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UAV based long range environment monitoring system with Industry 5.0 perspectives for smart city infrastructure

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ABSTRACT

Air quality defines the condition of the air within the environment. However, the quality of the air is deteriorating due to the emission of pollutants from vehicles, industries, and landfill sites. Concerning the landfill scenario, it is a challenge for a human to monitor the air quality continuously due to the emission of stinky smells and gases from the landfill sites. In this study, we implement a UAV network based on IoT (Internet of Things) and a cloud server for the smart city for tracking the air quality of the landfill sites in real-time and alerting the UAV for capturing the visuals from the camera for detecting the exact cause of the pollutant in the landfill sites. The gas that causes the most air pollution is Nitrogen dioxide (NO_2), Volatile Organic Compounds (VOC), Carbon monoxide (CO), Sulphur dioxide (SO_2), Ozone, dioxins and furans, etc. In this paper, continuous monitoring of these harmful gases is done to alert the people to protect them from harm. The study is also carrying the discussion about the industry 5.0 perspectives using UAV long-range communication. The objective of this study is to record the sensory data and visuals of the various gases (NO_2, VOC, CO_2, SO_2) of landfill sites using IoT & UAV and then visualized in a graphical user interface form. The concentration of each gas that is stored in the cloud server is presented in the graphical representation. Different parameters such as Eigenvalues, Correlation Coefficients, and Regression Parameter have also been analysed graphically for the recorded data. The visuals captured from the UAV camera are employed for estimating the cause of the rise in pollutants in landfill sites.

1. Introduction

According to the Organization for Economic Co-operation and Growth (OECD) in 2012, air pollution is expected to be the world's leading source of environmental mortality by 2050 (Marchal, 2011). World Health Organization (WHO) reports revealing that shortly thereafter in 2012 that seven million people died from exposure to air pollution, rendering it the major environmental concern in the world (WHO, 2014). In consequence, by realizing that clean air is necessary to protect human health and that, at the same time, the benefit to climate and habitats, including flood protection, has been put top priority on sustainable growth in 2014 in the United Nations Environment Assembly (UNEA)(Session & Resolutions, 2011). Environment, human well-being, and habitats – they all have wider socio-economic growth ramifications that we have considered. Air pollution and climate change are constantly seen as two issues that are inevitably associated and need to be handled in a sustained way. At one step, this is gradually understood by the creation of international organizations such as the Environment and Clean Air Coalition (CCAC) or the Global Alliance for Clean Cooking, which is seeking to minimize emissions of air pollution that both warm the climate and adversely affect human health and habitats (Climate, 2014). Concerning these concerns, national and regional governing bodies are interconnected together to undertake necessary measures of air quality and climate change simultaneously(GACC, 2016). The most widely known air contaminants are particulate matter (PM), ground-to-ground ozone (O_3), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2)(Krzyzanowski & Cohen, 2008). Carbon monoxide (CO) and volatile organic compounds (VOC) are also often taken into consideration for air quality and regarded as precursors to the formation of ozone and particulate matter(Nitrous oxide (N_2O), carbon dioxide (CO_2), fluorinated gases, methane (CH_4)). Methane is most often recognized as a volatile organic compound and a contributor to the formation of ozone when it comes to air quality(AR5 Climate Change, 2013).

Landfills are a significant contributor to the world's anthropogenic greenhouse gas (GHG) emissions, as an immense amount of CH_4 and CO_2 is produced by the process of depletion of waste stored in landfills (Kumar, Gaikwad, Shekdar, Kshirsagar, & Singh, 2004). Residents of

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sites close to sites are concerned about many hazardous pollutants from landfills(Vaverková, 2018). Degradation of the environment leads to chronic diseases, adversely affects climate and aquatic. There is a significant necessity of maintaining air quality at an optimal level. To achieve this goal, the only convenient way is continuous monitoring of the air. Continuous monitoring of air is required for identifying the exact pollutant for the emission of gases in the environment(Marć, Tobiszewski, Zabiegała, de la Guardia, & Namieśnik, 2015). Nitrogen dioxide (NO_2), Carbon monoxide (CO), sulfur dioxide (SO_2), ozone gas (O_3), and particulate are the pollutants that severely affects on lungs and lead to chronic & pulmonary diseases in humans(Chen, Gokhale, Shofer, & Kuschner, 2007). Making an appropriate decision by computation and analysis of air quality on an adequate period leads to the establishment of real-time air quality monitoring(Kumar & Jasuja, 2017). Sensors play a vital role in sensing physical parameters without human intervention. Advancement and affordability in the sensors enable implementation in the various areas for establishing a real-time monitoring system(Kim, Chu, & Shin, 2014). A feasible platform is required for implementing the real-time monitoring system and IoT (Internet of Things) is an emerging technology that is capable of implementing a real-time system in any field/area(Gubbi, Buyya, Marusic, & Palaniswami, 2013; Singh, Gehlot, Khilrani, & Mittal, 2020). Internet of Things (IoT) network is the integration of sensors/actuators and wireless communication protocol. Low power consumption and long-range transmission are the requirements of the Internet of Things (IoT)(Mekki, Bajic, Chaxel, & Meyer, 2019). In the case of landfill sites, it is very harmful to humans to monitor the environmental parameters. UAV (Unmanned Aerial Vehicle) is potential and capable of environment monitoring through aerial and ground sensing systems(Cook, 2020; Manfreda, 2018; Singh et al., 2020). UAV is an aerial vehicle that is guided automatically with a remote controller in many areas where human intervention is challenging. UAV (UAVs) is implemented in the agriculture, oil & gas industries, and seaports for inspection, security, and surveillance(Menouar et al., 2017). With the advancement in technology, the sensor module has been integrated into UAVs for sensing the environmental parameters of greenhouse gases through aerial sensing(Barrientos, 2015). Communication is also integrated into the unmanned aerial vehicle (UAV) for transmitting the sensory data from the sensor node to the server which enables the establishment of the Internet of Things (IoT), where the sensory data can be visualized in the cloud server for smart analysis and estimation of pollutants(Angrisani, 2019; Chen et al., 2018; Hernández-Vega et al., 2018; Hu et al., 2019). In some cases, Unmanned Aerial Vehicle acts as an intermediate node for transmitting the sensory data to the server for achieving reliable and error-free messages(Saraereh, Alsaraira, Khan, & Uthansakul, 2020).

Industry 5.0 is an intelligent concept, which can make the industry smarter and more connected with many things using a single platform such as IoT, and UAV technology. The UAV technology can boost up the speed of Industry growth by connecting the multiple manufacturing units with a long-range communication channel. The UAV technology is becoming more important as this can be coupled with other applications such as smart city, IoT etc. The UAV technology can improve the output of manufacturing units, which will take Industry 5.0 up to the next level.

Unmanned Aerial Vehicles (UAVs), which have evolved a great deal in the last years in terms of technology (e.g., control units, sensors, UAV frames) and have significantly reduced their cost. The UAV is completely autonomous and acts as a gateway for logging the sensory data to the cloud server via internet protocol (IP) with the assistance of a wi-fi module, which will lead this technology to be used for different applications in smart cities such as the environmental monitoring, transportations, and Industry 5.0, etc.

UAVs can help the industry in automatable and tedious tasks, like the ones performed regularly for determining the inventory and for preserving item traceability(http, 2022). The Fifth Industrial Revolution will pair humans and machines to further utilize human brainpower and creativity to increase process efficiency by combining workflows with intelligent systems(Nahavandi, 2022). Smart UAVs are the next big revolution in UAV technology promising to provide new opportunities in different applications, especially in civil infrastructure in terms of reduced risks and lower cost(Shakhatreh, 2019). This paper includes a brief study about the use of drones for smart city applications such as environmental monitoring.

In this study, we implement a UAV network based on IoT (Internet of Things), and a cloud server for tracking the air quality of the landfill sites in real-time and alerting the UAV for capturing the visuals to detect the exact cause of the pollutant at the landfill sites. Each sensor node senses the air quality of the landfill and transmits the sensory data to the UAV via LoRa communication. The objective of this study is to record the sensory data and visuals of the various gases (NO_2, VOC, CO_2, SO_2) of landfill sites using IoT & UAV and then visualized in a graphical user interface form.

