ISSN NO. 2320-5407

Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/16686
DOI URL: http://dx.doi.org/10.21474/IJAR01/16686

RESEARCH ARTICLE

CROP GROWTH MONITORING SYSTEM BASED ON DRONE AND LOW POWER WAN

Ayouziayoub and Jingzhao LI

……

Manuscript Info

……

Manuscript History
Received: 15 February 2023
Final Accepted: 19 March 2023
Published: April 2023

Key words:-
Internet of Things, Agriculture, LPWAN, LoRa, UAVs, Wireless Sensors Network (WSN)

Abstract

……

Smart farming is currently seen as an effective way to increase farm productivity and has gained a lot of attention from service providers. It offers a variety of applications, from identifying pests to monitoring assets. The emergence of digital technologies such as IoT and LPWANs has improved the smart farming industry, but more efficient solutions are still needed. Unmanned aerial vehicles, or drones, are increasingly being used across various civil domains, and this paper aims to create a farm monitor-ing system that combines UAVs, LPWANs, and IoT technologies. This system aims to revolutionize current farm management practices and provide farmers with valuable data for their operations. To ensure the quality of soil in farming development, a system for monitoring soil quality using IoT technology was created. The collected data from the sensors was transmitted to the cloud for analysis through a multi-channel LoRaWAN® gateway integrated into a drone that uses dynamice mode. Various simulations and measurements were done to develop aerial communication based on LoRaWAN®, and the UAV path planning was optimized to improve the efficiency of data collection.

……

Introduction:-

The Internet of Things (IoT) is a network of physical objects that have internet connectivity and sensors, such as household appliances, vehicles, and devices [1]. These objects can collect and share data with each other and their surroundings, enabling communication and interaction. IoT is a cutting-edge wireless communication technology that allows the exchange of information among various physical things or objects via unique addressing schemes. It has countless applications across different industries, including transportation, healthcare, agriculture, smart homes, and manufacturing. For example, IoT devices can provide valuable insights on various physical parameters to enhance farming practices [2].Wireless sensor networks (WSNs) are an essential component of IoT technology since most IoT applications in diverse markets depend on data transmission through wireless means. The traditional farming systems are transforming into intelligent farming systems by exploiting internet connectivity, networking, and sensing. The agricultural industry is moving towards a promising era of agri-food production, known as Agri-Food 4, by incorporating various emerging technologies such as IoT, smart sensors, remote sensing, UAV technology, Low Power Wide Area.When it comes to smart farming, there are three main types of technologies: those that collect data, those that analyze and evaluate it, and those that enable precision application. These technologies have been combined in different ways to create successful smart farming systems in many countries, including Europe, the United States, Australia, Brazil, India, Italy, and Ireland [3]. Smart farming tools are being developed and implemented globally, with the help of advanced sensor systems that can monitor and regulate agricultural production and feed [4].Drones and unmanned aerial vehicles are also among the most promising and

Corresponding Author:- Ayouziayoub

widespread technologies. Drone farms are changing the way farmers grow crops [5]. One of the most popular and promising technologies are drones and unmanned aerial vehicles. Farmers are using drone farms to revolutionize the way they plant crops by utilizing the data collected by drones in the early stages of planting. This data includes important information about the field geography and soil composition, which helps farmers optimize their planting patterns. Drones are also able to determine when crops need watering, harvesting, and sowing [6].

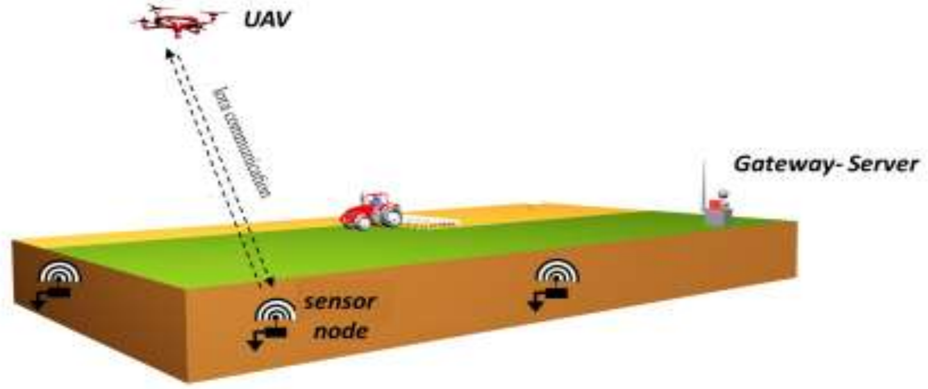


Figure 1:- System Architecture.

I. Related Work

Having reviewed related work, we now present the main body of our researchof drones in smart agriculture to crop growth monitoring systems while drones collect data via cameras and via nodes using Lora communication and optimization of drone path planning:

1. Wireless Communication Networks

A wireless network is a type of network that enables the exchange of information and communication between at least two endpoints without the need for wires. It allows for staying connected while moving within a certain area. Wireless networks are advantageous in connecting distant elements with ease and without significant infrastructure setup compared to wired networks, which require specific infrastructure to be established. Due to this advantage, wireless networks have been more rapidly developed in recent years [7].

Types of Wireless Networks:

A- WWANS (Wireless Wide Area Networks):

WWANs cover vast regions such as cities or countries, and rely on technologies like GSM, 3G, 4G or 5G. They are exclusively used for cellular networks enabling long-range connections that span the entire nation. Service providers of cellular networks are the primary source for this kind of service[8].

B- WLANS (Wireless Local Area Networks):

A network that covers a limited space, which may include a school, home, university, or campus, is called a local area network (LAN). Its purpose is to connect two buildings, for instance, and it relies on radio waves or WIFI for communication [8].

C- WMANS (Wireless Metropolitan Area Networks):

This network is categorized as a medium-sized network, falling between WWANS and WLANS in terms of size, with a limited range of 40 km. It can be seen as a collection of several WLANs, and it uses ViMax technology to enable communication [8].

D- WPANS (Wireless Personal Area Networks):

This kind of network is designed for personal use and can transmit information over short distances. It is highly scalable and relies on technologies like Bluetooth or Zigbee. What sets it apart is that it is cost-effective, energy-efficient, easy to manage, and doesn't require any infrastructure [8].

Year	Technology	Standard(s)	Transmission range	Frequency Bands	Data rate	Power	Security
1991	2 G (GSM)	GSM, CDMA	Mobile	865 MHz, 2.4	50-100 kb/s	Medium	TMSI

			network area	GHz			
1999	WiFi	IEEE 802.11/a/c/b /d/g/n	20-100 m	2.4, 3.6, 5, 60 GHz	1 Mb/s-6.75 Gb/s	High	WEP, WPA, WPA2
1999	Bluetooth	IEEE 802.15.1	100 m	2.4 GHz	1-24 Mb/s	Medium	56/128 bit
2001	WiMAX	IEEE 802.16	50 km	2-66 GHz	1 Mb/s-1 Gb/s	Medium	AES, DES
2001	ZigBee	IEEE 802.15.4	< 1 km	2.4 GHz	250kb/s	Low	128 bit
2001	3G	UMTS, CDMA2000	Mobile network area	865 MHz, 2.4 GHz	0.2-100 Mb/s	Medium	SNOW 3 G, Stream Cipher
2004	Z-Wave	Z-Wave	100 m	908.42 MHz	100 kb/s	Low	Triple DES
2009	4G	UMTS, CDMA2000	Mobile network area	865 MHz, 2.4 GHz	100 Mb/s-1 Gb/s	Medium	SNOW 3 G, Stream Cipher
2010	SigFox	SigFox	Rural: 30-50 km	908.42 MHz	10-1000b/s	N/A	N/A
2014	Thread	IEEE 802.15.4	30 m	686/915/2 450 MHz	250 kb/s	Low	N/A
2015	LoRa	LoRaWAN	20 km	Varioussub-GHz	0.3-50 kb/s	Verylow	AES 128 bit
2015	NB-IoT	3GPP Rel.13	LTE/4 G base stations	180 kHz	DL:234.7 kb/s, DI:204.8 kb/s	Low	LTE encryption
2019	5 G	3GPP, ITU, IMT-2020	Mobile network area	0.6-6 GHz, 26, 28, 38, 60 Hz	3.5-20 Gb/s	Medium	SUPI

Table 1:- Comparison of Wireless Networks.

