equipped with hyperlinks to a live-feed video from the ESP-cam, and live location. The hyperlinks are a convenient solution to easily access live feed and live location of the vehicle, while still monitoring the data results on the dashboard. Similarly, a dedicated GPS webpage is accessible directly from the dashboard by (How to access GPS). This feature displays the live location of the car on an interactive map, allowing authorities to quickly pinpoint the site of the fire. In addition to emergency response, this functionality also aids in tracking and recovering the vehicle when necessary.

ESP32 GPS Location

Latitude: 30.047040, Longitude: 31.465242

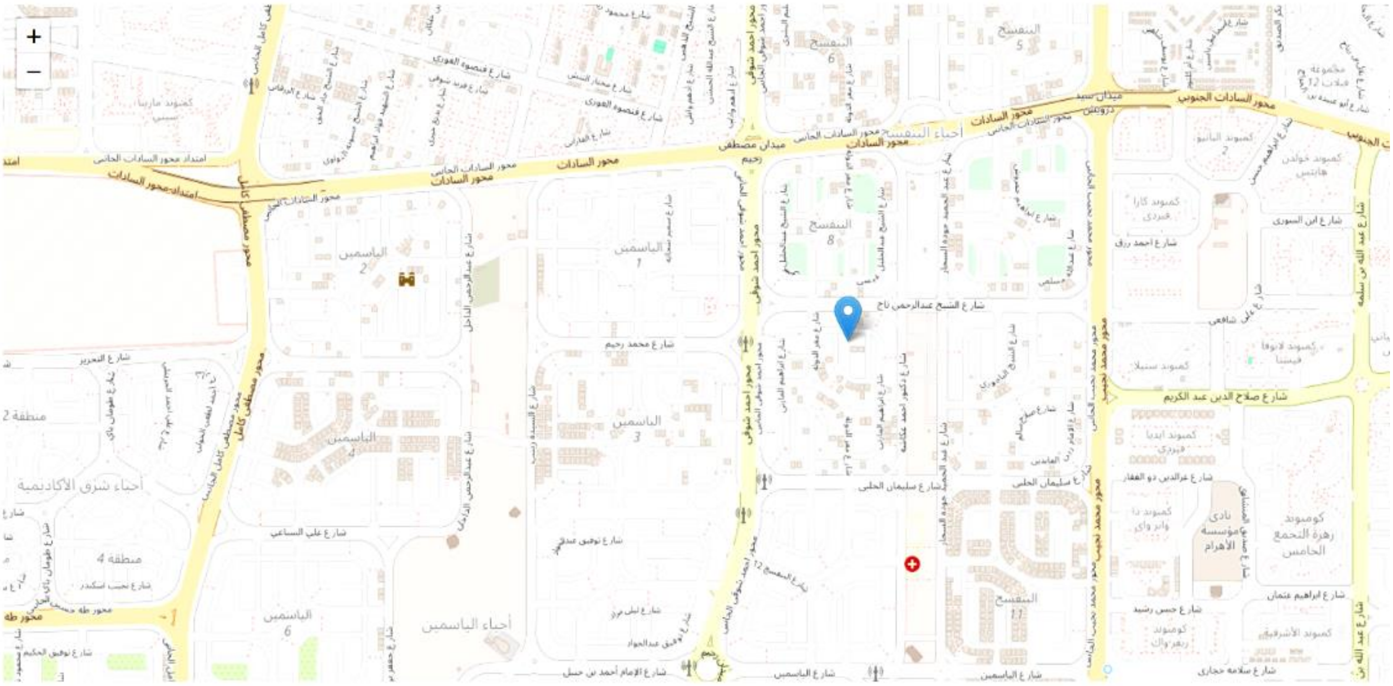


Figure.7 Map

FUTURE IMPROVEMENTS

While the current implementation achieves the intended objectives, several future enhancements can be considered to improve the system's performance, reliability, and scalability. One potential improvement is the integration of machine learning algorithms to enable intelligent decision-making based on historical data. This would allow the system to recognize patterns and adapt its responses over time. Additionally, implementing edge computing on the ESP modules could reduce latency by processing critical data locally before sending it to the cloud. Enhanced data encryption and authentication mechanisms could also be introduced to ensure secure communication between devices and the cloud platform.

From a hardware perspective, incorporating additional sensors such as gas, humidity, or thermal cameras could provide more detailed environmental data. The system could also benefit from automated route planning and navigation, allowing the vehicle to operate more autonomously in complex environments. Additionally, the integration of a suspension system to enable the vehicle to navigate uneven or rough terrains more smoothly. This would improve the system's overall mobility and allow it to operate in outdoor environments or during emergency situations where the terrain may not be flat or predictable.

Finally, expanding the platform to support multi-vehicle coordination and centralized monitoring would make the solution more suitable for large-scale deployment and wide area coverage in case of emergencies. This capability could be further enhanced by enabling the vehicle to assist in civilian rescue operations, using AI to autonomously navigate through complex environments safely. Such functionality would allow the system to handle search and assistance tasks, enabling authorities to concentrate their efforts on more critical or large-scale challenges.

Conclusion

To conclude, the effect of IOT for long distance solution for forest fires such as the vehicle we created introduces a huge opportunity for further wireless implementations of environmental safety. The project's main goal is to reduce the overall increase in random fires percentage in agricultural fields and forests.

IOT is perfectly utilized in this project as it employs a unique solution to rising and upcoming potential dangers. As well as giving the ability to record and display sensor data results simultaneously and without major delays. This fast response system is perfect for emergency situations to alert and send the exact initial location of potential forest fires.

Finally, this implementation helps in the overall safety of nearby civilians that could be potentially involved in any wildfire. As well as a major help to the relevant authorities that are responsible for nature reserves and forest research. Meanwhile, reducing the cost and fundings necessary to control and put out wildfires that have escalated due to late notice.

Development timeline

23 May – 26 May 2025: Component Selection

This stage focused on choosing the required components for the system, including the microcontroller, sensors, and actuators.

27 May – 31 May 2025: Modelling (SolidWorks)

During this phase, a 3D model of the vehicle was designed using SolidWorks.

1 June – 4 June 2025: Wiring Diagram and Code Development

The electrical wiring of the system was designed using Proteus to prevent any wiring errors during assembly.

The control code for the system was written, tested, and debugged, covering sensor integration, motor control, and IoT communication.

5 June – 8 June 2025: Repair Manual

A repair manual was created to guide troubleshooting and maintenance, listing component specifications, wiring, and connections.

9 June – 12 June 2025: 3D Printing the Vehicle

The vehicle was 3D printed based on the SolidWorks model.

13 June – 15 June 2025: Component Assembly

All components were assembled at this stage, resulting in a functional prototype.

16 June – 18 June 2025: Final Adjustments

Final adjustments were made, including IoT communication setup and sensor placement optimizations.

19 June – 27 June 2025: Testing and Validation

The prototype underwent extensive testing to validate its performance and overall functionality.

References

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