In this study, two different Wireless communication (LoRa radio modem and Wi-Fi) are integrated for establishing an energy-efficient and long-range connectivity for air quality measurement. LoRa radio modem functioned as a transceiver for the sensory data reception from the sensor node in the UAV. Wi-Fi modem connectivity allows the UAV to upload the data to the cloud server via the Internet protocol stack. Sensory data are being stored on the cloud platform and displayed visually. Data of each sensor node and site are labeled independently for effective air quality monitoring of each site. The cloud server predicts the air quality index patterns of different locations using sensory data and visuals. The IoT and cloud infrastructure allow the real-time monitoring of air quality with a UAV from a remote location.

This study is focused on the continuous monitoring of harmful gasses using the UAV for the area which are located at the hill areas or at a far distance from the range of physical monitoring. The UAV concept is helpful to monitor or record the pollution conditions in different regions. The study is also carrying the discussion about the industry 5.0 perspectives using UAV long-range communication.

The contribution of the paper is as follows:

- The Implement of a UAV network based on IoT (Internet of Things) and a cloud server for tracking the air quality of the landfill sites
- Continuous monitoring of Nitrogen dioxide (NO_2), Volatile Organic Compounds (VOC), Carbon monoxide (CO), Sulphur dioxide (SO_2), Ozone, to alert the people to protect them from harm.
- The concentration of each gas is stored in the cloud server and is presented in the graphical representation
- Different parameters such as Eigenvalues, Correlation Coefficients, and Regression Parameter have also been analysed graphically for the recorded data.

The paper is layout in the following sections, in section 1, the introductory part about the UAV, IoT, and environment monitoring processed has been discussed. Section 2, is a brief review of the different literature published in reputed journals. The history and the different applications of IoTs are discussed in Section 3. The UAV technology for Smart City and Industry 5.0 along with the Area Covered by UAV and The line-of-sight probability have been discussed in Section 4. In Section 5, a brief discussion about the proposed system has been done. Results and discussion are in Section 6. The study has been concluded in Section 7.

2. Review of literature

Traditionally, air quality measurements have been performed by ground-based inspection, satellite imagery, and aircraft. These are a bit challenging due to uneven and complex barriers. However Unmanned Aerial Vehicles are capable of monitoring air quality with the assistance of the sensors embedded in them(Villa, Gonzalez, Miljievic, Ristovski, &

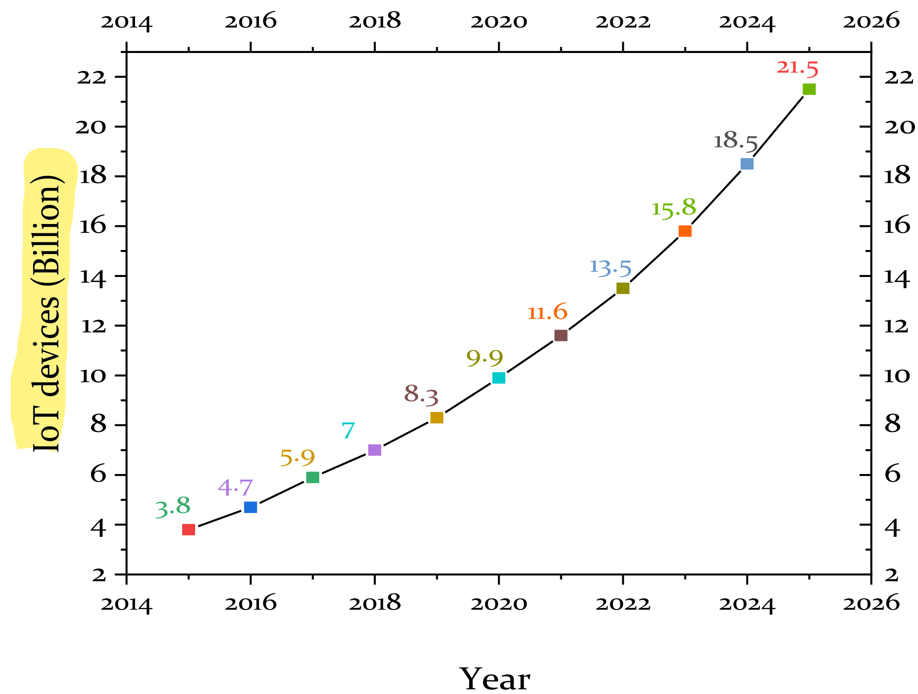


Fig. 1. Growth of IoT devices (2015–2025) (State of the IoT, 2018).

Morawska, 2016). A UAV is implemented for collecting the air quality data with the assistance of distinct sensors in the 3-dimensional form and the data is logged in the cloud server for further analysis(Wivou et al., 2016). Unmanned Aerial Vehicle technology is widely spread in areas for monitoring things in the place where human intervention is a challenging one. Mobility in UAV enables the replacement of the wireless sensor network for monitoring things in the wireless scenario. A low-cost effective vertical UAV is proposed for monitoring the air quality parameters and can be afforded by the individual citizen due to the low-cost factor(Bolla, 2018). Environment UAVs (E-UAVs) is specially designed for the automatic detection of excessive pollutants in the air at the specified height. Air Quality Health Index (AQHI) map is established in this study for mapping the environmental analysis concerning variation in the time intervals(Rohi, Ejofodomi, & Ofualagba, 2020).

An IoT (Internet of Things) based UAV is designed for automated real-time monitoring and detection of aerial plumes in the air via a particulate matter sensor, and this UAV facilitates the response team in determining the precise positioning of air plumes in real-time mode (Seiber, Nowlin, Landowski, & Tolentino, 2018). An autonomous UAV vehicle is proposed for sensing the real-time air quality parameters like CO (carbon monoxide), CO2 (Carbon dioxide), O3 (Ozone gas), temperature, dust, and humidity with the sensor module and transmitting the sensory data to the server via internet connectivity(Al-Hajjaji, Ezzin, Khamdan, El Hassani, & Zorba, 2017). Dr-TAPM is a real-time and cloud server-based air pollution monitoring UAV that monitors the air quality through CO, NO2, SO2, and O3 sensors and communicates to the cloud server via internet connectivity(Duangsuwan & Jamjareekulgarn, 2020). Air pollution is a global problem that causes deaths due to emission of the gases that severely affect human health and leads to death. PM 2.5 is a pollutant that seriously affects the human lungs. However, traditionally air monitoring is limited to monitor the air pollutants at the ground surface. Balluino is a balloon / UAV-based system proposed for monitoring the PM 2.5, other pollutants in the air and transmitting the sensory data to the cloud server where the users can monitor the air quality in real-time(Shah & Xiong, 2019).

A hybrid IoT-based quadcopter monitoring system is proposed for monitoring the contamination of air and water with distinct UAVs. One master UAV controls the two slave UAVs for air quality & two slave UAVs for water contamination(Agarwal, Shukla, Singh, Gehlot, & Garg, 2018). Wireless Sensor Network and Cloud-based environment monitoring system is implemented with the integration of sensors, Zigbee communication, and Node MCU module(Singh et al., 2020). A robot is designed that operates based on a cloud-based mobile application and Zigbee & Node MCU communication protocol has been integrated for enabling the communication between robot and cloud server(Singh, Gehlot, Mittal, Samkaria, & Choudhury, 2018). Internet of Things (IoT) based UAV system is proposed for detecting human intrusion with a geophone sensor, a seismic sensor, and Zigbee. Wi-Fi communication protocols are integrated for the transmission of any intrusion data to the cloud server(Singh et al., 2018).