The information in Table 1 provides a concise overview of various wireless networks, including their coverage limits, performance rates, and communication types. The table also highlights the specific applications for each type of wireless sensor network. It is important to consider the specific characteristics of IoT applications in agriculture, such as expansive fields, outdoor environments, limited energy, and inconsistent performance. To accommodate these requirements, remote sensors and wireless devices typically transmit small amounts of data and rely on long-range connections with sufficient power sources.

The Low Power Wide Area Network (LPWAN) is a wireless communication network designed for long-distance, low-bit-rate communication between connected objects like sensors that operate on batteries. LPWAN can cover a few kilometers in cities and up to 15-30 kilometers in rural areas, with an estimated service life of over 10 years. The radio chipset costs are low, and the subscription costs for each device are also minimal. LPWAN is a popular technology for IoT solutions, while consumer-level IoT is better suited for Bluetooth, Zigbee, and Wi-Fi. Although LPWAN is a single technology, there are different types of LPWAN with distinct features like Sigfox, RPMA, NB-IoT, and LoRa, which is particularly suitable for outdoor applications.Lo-Ra communication technology enables long-range communication ranging from 10 to 40 kilometers in rural areas. However, in urban areas, several obstructions can interfere with Lo-Ra communication, and its network coverage is limited to a few kilometers, approximately 1 to 5 kilometers**[8]**.

The new wireless communication technology, 5G, utilizes high frequency electromagnetic waves and has low latency. It boasts faster data transmission speeds and larger data throughput compared to current wireless communication technology. These qualities make it ideal for device communication, user-side AI algorithms, distributed fault diagnosis methods, and complex security strategies. No information has been omitted in this paraphrased text**[9]**.

2. Wireless sensor network

One of the primary roles of an IoT network is to gather data, which can present challenges for large WSN deployments due to the complexity of the geographic environment. Two categories of data collection tasks exist: static and dynamic. In the static approach, WSN nodes transmit collected data over a multi-hop network, while in the dynamic approach, a mobile data collector like a drone gathers data from distributed nodes. Dynamic data collection has some advantages over static methods, including reduced energy consumption for data transmission, improved network coverage, and expanded flexibility for WSNs to operate in diverse environments [10].

The wireless sensor network consists of a large number of sensor nodes that include acquisition, processing, transmission, mobilizer, positioning system, and power units (some of these components, such as the mobilizer and positioning system, are optional). Figure 2 shows the components of the sensor node. These nodes are densely distributed either within or very close to the phenomena. Sensor node locations do not need to be constructed or predefined. Sensor nodes work together to generate high-quality information about the physical environment. Each of these distributed sensor nodes is capable of collecting and relaying data to other sensors or back to an external base station. A base station may be able to connect the sensor network to an existing communication infrastructure or the internet where a user can access the reported data [11].

As stated in the literature, WSN offers advantages over remote sensing in smart farming applications [12]:

1. Reducing the cost of deploying and operating a viable precision farming framework.
2. Recording and communication can now take place in real time, resulting in better response times. Suitability for distributed data acquisition and monitoring in harsh environments.
3. Able to economically control climate, irrigation and nutrient supply to achieve the best crop condition, increase production efficiency while reducing costs and providing real-time information.
4. Gives better spatial and temporal variability than satellites.
5. Allows collection of other soil and plant data different from satellite surveys, such as soil temperature, moisture, pH and electrical conductivity.
6. Ability to form a highly automated farming system.
7. Gives better resolution. Ability to monitor crop condition over long periods of time.
8. Analytical information storage to create a case record of the crop.
9. Friendly graphical user interface (GUI) with the surveillance system.
10. Potential for accurate evaluation of new cultivation methods and techniques.

Sensor node

It is considered as an entity directly in contact with the field. It is responsible for sensing data and transmitting it to the system. Figure (2) shows the main elements of each sensor node.

Sensor node

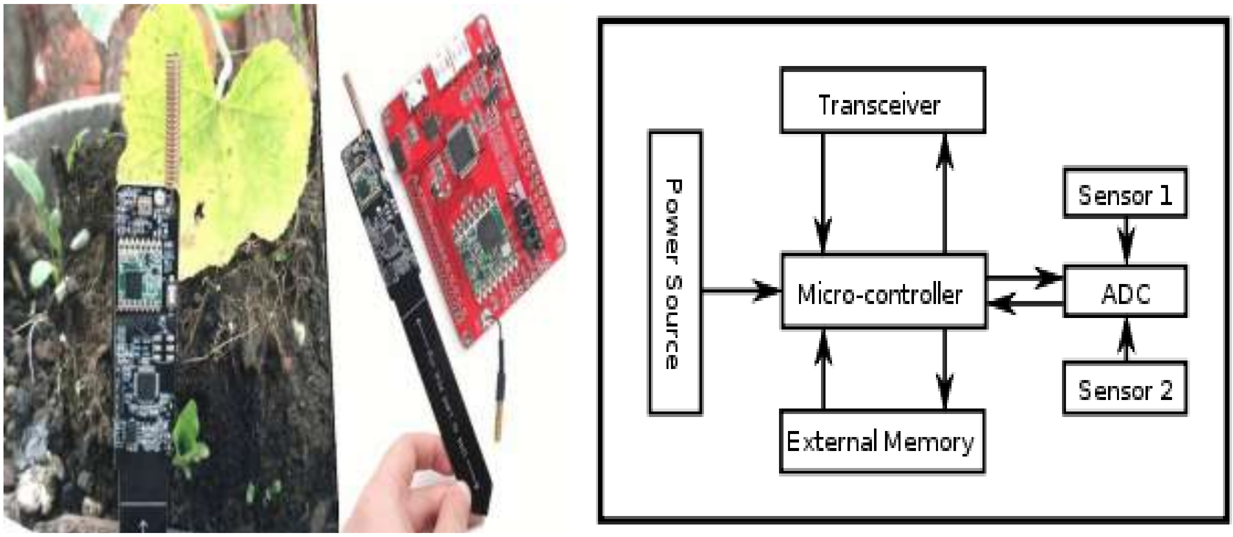


Fig 2:- Composition of a Sensor Node.

Power source:
The sensors constantly need a power source since it is a piece of hardware that is constantly busy collecting information. After deploying sensors in various unreachable terrains, it becomes difficult and costly to replace the batteries. Better adapted sensors are able to renew their energy from solar sources, temperature differences or vibrations [13].

Transceiver:
The wireless sensors combine the functions of transmitter and receiver in a single device. Each wireless sensor node has a radio transceiver with an internal or external antenna [13].

Sensor:
A sensor is a hardware device used to collect data from the external environment. Parameters such as temperature, pressure or chemical composition [13].

Controller:
The controller processes data and controls the functionality of other components in the sensor node. The most common is the microcontroller [13].

External memory:
From an energy point of view, the most relevant types of memory are on-chip memory of a microcontroller and flash memory. Off-chip RAM is rarely, if ever, used. A memory is available in the microcontroller and can be removed at any time [13].

3. Unmanned Aerial Vehicule

Drones or unmanned aerial vehicles (UAVs) are robotic vehicles that can be operated remotely for various purposes. Although initially developed for military applications, they have become widespread across different sectors. Research shows that over 25 million hectares of land across 7 continents and 160 countries are currently utilizing drone technology. The agricultural industry is no exception, with drones being adopted to address labor shortages and enhance precision farming. Previously considered an unaffordable technology for small farms, drones are now an attainable option with a moderate financial investment [14]. UAVs have the capability to gather high-resolution data in difficult-to-access areas such as farms, mountains, and islands, and are beneficial in 3D and source mapping applications. Farmers require cost-effective methods to monitor their farms on a regular basis. By incorporating infrared sensors in unmanned aerial vehicles (UAVs), it becomes possible to oversee the wellness of crops, which, in turn, can aid farmers in enhancing crop health through the application of insecticides or fertilizers. This approach also results in a greater yield of crops [15].

UAV types

There are numerous types of UAVs. Application-specific types are required for efficient UAV use. UAVs are classified based on their height and the type of wings they have. They are classified as either low-altitude or high-altitude UAVs as shown below [16].