ARMS is an unmanned aerial vehicle (UAV) that is designed for measuring the air quality index (AQI) and it can generate real-time fine grade mapping of AQI(Yang, Zheng, Bian, Song, & Han, 2018). AQ 360 is a novel designed unmanned aerial vehicle (UAV) that can monitor the air quality level from 360° aerial image and the low energy consumption is the advantage(Gao, Hu, Bian, Mao, & Song, 2020). A hybrid UAV system monitors the air quality based on aerial and ground sensing and it can deliver energy-efficient and fine graded AQI(Hu et al., 2019). Long Range (LoRa) communication-based unmanned aerial vehicle is designed for sensing the air quality parameters and communicating the air quality sensory data over long distances without human intervention (Chen et al., 2018). Long Range (LoRa) wireless communication-based unmanned aerial vehicle (UAV) is proposed for monitoring the CH4 over the oil fields with the assistance of gas sensors and precise location is provided via Global Positioning System (GPS)(Liu, Yang, & Zhou, 2020). A vision-based system for predicting and monitoring the air quality index from the haze images captured by unmanned aerial vehicle (UAV) of the aerial and grounded sensing system(Yang, Hu, Bian, & Song, 2019). Wireless Sensor Network (WSN) & IoT-based Unmanned Aerial Vehicle (UAV) are implemented for efficient data collection and analysis(Popescu, Stoican, Stamatescu, Ichim, & Dragana, 2020). A remote controller-enabled unmanned aerial vehicle with a wireless communication module is implemented for real-time sensing of air quality index(Zhi, Wei, & Yu, 2017). There are different types of UAV systems available for different applications such as Mini, close range, and short range. The specifications for these UAV systems are different

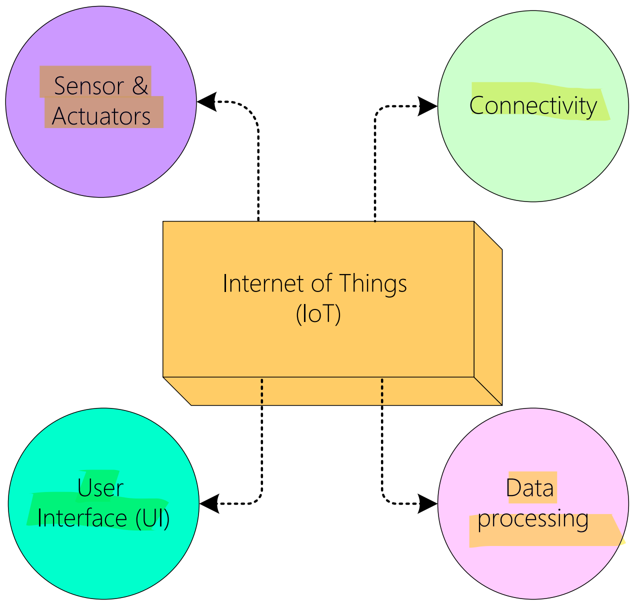


Fig. 2. Four components of the IoT (Singh & Kapoor, 2017).

from each other. The range of the Mini UAV system is less than 10 km and the flight height is 150 to 300 m. The range of the Close-range UAV system is from 10 to 20 km, and the flight is 3000 m. The range of the short-range UAV system is from 30 to 70 km and the flight height is 3000 m. The quality of the recorded image or data may be degraded if the UAV systems will be used at a range more than its specifications (Yearbook, 2011).

In another paper, the authors have introduced an approach, in which unmanned aerial vehicles are used for fire detection applications. In this study, two parameters were considered, which are communication throughput and network delay with maximum coverage(Sharma & Singh, 2021). In this study(Zeng & Zhang, 2020), the authors introduced an energy-efficient technique for unmanned aerial vehicle communication. In this technique, the author proposed an approach to reduce energy consumption during communication using a UAV. Concerning the landfill scenario, it is a challenge for a human to monitor the air quality continuously due to the emission of stinky smells and gases from the landfill sites. In another manuscript(Wang, Jiang, Zhang, Ma, & Hao, 2020), UAV-based recognition and target tracking system has been developed. This system is used an intelligent gimbal system with the facilities of fast image processing and accurate camera positioning. For anomaly detection of UAV flight data, a spatio-temporal correlation has been proposed in another manuscript(Zhong, Zhang, Wang, Luo, & Miao, 2022). This correlation technique is based on short-term memory (LSTM) method. The finding of the literature is stating that UAV and IoT could be a good solution for continuously measuring the pollutants in landfill sites. Therefore, in this study an-internet of things (IoT) based UAV system is proposed and described. The main objective of IoT-based UAVs is for monitoring the air quality parameters and capturing the visuals of the landfill sites where they are harnessed for the health of humans.

3. Internet of things (IoT)

According to Global system for mobile association (GSMA) intelligence forecasting, the number of IoT connections will reach 25 billion globally by 2025 and The growth of IoT devices from 2015 to 2025 is presented in the Fig. 1 (GSMA, 2021).

IoT is an interconnection of physical things with a virtual environment through internet protocol (IP) connectivity(Mohammed & Esmail, 2015). In IoT, the physical things are embedded with sensors and actuators for sensing and controlling(Singh & Kapoor, 2017). A communication protocol is integrating with the sensors & actuators for updating and transmitting the sensory data to the server. Integration of sensor/ actuators, connectivity, data processing, and user interface (UI) forms an IoT network(Mohammed & Esmail, 2015).

In Fig. 2 illustrates the key components of the IoT. Sensor/actuators, connectivity, data processing, and UI are the key components of IoT. A sensor is a device that senses and responds to the input from the physical environment. The output signal of the sensor is converted into a digital signal. Connectivity is necessary for the transmission of sensory data and they are different wireless protocols for establishing connectivity. The distinct kinds of wireless communication technologies are existing in the IoT. Global system for communication/ global packet for radio service (GSM/ GPRS), Zigbee, BLE (Bluetooth Low Energy), 6LoWPAN, Radio frequency identification (RFID), long-range (LoRa), Sigfox, Narrowband IoT (NB-IoT), Long Term Evolution (LTE), IEEE 802.11 g Wi-Fi, near field communication (NFC), and Z-wave are the communication technologies. Zigbee, Z-wave, BLE, 6LoWPAN, and IEEE 802.11 g are short-range wireless communication technologies, and GSM / GPRS, LTE, LoRa, Sigfox, and NB-IoT are the communication technologies for the long-range distance. Generally, the transmission range of these communication technologies like IEEE 802.11 Wi-Fi, IEEE 802.15.4 Zigbee, and IEEE 802.15.1 BLE are short-range, however, except IEEE 802.11 Wi-Fi remaining two wireless communication technologies consume low power for the data transmission. LoRa, NB-IoT, and Sigfox are the emerging low power and long-range communication technologies that meet the goal of the IoT. Among the three LPWAN technologies, LoRa (Long Range) is the optimal communication system with secure bi-directional communication and free licensed band capabilities. RFID and NFC identification technologies that work on radio waves and these technologies transmission range are up to 4 cm-10 cm. The technical specifications of the communication technologies are briefly mentioned in Table 1.

Table 1
Technical Specifications of wireless communication technologies (Jawad, Nordin, Gharghan, Jawad, & Ismail, 2017).

Parameters	Zigbee	BLE	6LoWPAN	LoRa	Sigfox	NB-IoT	GSM/GPRS	Wi-Fi
Network	LAN	PAN	PAN	WAN	WAN	WAN	LAN	LAN
IEEE Standard	802.15.4	802.15. 1	802.15.4	802.15.4 g	802.15.4 g	NA	NA	802.11a, b, g, n
Frequency Band	868/915 MHz and 2.4 GHz	2.4 GHz	868/915 MHz and 2.4 GHz	433 MHz, 868 MHz, 915 MHz	868/915 MHz	Licensed LTE bands	850–1900 MHz	2.4 / 5 GHz
Range	(10–50) metre	10 m	(10–50) metre	5 km (Urban), 20 km (Rural)	10 Km (Urban), 40 km (Rural	1 Km (Urban), 10 Km (Rural)	(5–30) km	100 m
Network Topology	Star, P2P, mesh, tree,	Star, bus	Star, mesh	Star of stars	Star		Cellular system	Point-to-hub
Power consumption	Low	Low	Low	Low	Low	Low	High	High
Company	Zigbee Alliance	Bluetooth Special Interest Group	Internet Engineering Task Force	Semtech alliance	Sigfox company	3GPP	GSM Association.	Wi-Fi Alliance

Table 2
Data processing platform.

Data processing Platform	Cloud type	Graphical User Interface (GUI)	Analytics
AWS	Private	Dashboard	–
Cayenne	Public	Dashboard, mobile app	Real-time analytics
IBM Watson IoT	PaaS	Dashboard	Edge analytics
Nimbits	Hybrid	Dashboard	Google analytics
Oracle IoT cloud	Public (PaaS)	Dashboard, mobile app	Business analysts
The things.io	Public	Dashboard	AI-based analytics
ThingSpeak	Public	Dashboard, mobile app	MATLAB
The ThingsBox	Private (IaaS)	Emoncms	Emoncms
Ubidots	Public	Dashboard	Google analytics

Data processing is one more component of the IoT, where the sensory data is converted to machine-readable form. Classification, sorting, and calculations are performed on the data for getting meaningful information. Different tools are existing for data processing in the internet of things (IoT). Table 2 illustrates the different IoT data processing platforms with parameters like cloud type, GUI, and analytics.

3.1. Long range

IoT is an emerging area where wireless communication is the key contributor for robust and effective implementation of connecting physical things on the internet for real-time monitoring(Silva, Rodrigues, Al-Muhtadi, Rabêlo, & Furtado, 2019). Multi-hop short-range communication systems, such as ZigBee and Bluetooth, have been perceived as a feasible way to introduce IoT services for several years (Biral, Centenaro, Zanella, Vangelista, & Zorzi, 2015). Low power consumption and long-range transmission are the major characteristics that are required for the implementation of IoT systems(Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014). Low Power Wide Area Network (LPWAN) is a promising solution that meets the characteristics of IoT and utilizes the open Industrial, scientific & medical (ISM) band for transmitting the data. In LPWAN, the end devices are connected to the gateway node to bridge to the IP world. The fundamental architecture of these networks is designed to provide wide area coverage and guarantee connectivity to nodes that are deployed in the remote environment. LoRa is one of the novel physical layers of LPWAN solution that provide long-range transmission with low power consumption developed by Semtech(Ray, 2016). LoRa works mainly on the frequency bands of 902–928 MHz (United States) and 863–870 MHz (Europe) and also operates in the lower ISM bands at 433 MHz and 169 MHz(Mekki et al., 2019). Fig. 3 illustrates the fundamental architecture of LoRa.

From the architecture, LoRaWAN is the communication protocol and LoRa is the physical layer. LoRaWAN utilizes the long-range star-to-star topology as shown in Fig. 3. LoRa physical layer works on the chirp spread spectrum (CSS) modulation. In the LoRaWAN network, the nodes are not connected with a gateway. The data transmitted by a node is received by gateways and forwards the received packet from the end node to the cloud server via ethernet, cellular, or Wi-Fi). Sensors and actuators are the end nodes in the architecture that communicate with more than a gateway. The network server acts as a filter, for evaluating the duplicate packets from distinct gateways, sending the packet to the application server.

4. The UAV technology for smart city and Industry 5.0

Using UAV’s (Fig. 4) data is collected from different landfill sites (urban, rural, remote, etc). This collected data is sent to the base station and the ground control station. At ground control stations data is sent for storage, analysis, cleaning etc. Accordingly, data is refined and used in various applications such as: smart grids, emergency surveillance, emergency rescue, smart agriculture, smart metering, industries etc.

There is a big demand for new communication solutions which can support aeronautical applications including UAVs for smart cities and Industry 5.0. Many Aeronautics agencies such as (EUROCONTROL) European Organization for the Safety of Air Navigation and (NASA) National Aeronautics and Space CNPC links Administration are leading in the development of these communications systems. In applications, UAS Control and Non-Payload Communication (CNPC) links are widely used to enable the safe operation of UAV(Kerczewski & Griner, 2012). CNPC links are used to provide safety within aircraft safety applications. 2012 International Telecommunications Union World Radio

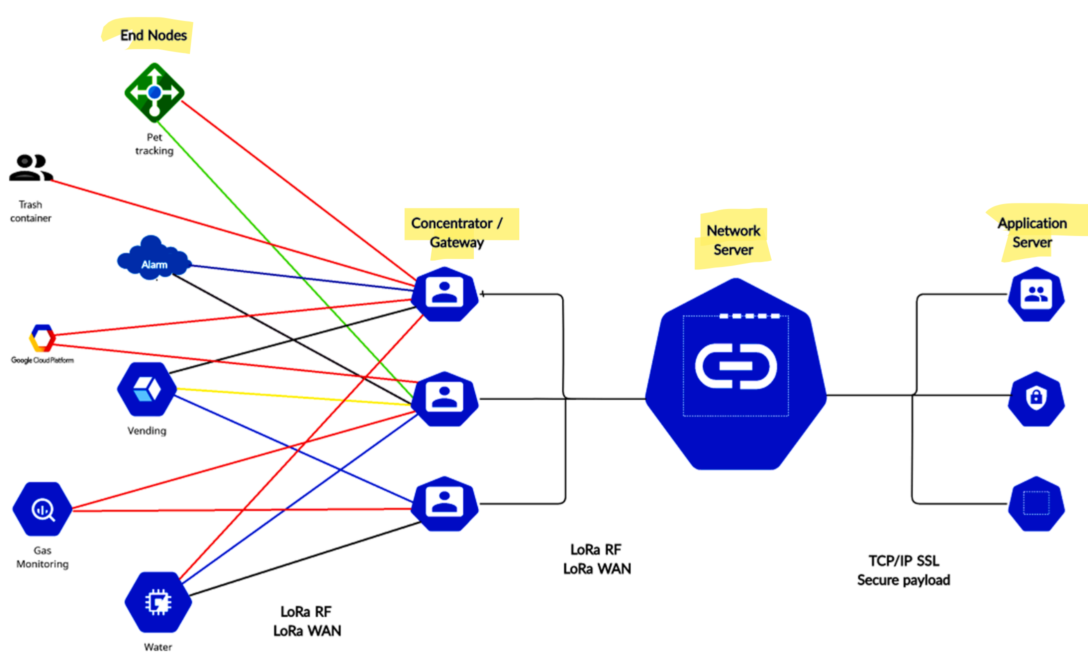


Fig. 3. The fundamental architecture of LoRaWAN (LPWAN, 2021).

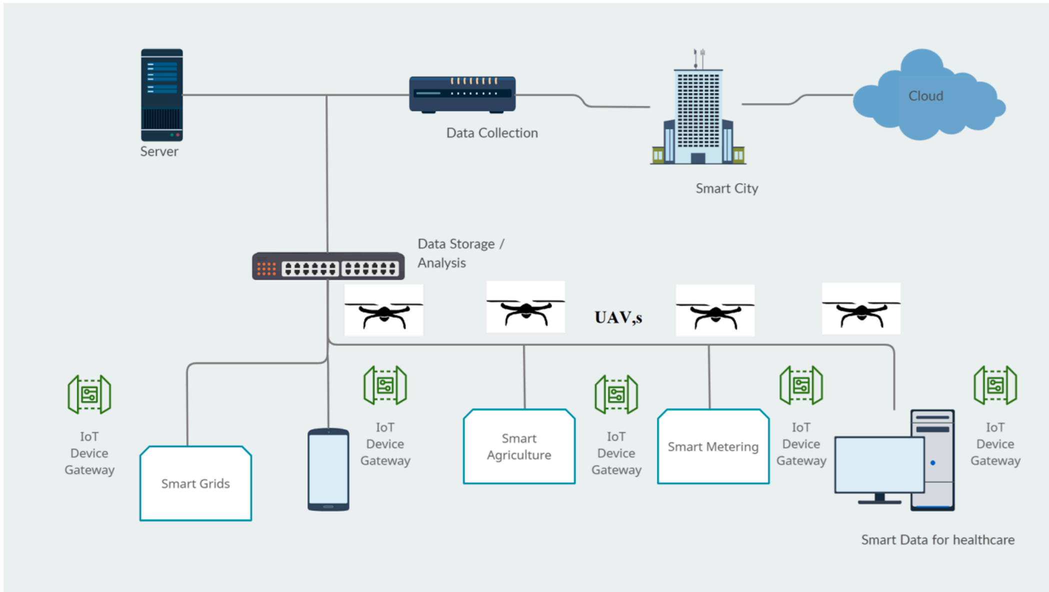


Fig. 4. Smart city data collection using UAV.

Table 3
CNPC data communication rates (Kerczewski & Griner, 2012).

Aircraft size	Downlink rate	Uplink rate	Downlink usages
Medium and Large (>55 kg)	234,134 bps	6925 bps	Basic, weather radar and video
Medium and Large (>55 kg)	34,133 bps	6925 bps	Basic and weather Radar
Medium and Large (>55 kg)	13,573 bps	6925 bps	Basic services only
Small (<=55 kg)	4008 bps	2424 bps	Basic services only

Communications Conference (WRC-12) has been assigned two frequency spectrums to CNPC, and these spectrums are from 960 MHz to 1164 MHz (L-Band) and from 5030 MHz to 5091 MHz.