1. Low Altitude Platforms (LAP) are easier to install and deploy than high altitude platforms, but they have a smaller coverage area and shorter lifespan [17].
2. High Altitude Platforms (HAP) could offer the mission for several months, but they have higher deployment costs than LAP. This makes LAP more cost-effective [18].
3. Depending on the wing type, the UAV can be either fixed wing or rotary wing and is given below:
4. Fixed wing creates lift from wings with forward airspeed. A runway is required for takeoff and landing, and forward speed must be maintained. It has simple structure, high speed and larger payloadRotary wings generated lift by rotating blades around a rotor shaft. It has the ability to levitate and move in any direction. Its take-off and landing mechanisms are vertical. Its characteristics are as follows: Typical are lower payload, lower speed and shorter range [19].

4. UAVs IoT& 5G

Conventional unmanned aerial vehicles (UAVs) are limited by their reliance on a radio communication system that restricts their range to the operator's line of sight. However, with the integration of 5G networks, UAVs can be remotely controlled and connected to the internet, enabling them to operate in inaccessible areas. Moreover, the low latency and high-speed capabilities of 5G networks can facilitate the coordination and communication of multiple

UAVs in a swarm, allowing them to work together in real-time to perform tasks such as surveillance, mapping, and rescue missions more efficiently. Unmanned aerial vehicles (UAVs) typically rely on radio communication between the operator and the UAV, which limits their range to the controller's line of sight. However, by connecting UAVs to 5G networks, they can be remotely controlled via the internet, allowing them to operate beyond the controller's view and access hard-to-reach areas. In addition, 5G technology can enable multiple UAVs to work together in swarms to accomplish tasks. The fast speeds and minimal delay of 5G networks facilitate real-time coordination and communication among swarm UAVs, enhancing their efficiency in tasks such as mapping, surveillance, and rescue missions.The implementation of 5G in UAVs faces some difficulties due to the restricted range of a 5G network. Although the use of stations or transmitters can expand the range, it may not always be practical or cost-effective. Additionally, there is a concern about interference in the radio frequency band utilized by 5G, which may have adverse effects on UAV performance. Nevertheless, the integration of 5G in UAVs has the potential to enhance performance significantly and create opportunities for numerous new applications. As technology advances, we can anticipate more drones with 5G technology and an increased number of UAVs utilizing this technology. Furthermore, 5G in UAVs also has the potential for several other applications [20]:

1. Infrastructure maintenance and inspection, increased security and fewer physical inspection teams.
2. Deliveries of medical supplies and equipment improve access to healthcare in remote or underdeveloped areas.
3. Actual functionality and video transmission out of line of sight.
4. Swarms are used for a variety of tasks, e.g. B. mapping, surveillance and search and rescue operations.
5. Data collection and transmission from a range of locations, civil protection, animal monitoring and weather forecasting.

As previously stated, there are various methods to incorporate UAVs and satellites into 5G networks for the purpose of supporting IoT applications, which presents numerous benefits. In situations where no other communication infrastructure is accessible, UAVs and satellites can be utilized in 5G-related fields to acquire and communicate data produced by IoT devices. UAVs can broaden the range of corporate IoT networks by functioning as mobile communication stations, allowing for the configuration and alteration of position and movement routes as needed.

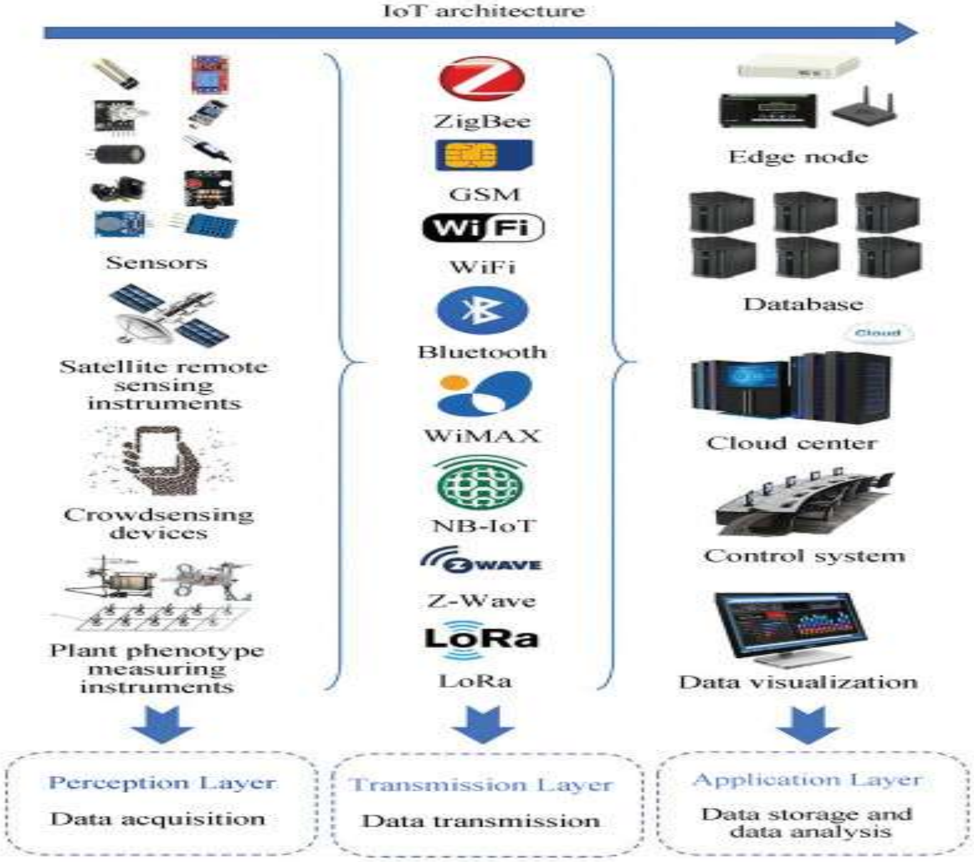


Fig 3:- Long-Range IoT.

The third figure demonstrates a possible method of achieving long-range Internet of Things (IoT) in remote and rural regions where the expenses of constructing and sustaining terrestrial communication infrastructure are more than the economic gains. In such areas, satellite gateways and payloads can function as 5G gNBs or link with them via land-based connections to spread internet access to smart farming and smart communities. This network can also include IoT devices, such as 5G UE.

As the usage of 5G networks increases, there will be a requirement for resources that can handle high traffic and a variety of services. Unmanned aerial vehicles (UAVs) can act as an edge computing platform for Internet of Things (IoT) gadgets that have limited information processing capabilities, and they can also assist in prefetching recognized components, ultimately decreasing data transfer latency during peak hours. By delegating computationally challenging tasks to a high-capacity processing UAV, mobile devices can preserve energy and decrease traffic load on stationary cloud servers. UAVs equipped with MEC-servers offer benefits over traditional terrestrial cellular networks, and a swarm of UAVs can share cellular spectrum with terrestrial users to prevent crashes and maintain consistent communication. Mobile devices have the ability to function independently, however, the MEC server present in UAVs has the capability to perform complex computing tasks soon after obtaining consent from the mobile device. It is possible for each mobile device to connect directly with a close-by UAV node that has sufficient battery life and processing power[21].

II. Conceptandmethodofcrop growth monitoringsystem

The main purpose of the designed system is to enable drones to fly optimally over large farms and collect data from different sensors deployed on the farm and convey them to the cloud. Ah shown in Figure 1, the architecture devised to provide a conceptual understanding of the system's functioning and interaction with the drone and distributed sensors. The system employs various sensors to gather data on the condition of the farmland, while LoRaWAN and drones are utilized to transmit this information.,LoRaWAN®- based network planning, integrating the LoRaWAN® gateway into the drone, and drone path planning optimization. The following subsections describe the methods used and works conducted to achieve the objectives of this study in detail.

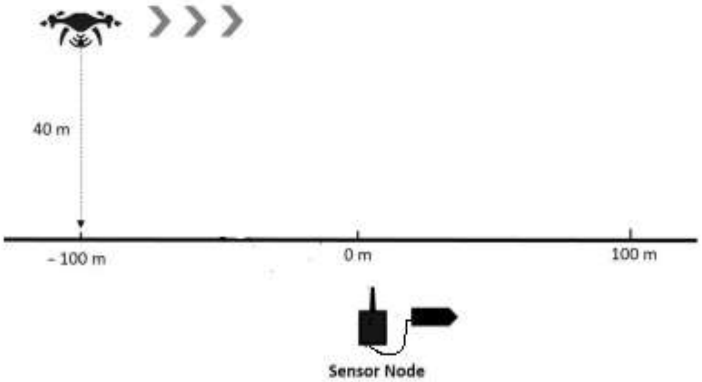


Fig 4:-The collector node measures the RSSI signal level at each data frame reception.