The CNPC data communication rates are categorized according to the Aircraft size (Table 3). The advantage of the UAV is that it can associate with several applications such as communications, atmosphere monitoring, Industry 5.0, agriculture, transportation, emergency conditions and smart things.

This is an emerging technology, which can dynamically change its location in an urgent condition. It is an intelligent solution for smart city applications and Industry 5.0 (Fig. 4). DJI family UAVs are widely used for public safety applications (Fig. 5). These family drones are very flexible in terms of land and take off, camera fitting and can fly around the object.

Because of the better SAR, DJI drones can be used in the applications such as 3D modeling, disaster management and environmental monitoring(Brokaw, 2016). This family drones can easily handle the problem such as fogging and dusting. Many studies have been carried out in terms of various design issues such as time flight constraint and 3D deployment. In(Alzenad, El-Keyi, & Yanikomeroglu, 2018), the study about the enhancement of QoS and the coverage area has been carried out.

The communication between UAV and Ground Control Station can be serviced by various protocol such as UranusLink(Kriz & Gabrlik, 2015); UAVCan(Development Team, 2014)and Mavlink(Khan, Jhanjhi, Brohi, & Nayyar, 2020). The protocol, which is widely used by the large number of UAVs and GCS is Micro Aerial Vehicle Link (Mavlink) protocol(Kwon, 2018). Micro Aerial Vehicle Link (Mavlink) protocol is developed by Lorenz Meier in 2009(Atoev, Kwon, Lee, & Moon, 2017).

4.1. Area Covered by UAV

In(Kosmerl & Vilhar, 2014), a discussion to enhance the coverage performance for public safety communications has been carried out. The coverage can be enhanced by deploying several drones in the concerned area, shown in Fig. 6.

Over an emergency condition or in the disaster area, these drones can communicate with each other as well as with responder too.

Fig. 5. Public safety DJI drone (Vattapparamban, 2016).

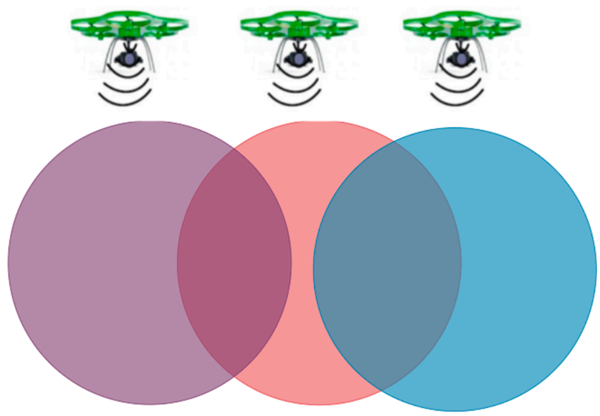


Fig. 6. Deployment several drones in the concerned area.

4.2. The line-of-sight probability

The line-of-sight probability is a straight path to the targeted location from the source in 3D space. For a better communication system, the received signal should be distortion free and should have sufficient signal strength. The capacity and the coverage area can be estimated by using the LoS probability of a UAV, which will help to collect data in smart environments. A UAV having a larges coverage area can connect and be serviced be too many devices.

If the coverage area radius is r and drone height is H, then the distance between the ground receiver and the drone D can be written as equation (1):

$$D = \sqrt{r^2 + H^2} \tag{1}$$

The elevation angle θ will also depend on the coverage radius and the height of the drone. The elevation angle can be expressed as equation (2):

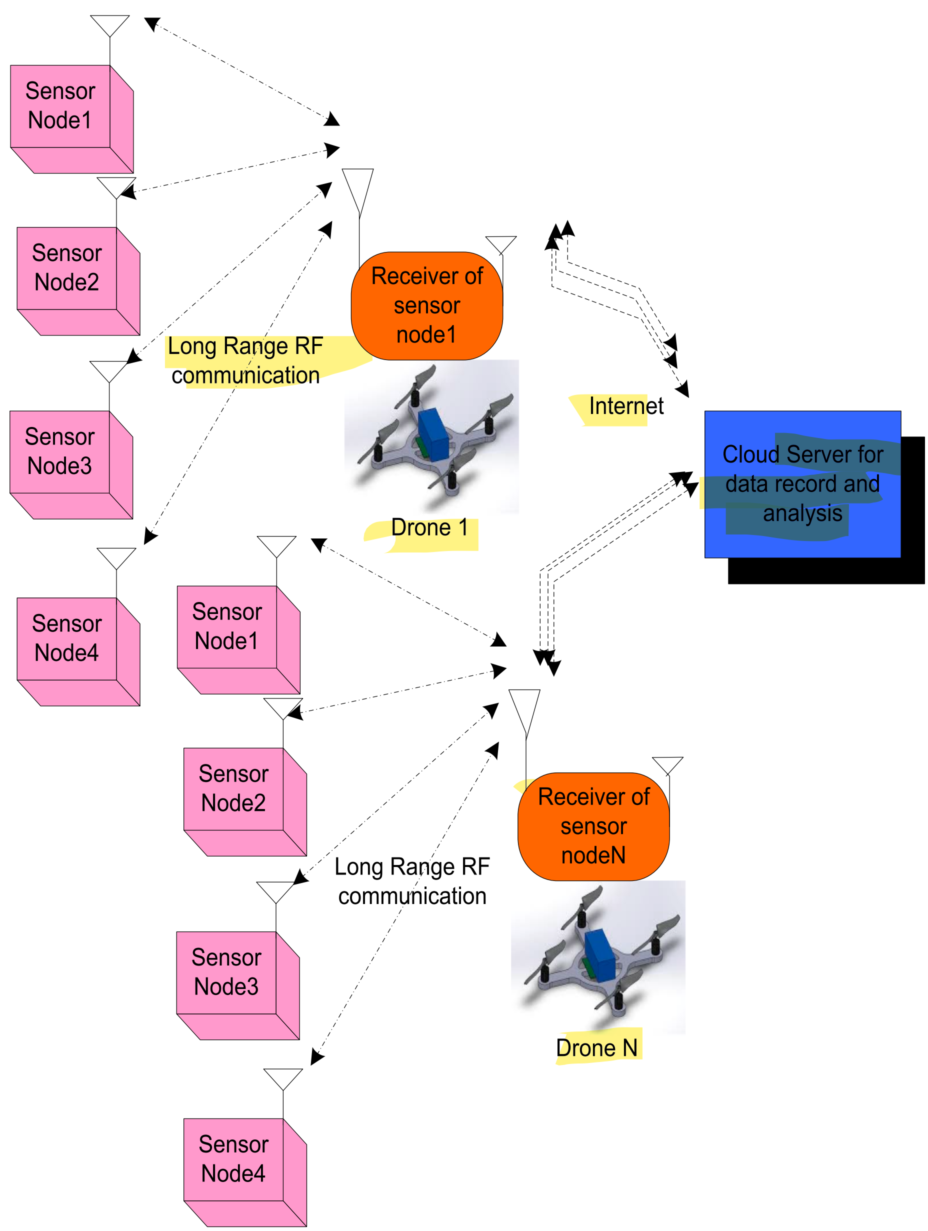


Fig. 7. Overall Architecture of the System.

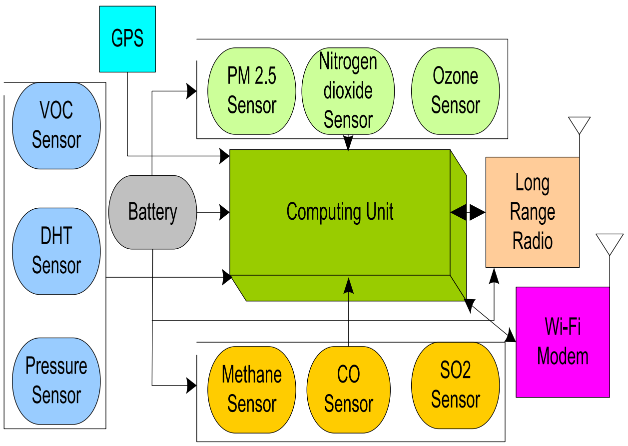


Fig. 8. Sensor Node.

$$\theta = \tan^{-1}\frac{H}{r} \quad (2)$$

The path loss is depending on the distance between the receiver and the drone, the speed of light C and the carrier frequency F_c. The path loss can express as the equation (3) (Al-Hourani, Kandeepan, & Jamalipour, 2014):

$$\text{PathLoss} = \begin{cases} 20log(4\pi FcD/C) + \varepsilon_{\text{los}} LoS \\ 20log(4\pi FcD/C) + \varepsilon_{\text{nlos}} NLoS \end{cases} \quad (3)$$

In equation (3), the average additional losses are represented by ε_{los} &$\varepsilon_{\text{nlos}}$. Line of site is one of the important advantages of UAV communication. Realistic path loss models can be obtained by predicting the accurate LoS probability. One of the most critical parameters to predict LoS probability is the elevation angle. LoS probability and plotting are depended on the environmental variable a, b, c, which values are varying according to the various locations(Al-Hourani, Kandeepan, & Lardner, 2014). The LoS probability can be expressed as by equation (4) (Al-Hourani et al., 2014):

$$\text{PLoS} = \prod_{m=0}^{n} [1 - e^{\frac{-[Ht - \frac{(m+0.5)(Ht-Hr)}{n+1}]^2}{2b^2}} \quad (4)$$

$$n = r\sqrt{ab} - 1 \quad (5)$$

$$r = Htan(\theta) \quad (6)$$

Equation (5) is representing the product index and equation (6) is representing the ground distance between the transmitter and receiver. The height of the transmitter and receiver is represented by Hr and Ht. Holis et al. (Holis & Pechac, 2008)calculated the P_{LoS} based on environmental parameters and θ, which is expressed as equation (7):

$$\text{PLoS} = \text{B1} - (\text{B1} - \text{B2})/(1 + (\frac{\theta - \text{B3}}{B4})^{B5} \quad (7)$$

The environmental parameters are denoted by B1 to B5 in(Holis & Pechac, 2008).

5. Proposed architecture

In this section, an internet of things (IoT) based UAV system is proposed and described. The main objective of IoT-based UAVs is for monitoring the air quality parameters and capturing the visuals of the landfill sites where they are harnessed for the health of humans. The architecture of IoT-based UAV is shown in Fig. 7, where the architecture comprises three different modules for monitoring the air quality parameters. A sensor node, UAV, and cloud server are three different modules. In this UAV carry the deploys the 'N' number of sensor nodes in

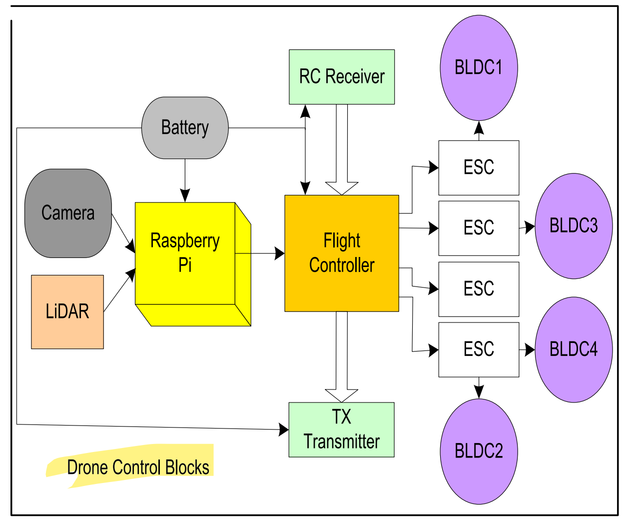


Fig. 9. The architecture of the UAV Control Board.

the landfill sites where the intervention of humans in that place is difficult and harmful. The function of the sensor node is to sense the air quality parameters in real-time, as well as providing real-time alerts to the UAV via long rang communication when air quality parameters exceed the standard level, and it is shown in Fig. 8. The data collection process was held in the Delhi NCR region. It is for testing the working of the proposed architecture. Two different Wireless communication (LoRa radio modem and Wi-Fi) are integrated for establishing an energy-efficient and long-range connectivity for air quality measurement. Different pollutants have been recorded using UAV and IoT sensors. The data has been recorded in the cloud on a real-time basis. The recorded data is further used for the calculation of different graphical parameters such as Eigenvalues, Correlation Coefficients, and Regression Parameter.

The sensor node comprises of PM2.5 sensor, NO_2 (Nitrogen dioxide) sensor, Ozone (O_3) sensor, methane (CH_4) sensor, CO (Carbon monoxide) sensor, Volatile organic compounds (VOC), DHT sensor, SO_2 (Sulfur dioxide) sensor, and pressure sensor provides the different environmental parameters in the landfill site. The location of each sensor node is tracked through GPS (Global Positioning System). Sensor node utilizes openly licensed spectrum LoRa (Long Range) as a wireless communication protocol. If the optimal range of gases in the air exceeds, the sensor node alerts the UAV via long-range communication. The UAV fly to the landfill sites concerning the location provided by the sensor node through GPS and UAV initiates the capturing of the visuals of the landfill site with the assistance of a camera.

A long-range communication protocol is integrated into both the sensor node and UAV to establish reliable and long-range communication. The UAV is integrated with a Long-range modem and IEEE 802.11 based wi-fi module, it receives the sensory data from the LoRa based sensor node and logs the data to the cloud server via a Wi-Fi module. The visuals which are stored in the cloud server are utilized for evaluating the exact cause of variation in the air quality. The sensory data of the different sites are visualized in the graphical user interface of the cloud server.

The sensor node is the primary unit in the architecture for collecting the air quality parameters via different sensors and it is shown in Fig. 8. The computing unit receives the sensory information from the sensors, and it activates the long-range radio modem for communicating the sensory information to the UAV. Every sensor in the sensor node senses the different gas in the air and it senses the humidity, temperature, and pressure. Global Positioning System provides the locality of the node for easiness in identifying the sensor node. The battery is the power source of the sensor node.

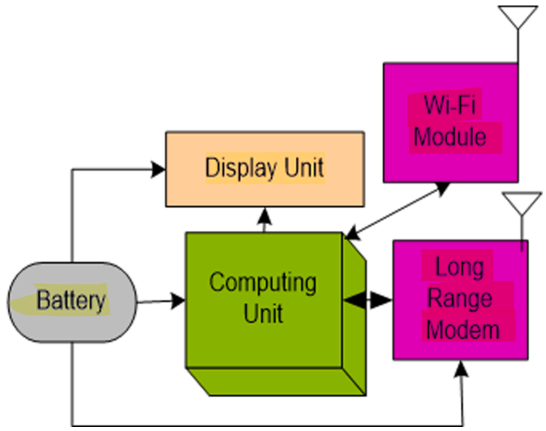


Fig. 10. Receiver for senor node on UAV board.

The control board of the UAV is for controlling the movement of the UAV. The UAV controller board is equipped with a radio transmitter that transmits the instructions received to the receiver in the UAV is shown in Fig. 9. The function of the UAV controller is also to control the power or RPM on each motor on the UAV concerning the command received at the controller. Four brushless DC motors are embedding in the UAV. LiDAR (Light Detection and Ranging) is embedded in the UAV for avoiding obstacles in the air. A camera module is integrated with a raspberry pi controller for processing the captured visuals.

The UAV board is also integrated with a sensor node for receiving the sensory data from the ground sensor nodes and it is shown in Fig. 10. The computing unit in the sensor node checks whether the sensory data from the sensor node is received. If yes, it initiates the long rang modem for receiving the data as the long-range modem is common in the sensor node. IEEE 802.11 based Wi-Fi module uses TCP/IP stack for logging the sensory data into the cloud server with internet connectivity.

5.1. Computer-Aided design model of UAV and sensor node

The 3D model of the sensor node and UAV is designed, and it is shown in the Figs. 11a and 11b. CAD represents computers that are used in aiding design. With CAD tech a full model can be built in an imaginary world, so that we can visualize properties such as height, weight, distance, material, and colour before the model is used for a certain purpose. The top view and side view of the sensor node in a 3D model. The sensor node is carried by the UAV to deploy in a landfill site.

The dimensions of each side in the UAV are represented in the Fig. 11c. The length, height of every component in the UAV is presented. Four propellers are embedded on the four sides of the UAV for smooth aerial movement in the air. The UAV is capable of carrying the sensor node. The dimensions of the sensor node that illustrates the length, breadth of each end are presented in the Fig. 11c.