1. Sensor node

We have created a system of sensor nodes that can periodically gather and store soil measurements, and transmit the data to a collector node on a UAV when it is nearby. The sensor nodes are controlled by a program running on an Atmega328-AU 8 MHz microcontroller, and are powered by a rechargeable lithium battery with the aim of being energy autonomous for several months. The sensor nodes spend most of their time in deep-sleep mode and are only active during measurements and specific communication time-windows. Soil moisture and temperature are measured using a Truebner SMT100 probe and the data is stored on an EEPROM 8 bit memory with I2C-bus interface. Radio communication is enabled through the LoRa module RFM95W (HopeRF) including the SX1276 chip of Semtech.

A temporal reference DS1378 is used to determine the timing for the measurement periods and communication time-windows. During active time-windows, the sensor node waits for a message from the collector node and transfers the data frames to the collector when communication is established, with the data frame structure outlined in figure 1.

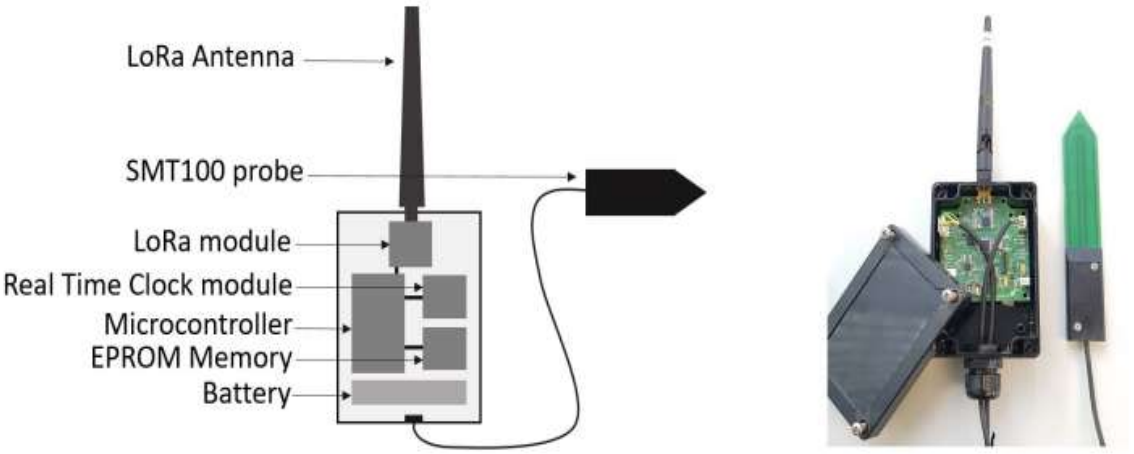


Fig 5:- The sensor node is built around an Atmega328 microcontroller, a DS1378 temporal reference, a RFM95W LoRa radio module operating at 868-MHz, and an SMT100 probe. The radio antenna is out of the box and will be directly in contact with the soil.

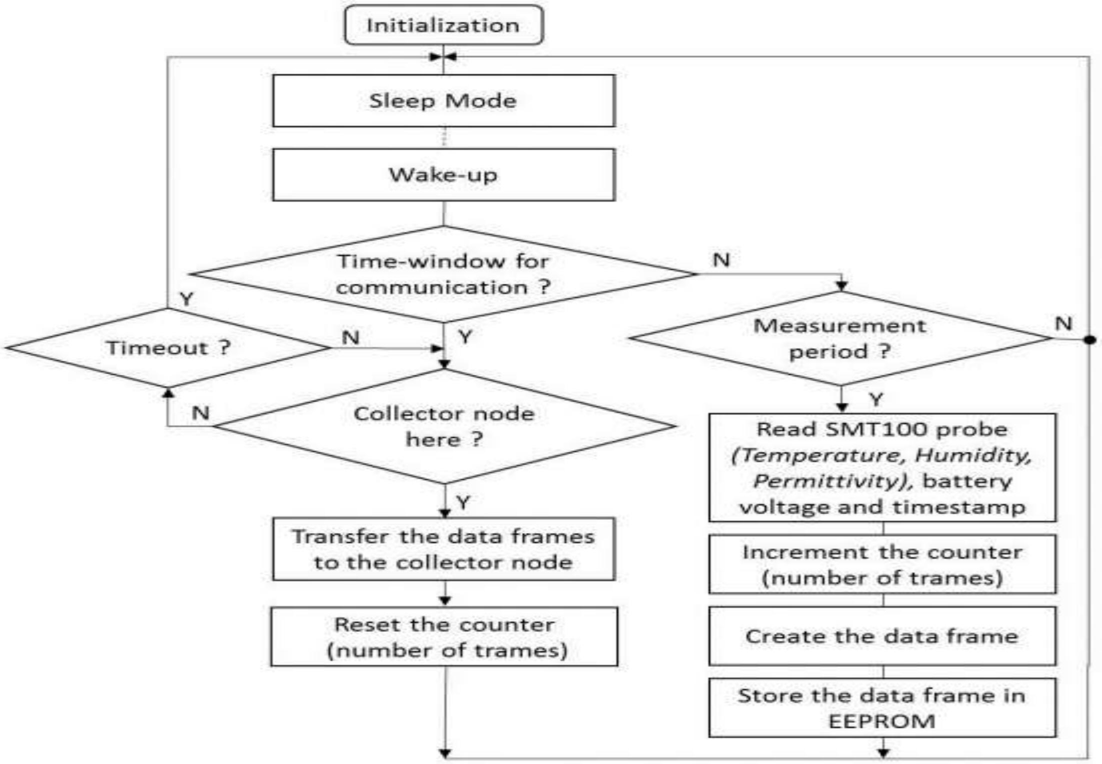


Fig 6:- Flow chart of sensor node.

2. LoRaWAN®-Based Communication Network

The proposed system was created using LoRaWAN® wireless communication technology, and consists of two main device types: the end node (EN) and the gateway (GW), both of which are based on Semtech SX1272 or SX1301 LoRa chipsets. The EN collects and pre-processes data, which is then transmitted wirelessly to the GW using LoRa signals. The GW forwards the data through an internet connection to an application server for further processing and visualization. The devices operate at the 915 MHz band and can be configured at either LoRa mode 1 or mode 10. Two types of GW were used: a single-channel GW and a multi-channel GW. The multi-channel GW can operate on up to eight frequency channels and supports an adaptive data rate (ADR) mode, making it suitable for larger networks and providing improved packet transmission reliability. However, it does not support offline mode, so it was modified to enable data collection in areas without internet access. This was achieved by using a different hat design based on a Raspberry Pi, which acts as a local storage device and mini server, saving and pre-processing data while offline. Once an internet connection is available, the GW pushes the data to the application server. Technical specifications for the LoRa multi-channel GW are listed in Table 3, and Figures 5 and 6 show the block diagram and components of the modified GW, respectively.

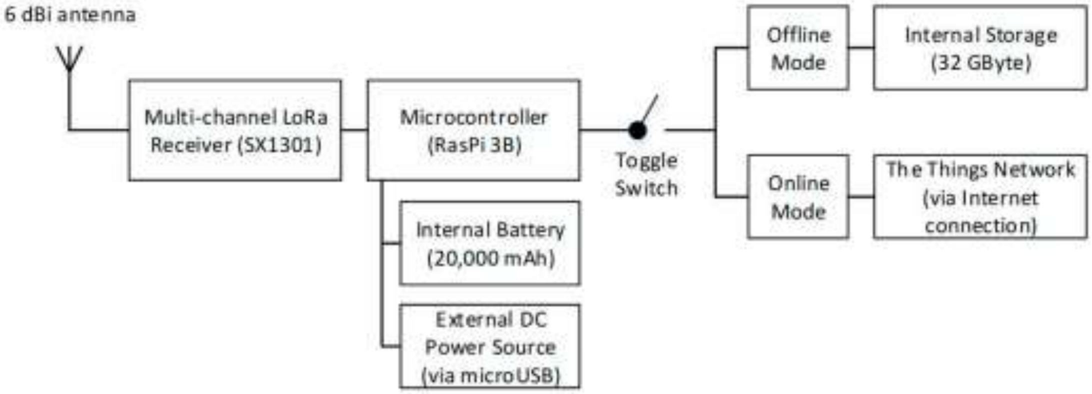


Fig 7:- Block diagram of the modified LoRaWAN® multi-channel GW.

Technical specification of the LoRa multi-channel Gateway

Item	Specification
Microcontroller	Rasberry Pi 3B
LoRa Chipset	Sx1301
Frequency	915 Mhz
Input	5V/205A
Antenne	SMA antenne 915 Mhz 50 ohm 5 dBi

3. UAV Path Planning Optimisation

This study employed a hybrid fixed-wing VTOL drone named AeroHawk [36] for measurements. The drone combines the benefits of fixed-wing and multi-rotor drones, allowing for vertical takeoff and landing without the need for a long runway while providing greater range and endurance due to the aerodynamic efficiency generated by the wings during flight. This is particularly advantageous for farmers with large plots of land.

To determine the shortest flight path for the drone, the problem was modeled as the TSP. The TSP aims to find the minimum overall distance to travel from one node to other nodes and back to the starting node without revisiting a node. The TSP uses the Euclidean metric to identify a Hamilton loop with the smallest weight in the weighted completely undirected graph. However, the TSP falls under the non-deterministic polynomial (NP) problems category. To simplify the computational complexity, metaheuristic algorithms like GA, PSO, ant colony optimization (ACO), and neural network (NN) are used. In this study, PSO was chosen due to its strong robustness, ability to store past iterations, easy implementation, and simulation evolution.

The PSO algorithm operates by randomly distributing particles across the search space and evaluating the objective function based on each particle's position. Next, each particle determines its next direction by considering its current position, its best position encountered thus far, its current velocity, and information from the best particles in the swarm. The particles then move, and the algorithm advances one step. If necessary, these steps are repeated until the algorithm discovers the optimal solution. In our simulation, we set the PSO algorithm to stop executing when it reached the specified number of function evaluations (NFE). This value is defined as a stopping criterion for the algorithm.

$$\mathrm{NFE}(t) = n_{pop} + (n_{pop} \times t) = n_{pop}(1 + t)$$

wheren_{pop} is the population size (swarm size), and t is the number of iterations.

To define how the particles behave, let us consider a swarm consisting of n particles, with the position and velocity of the ith particle at time t denoted as x^i and v^irespectively, where i belongs to the set of integers {1, 2, ..., n}. The best position that the ith particle has experienced up to time t is denoted as$x^{g,best}[t]$, and the best position experienced by the swarm so far is denoted as $x^{gbest}[t]$. At every iteration or generation, the swarm updates its global best position based on the objective value, while each particle updates its personal best solution and computes its next position using the following formula:

$$v^i[t+1] = \omega v^i[t] + c_1 r_1\left(x^{i,best}[t] - x^i[t]\right) + c_2 r_2(x^{gbest}[t] - x^i[t]$$
$$x^i[t+1] = x^i[t] + v^i[t+1]$$

The inertia coefficient is denoted as w, while the cognitive and social acceleration coefficients are represented by c1 and c2, respectively. Additionally, r1 and r2 are random numbers that fall within the range of 0-1. The classic PSO algorithm is not effective in solving TSP because it becomes trapped in local optima. To overcome this challenge, we incorporated three mutation operators (swap, reversion, and insertion) into the PSO algorithm, resulting in the modified EPSO algorithm. The flowchart of the EPSO algorithm, which was implemented in MATLAB, is illustrated in Figure 7. Swarm initialization is used to generate the initial parameters. The values of w, c1, and c2 greatly impact the performance of the PSO algorithm and its convergence speed to the best cost function. Therefore, we selected the values of w, c1, and c2 as [22].

$$\omega = \chi,$$
$$c_1 = \chi\varphi_{1,}$$
$$c_2 = \chi\varphi_{2,,}$$

The variables φ1 and φ2 are both positive values, and their sum is denoted as φ. It is worth noting that φ is equal to twice the sum of φ1 and φ2, which is greater than 4

$$\chi = \frac{2}{\varphi - 2 + \sqrt{\varphi^2 - 4\varphi}}$$

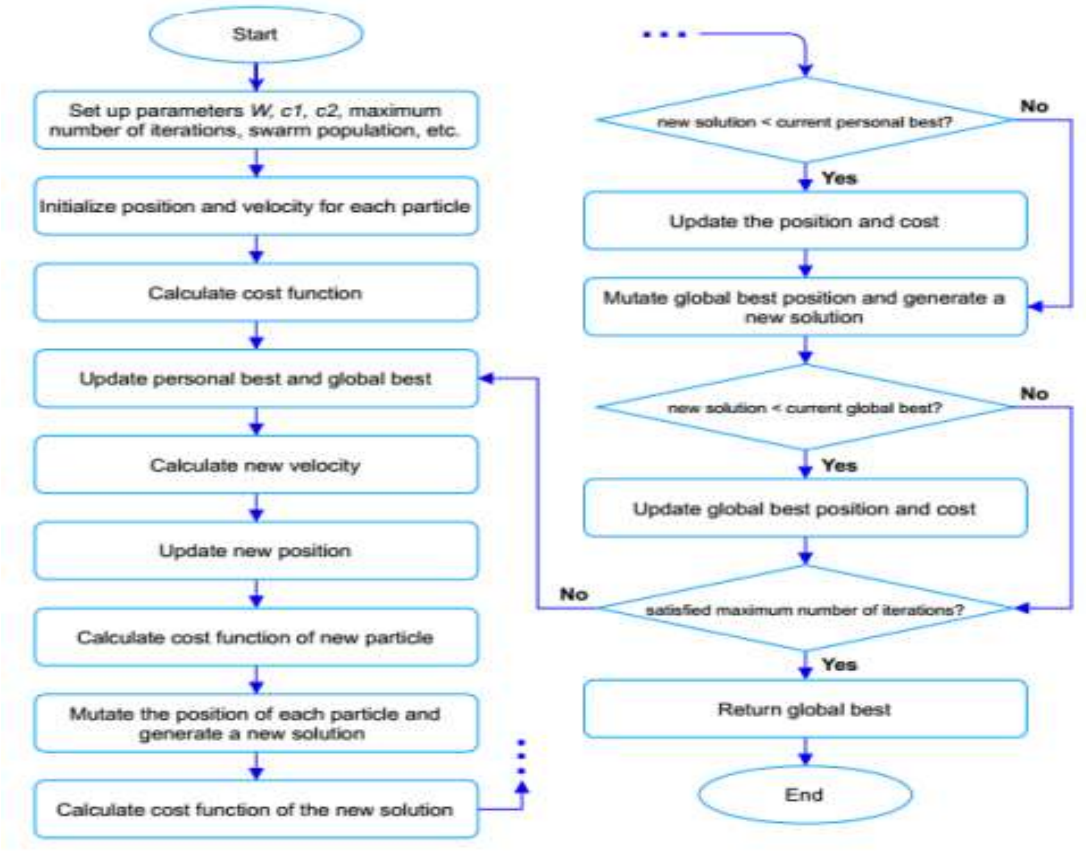


Fig 8:- Flowchart of Enhanced Particle Swarm Optimisation Algorithm.

The recommended parameters for the aforementioned values are φ1 = φ1 = 2.05, w = 0.7298, and c1 = c2 = 1.4962, as stated in [22]. The mutation operators used in this study are illustrated in Figure 8. The swap operator switches the positions of two nodes that are randomly chosen. The reversion operator switches the positions of all nodes within a randomly selected range. The insertion operator moves a randomly selected node to a different random location. The pseudocode for these mutation operators is presented in Figure 9.