6. Results and discussion

The measurement of air pollutants is presented in the graphical representation. The concentration of each pollutant is measured for two different hours at an interval of 20 min. The obtained sensory data is evaluated in Table 4 of the optimal range of gas.

The concentration of CO and O_3 is measured in the air by the CO sensor & the O_3 sensor is recorded in the cloud server. Fig. 12a illustrates the concentration of CO & O_3 recorded in the cloud server. Concerning the Table 4 both concentrations are in the optimal range.

PM 2.5 & SO_2 are the other two gas concentrations that are sensed and recorded in the cloud sensor with the assistance of PM 2.5 & SO_2 sensors. Fig. 12b. Illustrates the level of concentration of PM 2.5 & SO_2 in the air at different hours. When comparing this gas concentration level with the Table 3, PM 2.5 concentrations level is in the optimal range and SO_2 concentrations level exceeded the optimal range.

The sensory data of VOC and NO_2 concentrations in the air at different hours is shown in the Fig. 12c. The graph reveals that both

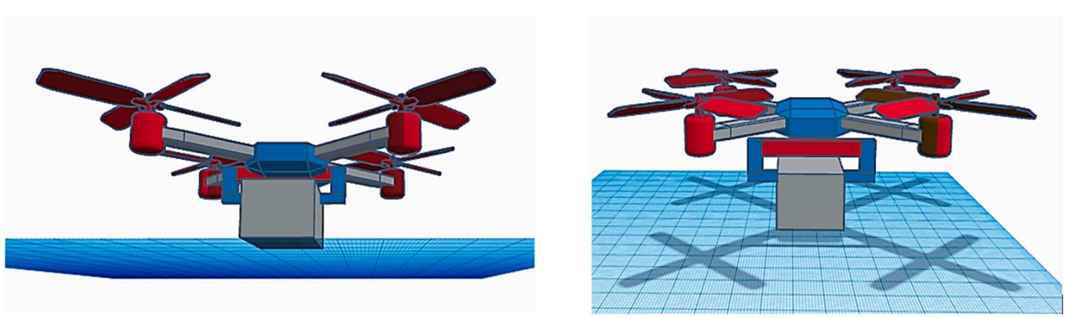


Fig. 11a. 3D model of sensor node.

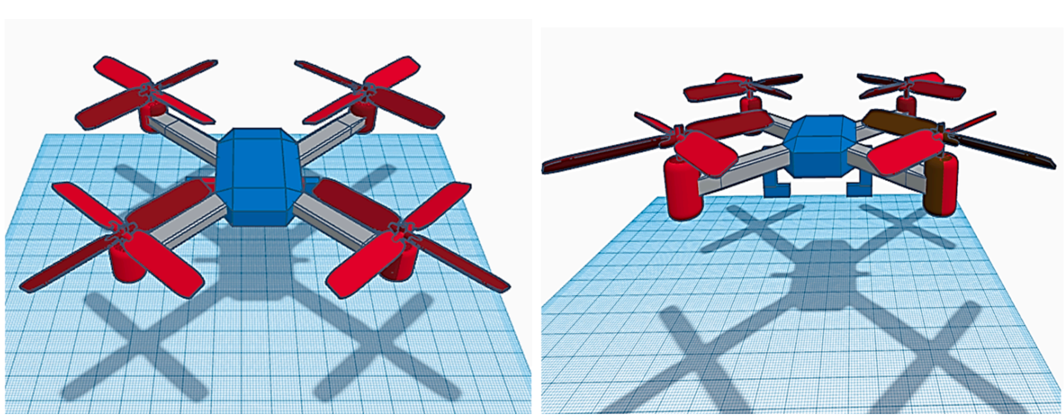


Fig. 11b. 3D model of UAV.

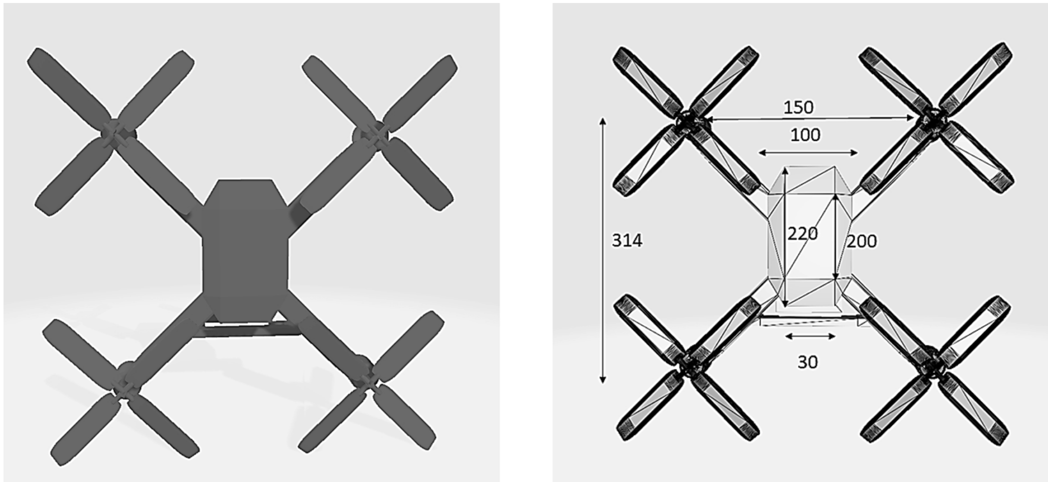


Fig. 11c. The layout of UAV and sensor node.

Table 4
The optimal range of gas in the air.

S. No	Gas	Optimal range
1	SO_2	(0–850 ug/m^3)
2	NO_2	(0–1000 ug/m^3)
3	CO	(0–16000 ug/m^3)
4	O_3	(0–240 ug/m^3)
5	VOC	(0–250 ug/m^3)
6	Particle	(0–150 ug/m^3)

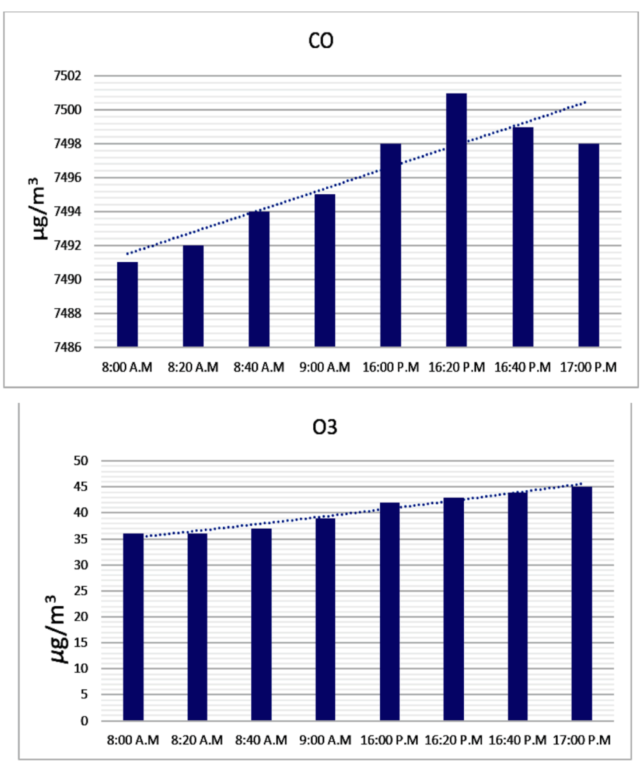


Fig. 12a. Sensory data of CO & O_3.

concentration levels are in the optimal range when comparing the optimal level range from Table 4.

Table 5 illustrates the sensory data recorded using UAV technique. It is seen that the value of pollutants is increasing with increment in time.