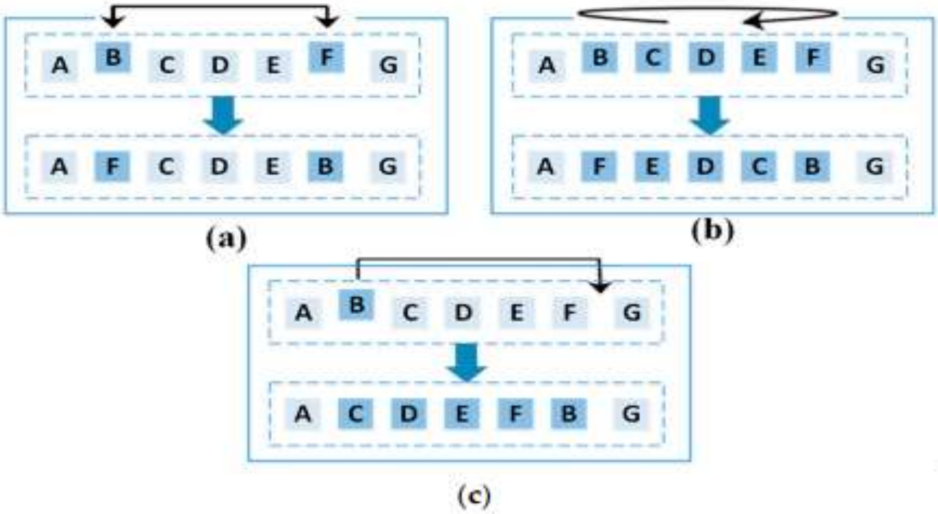
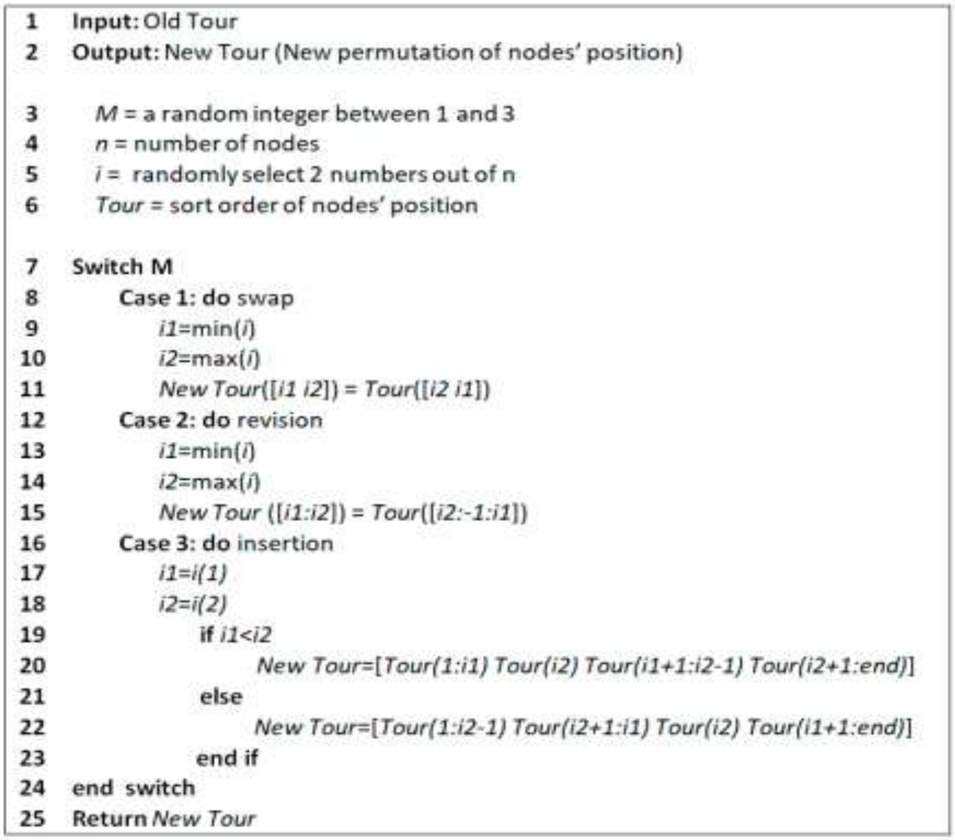


Fig 9:- A diagram demonstrating the mutation operators, (a) swap, (b) reversion, and (c) insertion.



```
Input: Old Tour
Output: New Tour (New permutation of nodes' position)

  M = a random integer between 1 and 3
  n = number of nodes
  i =  randomly select 2 numbers out of n
  Tour = sort order of nodes' position

Switch M
    Case 1: do swap
        i1=min(i)
        i2=max(i)
        New Tour([i1 i2]) = Tour([i2 i1])
    Case 2: do revision
        i1=min(i)
        i2=max(i)
        New Tour ([i1:i2]) = Tour([i2:-1:i1])
    Case 3: do insertion
        i1=i(1)
        i2=i(2)
            if i1<i2
                New Tour=[Tour(1:i1) Tour(i2) Tour(i1+1:i2-1) Tour(i2+1:end)]
            else
                New Tour=[Tour(1:i2-1) Tour(i2+1:i1) Tour(i2) Tour(i1+1:end)]
            end if
end  switch
Return New Tour
```

Fig 10:- Pseudocodeforthemutationoperatorused (swap, reversion, insertion).

III. Results and Discussions:-

1. Experimental Results

The test was carried out in experimental field of the entrance of the parking building. This field is a flat and free-obstacle pasture with a fertile soil. The weather conditions were moderate temperatures (about 23 ◦C) with cloudy sky. A sensor node was buried at 20 cm deep (top of the antenna) and covered with soil. The probe connected to the node was positioned in the hole at the same depth as the radio antenna. The measured values were a soil moisture of 5.47%, a soil temperature of 3.98 ◦C, and a dielectric permittivity value of 10.38.

Table 2:- Structure of a data frame sent by a sensor node (25 bytes).

Name	**Description**
SensorNodeID	Sensor node identifier
Counter	Auto increment of the frame
TimestampMeasure	Measurement Timestamp (UTC time)
NodeBatt	Battery voltage of the node
Permittivity	Data of the probe SMT100
Humidity	Data of the probe SMT100
Temperature	Data of the probe SMT100

According to Table 2, transmitting a 25-byte data frame via LoRa can take anywhere from 45 to 958 milliseconds, depending on the spreading factor (SF) chosen, as shown in Table 3. To minimize energy consumption on the sensor node, we opted for the lowest SF value (SF = 7), which also reduces the time on air. The collector node's LoRa module was also tuned to SF = 7. While a low SF value can limit the communication range, this was not an issue as the UAV could approach the sensor node closely. For the tests, we maintained a transmit power of +14 dBm/25 mW, which is the maximum allowed in the 868 MHz frequency band.

	SF7	SF8	SF9	SF10	SF11	SF12
RF Tx time (ms)	45	80	160	280	561	958

Table 3:- RF transmit time of a data frame of 25 bytes with respect to SF (BW = 125 KHz, CR = 4/5). Values obtained from Semtech's datasheets [23].

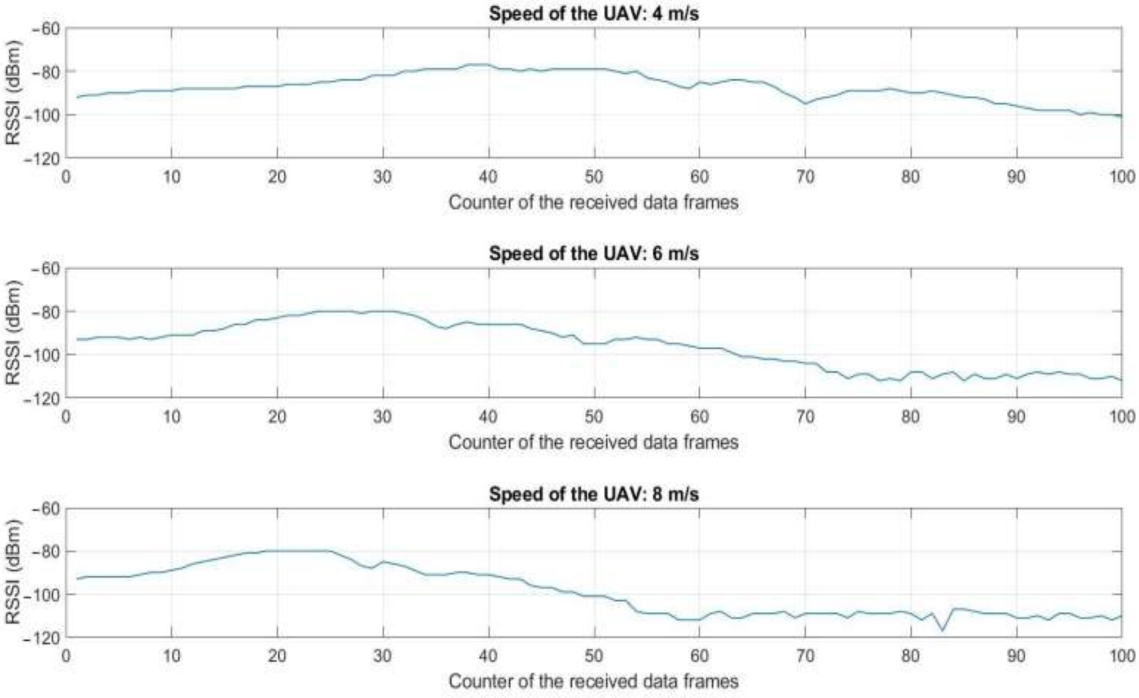


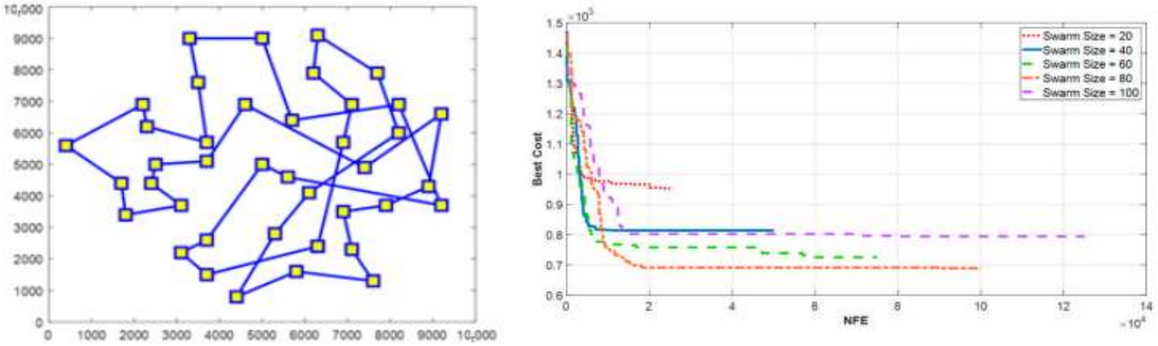
Fig 11:- The collector node recorded RSSI levels during three different speeds of the UAV's flight (4 m/s, 6 m/s, and 8 m/s) as it followed a 200 m trajectory. Each of the experiments involved collecting 100 data frames.

For the dynamical tests, the setup described in Figure 4 was used. The measured RSSI levels during the UAV's flight at an altitude of 40 m and speeds of 4 m/s, 6 m/s, and 8 m/s are shown in Figure 17, without omitting any relevant details.

During each experiment, the highest recorded RSSI value (which was around −80 dBm) corresponded to the moment when the UAV was directly above the node. At a speed of 4 m/s, this moment occurred slowly during the reception of data frame 40, while at 6 m/s it was during the reception of data frame 30, and at 8 m/s it was at data frame 20. In the last case, the UAV reached the end of its 200 m trajectory and was in hover flight while data continued to be stored from data frame 60 to 100. These findings indicate that data frames can be collected while the UAV is in motion, but it is important to properly plan the UAV's speed in relation to the time required to retrieve all the data stored in the sensor node. In our experiment, it took about 35 seconds to transmit and retrieve the set of 100 data frames, with a delay of 300 ms added between each transmission, and each data frame of 25 bytes taking 45 ms to transmit, as shown in Table 3.

2. Path Optimization

In order to determine the most efficient route for collecting aerial data on a farm, the positions of the sensors were input into the TSP, and the PSO and EPSO algorithms were used to solve the problem. Figure 19a shows the result of the PSO algorithm produced intersecting paths when a swarm size of 100 was used during the simulation, indicating that it could not find the global optimum due to its tendency to get stuck in local optima. To assess the algorithm's performance, different swarm sizes were tested (20, 40, 60, 80, and 100) with a maximum of 1250 iterations.

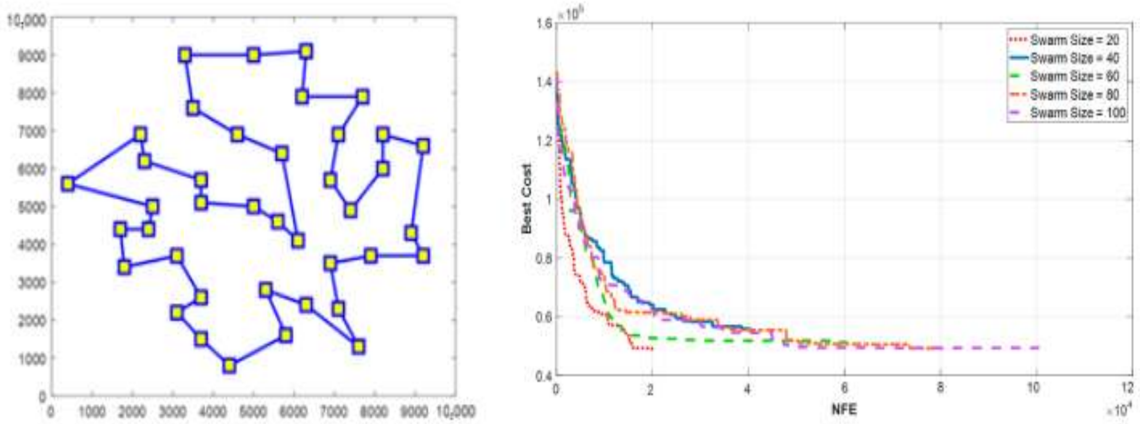


(a) (b)

Fig 12:- (a) The PSO algorithm computes the most efficient route for flying and (b) The PSO algorithm's effectiveness was tested in various swarm sizes to evaluate its performance.

According to Figure 12b, even altering the swarm size does not lead to the best cost function convergence. Even with a swarm size increase to 100, the cost increases and worsens. This is due to the random initial answers of evolutionary algorithms, and the complexity of TSP. As the number of nodes increases, particles tend to exploit their local optimum neighborhood rather than exploring the entire search space for the global optimum. To address this issue, the EPSO algorithm incorporates the concept of mutation from GA, generating random new solutions for both personal and global cases in each iteration, leading to a higher exploration rate. The figures 13a and 13b depict the ideal flight path that does not intersect and the ESPO algorithm's performance as the swarm size varies, respectively.

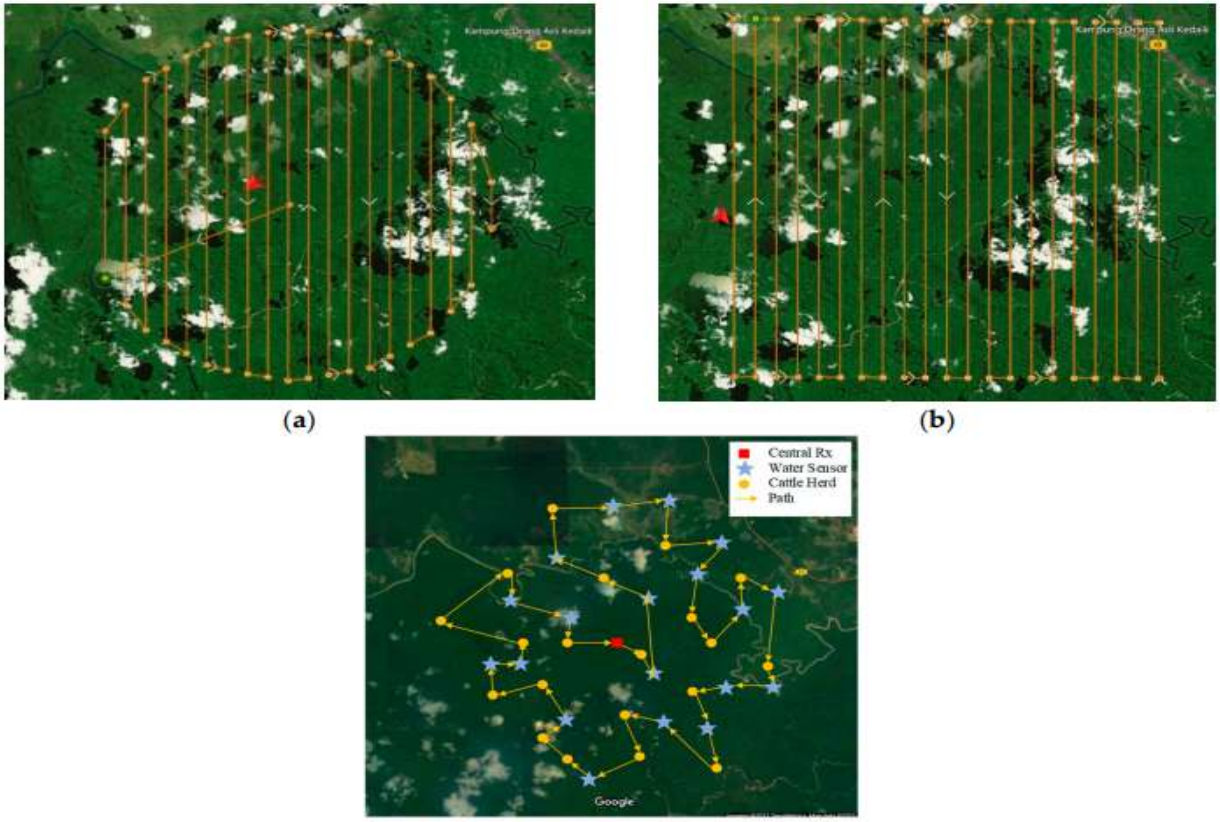
The results show that the algorithm converges to the lowest cost function irrespective of the swarm size. When compared to PSO, EPSO can lower the cost function by 35%, as demonstrated in figures 12b and 13b. To put it differently, the EPSO algorithm successfully decreased the overall distance of the route by 30 km.



(a) (b)

Fig 13:- (a) The optimal flight path calculated by improved PSO algorithm and (b) the performance of the EPSO algorithm at various swarm sizes.

When deploying industrial farming drones for data collection, they typically follow a set route plan using flight mission planner software. This plan often involves zigzag, square, or circular routing patterns to cover the entire farm. To demonstrate the importance of optimizing these route plans for large-scale data collection, researchers utilized the Ardupilot® mission planner to plan circular and square flight paths. Figure 14a,b represent these path plans, while Figure 14c shows the optimized route for the specific farm in question. To ensure adequate data collection, the distance between adjacent routes was set at 500m. The results indicated that the total length of the circular and square paths were approximately 175km and 212km, respectively.



(a) (b)

(c)

Fig 14:-(a) Circular model path planning, (b) square model path planning, and (c) optimized path planning.

In Table 6, the developed system's performance was compared in different flight mission modes, assuming a maximum flight time of 60 minutes based on the drone's specifications and small industrial VTOL drones. The results showed that optimizing the flight path could significantly reduce the distance (49 km) and time (40 min) required for the same mission without needing to change or recharge the battery. This indicates that using EPSO-based flight mission planning can generate an efficient path for a VTOL drone equipped with LoRaWAN® to gather data from a vast farm.

Table 4:- Compare total distance traveled, active hours and charging stops needed for different types of flight mission planning on the farm under consideration.

Flight Mission Mode	Total Path Length (km)	No. of Stops/Battery Replacements	Continuous Operation Time
Square	212	2	2.15 min
Circular	175	1	1.50 min
PSO-based	79	0	50 min
ESPO-based	49	0	40 min

In today's agricultural and livestock industries, there is a growing need to incorporate advanced technologies. The combination of agriculture and technology has opened up new opportunities for entrepreneurs and investors. As a result, in recent years, many new companies have emerged to offer technology-based services to farmers, including leasing agricultural drones for tasks like pesticide spraying, weed mapping, and crop monitoring. Either seasoned farm technicians or companies that provide drone services can operate the system described in this article.

Conclusion:-

The research paper examines scenarios where GSM or WiFi networks are not available in natural environments. It conducts experiments to show that data can be collected from sensor nodes using a UAV flying over the targeted areas, which stores the data frames through an embedded collector node. These data frames are transmitted through LoRa communication and delivered to a gateway at the end of the flight. The experiments also demonstrate that data collection can be done while the UAV is moving, which requires adjusting the UAV's speed. Additionally, two evolutionary algorithms were used to determine the most efficient route for the UAV to minimize flight time when dealing with multiple sensor nodes distributed in the environment based on Euclidean distance.

The use of drones in collecting aerial data has several benefits, including improving data availability, speeding up farm monitoring, and enhancing farm productivity by optimizing resource use and increasing production. We consider the developed drone-based system for collecting aerial data to be a successful solution to address farm management, aerial livestock monitoring, and data collection from IoT sensors.

References:-

[1] Z. Chen, H. Xu, D. Liu, B. Wang, "A vision of IoT: Application challenges, and opportunities with china perspective," IEEE Internet Things J, pp. 349-359, 2014.
[2] R. F. P. H. N. B. A. Walter, "Smart farmin is key to developing sustainable agriculture," Proc. Natl. Acad. Sci 114(24), pp. 6148-6150, 2017.
[3] W. Q, "Advances in environmental remote sensing: sensors, algorithms, and applications (remote sensing applications series).," CEC Press Taylor & Francis Group, 2011.
[4] L. Yu, "Research progress on soil moisture sensor technology: A review," Int. J. Agic. Biol. Eng. 14, 2021.
[5] C. I. a. M. P, "“Unmanned aerial systems for photogrammetry and remote sensing: A review”," ISPRS Journal of Photogrammetry and Remote Sensing 92, pp. 79-97, 2014.
[6] R. P. C, "“Precision agriculture: new developments and needs in remote sensing and technologies”," Ecosystems’ Dynamics,Agricultural Remote Sensing, Modelling and Site-Specific Agriculture 5153, 2004.
[7] M. A. K. A. a. M. A. S. Al-Sarawi, " “Internet of Things (IoT) communication protocols: Review,”," 8th International Conference on Information Technology (ICIT), 2017.
[8] F. C. a. N. S. A. Gloria, "“Comparison of communication protocols for low cost Internet of Things devices,”," South Eastern European Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM), 2017.
[9] M. A. H. Z. K. M. N. Rizwana Shahzadi, "UAV assisted 5G and beyond wireless networks: A survey," Journal of Network and Computer Applications 189, 2021.

[10] L. P. a. A. V. L. Mainetti, "“Evolution of wireless sensor networks towards the internet of things: A survey,”," 19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), pp. 1-6, 2011.
[11] R. S. B. S. Anurag D, "AGRO-SENSE: precision agriculture using sensor-based wireless mesh networks.," Proceedings of ITU (international telecommunications union), 2008.
[12] B. M. M. E.-B. Sherine M. Abd El-kader, "Precision farming solution in Egypt using the wireless," Egyptian Informatics Journal , pp. 221-233, 2013.
[13] T. J. H. J. K. J.] Mikhaylov K, "Wireless sensor networks in industrial environment: real-life evaluation results.," Proceedings of 2nd IEEE baltic congress on future internet communications (BCFIC);, pp. 1-7, 2012.
[14] N. S. K. Y. K. M. B. K. K. Gayathri Devi, "Review on application of drones for crop health monitoring and spraying pesticides and fertilizer," J Crit Rev,, pp. 667-672, 2020.
[15] W. Maes and K. Steppe, "Perspectives for remote sensing with unmanned aerial vehicles in precision agriculture.," Trznds Plant Sci., pp. 152-164, 2019.
[16] W. He, X. Mu, L. Zhang and Y. Zou, "Modeling and trajectory tracking control for flapping-wing micro aerial vehicles.," IEEE/CAA J. Automatica Sinica 8(1), pp. 148-156, 2020.
[17] W. He, T. Wang, X. He, L. Yang and O. Kaynak, "Dynamical modeling and boundary vibration control of a rigid-flexible wing system.," IEEE/ASME Trans. Mechatron. 25(6), , pp. 2711-2721, 2020.
[18] D. Floreano and R. Wood, "Science, technology and the future of small autonomous drones.," Nature 521, pp. 460-466, 2015.
[19] R. J. D. H. T. K. J. S. B. C. M. .. &. P. N. D'Sa, "SUAV: Q-An improved design for a transformable solar-powered UAV," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) IEEE,, pp. 1609-1615, 2016.
[20] W. T. S. I. C. R. D. J. &. D. Y. I. Alshaibani, "Mobility management of unmanned aerial vehicles in ultra-dense heterogeneous networks.," MDPI journal, 2022.
[21] G. A. Akpakwu, B. J. Silva, G. P. Hancke and A. M. Abu-Mahfouz, "A Survey on 5G Networks for the Internet of Things: Communication Technologies and Challenges," IEEE Access, pp. 3619-3647, 2017.
[22] M. Clerc and J. Kennedy, "The particle swarm—explosion, stability, and convergence in a multidimensional complex space.," IEEE Trans.Evol.Comput, pp. 58-73, 2022.
[23] R. 7. S. 2. A. o. h. (. o. 1. A. 2.). LoRa SX1276/77/78/79 Datasheet.