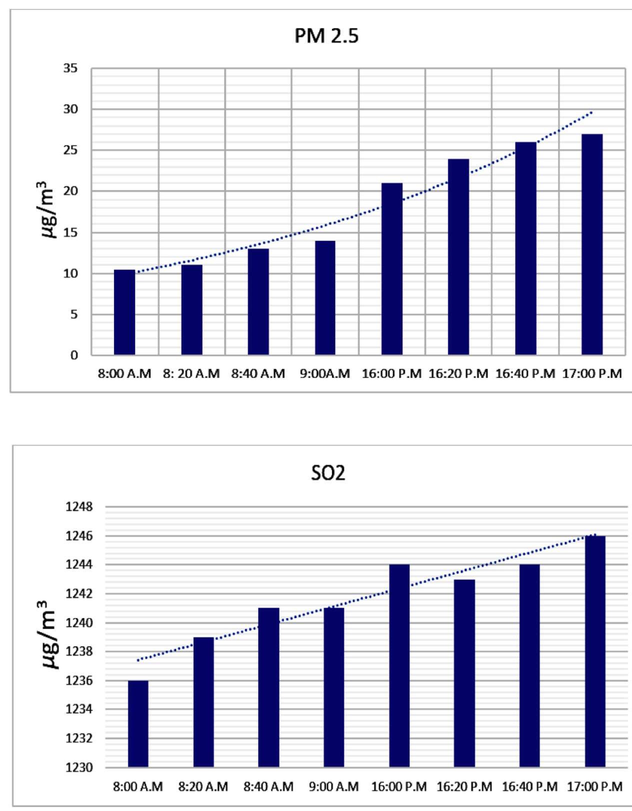


Fig. 12b. Sensory data of PM 2.5 & SO_2.

It is due to the emission of pollution through vehicles, industries, and other sources.

Table 6 illustrates the measurements of different variables such as mean and standard deviation and in Table 7, the measurements of eigenvalues have been discussed. The analysis of eigenvalues has been elaborated graphically in Fig. 13 (a). The correlation between different recorded parameters is shown in Fig. 13 (b). The correlation graph showing that how the recorded parameters have been correlated with each other. The correlation concerning time can be shown in Fig. 14 (a) & (b).

The graphical representation of regression analysis for CO, O_3, PM2.5, SO_2, VOC and NO_2 can be shown in Figs. 15 to 17.

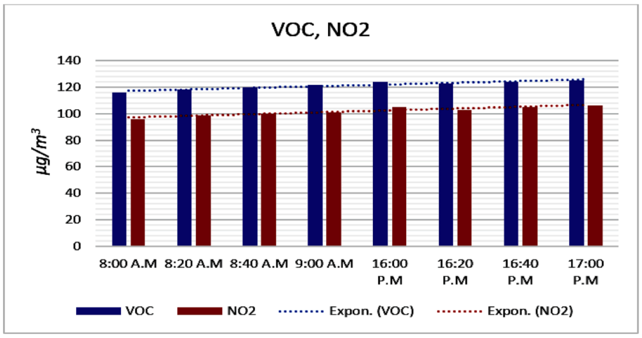


Fig. 12c. Sensory data of VOC & NO2.

The regression analysis of Nitrogen dioxide (NO_2), Volatile Organic Compounds (VOC), Carbon monoxide (CO), Sulphur dioxide (SO_2), PM2.5 and O_3 in Figs. 15 to 17 is showing that the pollutants level is linearly increasing concerning time. Table 8 illustrates the comparison of the proposed study with recent studies. Most studies focused on monitoring the air quality parameters on the outdoor environment as part of smart cities. As discussed earlier in the review of literature UAVs are providing an opportunity to monitoring in such an environment where human involvement is difficult. In a few studies' UAV is for implemented monitoring the air quality parameters with the onboard sensor unit. However, the onboard sensor unit is embedding with a communication protocol that is limited to the short-range transmission and high-power consumption.

6.1. Forecast analysis

A forecast analysis has been performed for a period of the next few hours, which can be shown in Fig. 18. Nitrogen dioxide (NO_2), Volatile Organic Compounds (VOC), Ozone and PM2.5 are the pollutants that were considered for the forecast analysis. The results of this analysis are showing that the level of pollutants is raising hour by hour. Which is an indicator of high pollution in the future. This analysis is helpful to alarm the situation and indicate the pollution control board in advance.

In recent studies, the UAV is the only medium for sensing and transmitting the air quality data to the cloud server. However, it is somehow challenging for gathering the air quality data of the complete area. When it comes to landfill air quality monitoring limited studies have implemented UAV for sensing air quality. In the proposed study, we have proposed a system that is integrated into two distinct nodes. The first node is LoRa based sensor node that is deployed in the landfill site for sensing the threshold limit of gases emitting with the assistance of air quality sensors. The receiver node is a UAV where it acts as a gateway node for gathering the data from the sensor nodes that are deployed in the landfill site through the long-range transmission. UAV is capable of handling multiple wireless communication protocols. Wi-Fi is embedded in the UAV logs the sensory information of every node to the cloud server on internet protocol. The deployment of this system in the landfill site enhances the monitoring of the air quality in real-time.

7. Conclusion

Air quality monitoring of the landfill site is key for combating the emission of GHG houses. With technology advancement, the communication protocol and UAV are providing an opportunity for real-time monitoring of the air quality parameters of a landfill site. The real-time monitoring of the landfill sites is required for monitoring the variations in the concentration level of the pollutants in the air. In this research, we propose a system to track the air quality of landfill sites and alerting the UAV for gathering sensory data of individual nodes and capturing the visuals in evaluating the exact pollutant in the air via long-range & Wi-Fi. UAV can deploy sensor nodes and act as a gateway for transmission of the sensory data to the cloud server via long-range (LoRa) and wi-fi modem. In the cloud server at a different period, the sensory data of the different sensor nodes are recorded. The proposed system will facilitate the surveillance of landfills without human interference in real-time and encourage municipal authorities to enact the necessary measures for maintaining the optimal air quality. The forecast analysis is showing that the level of pollutants is raising hour by hour in the concerned areas. Which is an indicator of high pollution in the future. The proposed system can also be used in other applications such as agriculture, mining, and conservation. The future scope of our proposed work is that we can use drone technology to manage livestock and survey crops. UAV can be used strategically to monitor and spray crops. An advanced approach will be carried out for collecting data from UAVs, which will work more accurately. An accurate data collection will lead to forecast about the pollution levels more accurately.

Table 7
Measurement of Eigenvalues.

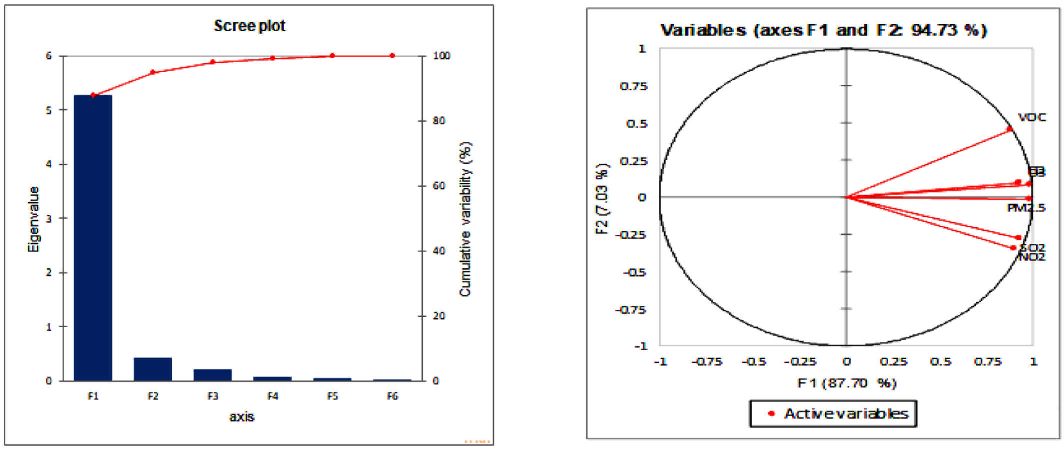
	F1	F2	F3	F4	F5	F6
Eigenvalue	5.262	0.422	0.197	0.078	0.035	0.005
Variability (%)	87.697	7.032	3.292	1.307	0.590	0.082
Cumulative %	87.697	94.729	98.021	99.328	99.918	100.000

Table 5
Data Collected through UAV.

µg/m3	8:00AM	8:20AM	8:40AM	9:00AM	16:00PM	16:20PM	16:40PM	17:00PM
CO	7491	7492	7494	7495	7498	7501	7499	7498
O_3	37	36	37	40	42	43	44	45
PM2.5	10	11	13	13	22	24	26	28
SO_2	1236	1239	1241	1241	1244	1243	1244	1246
VOC	121	120	120	121	122	122	122	122
NO_2	98	100	100	101	101	102	105	105

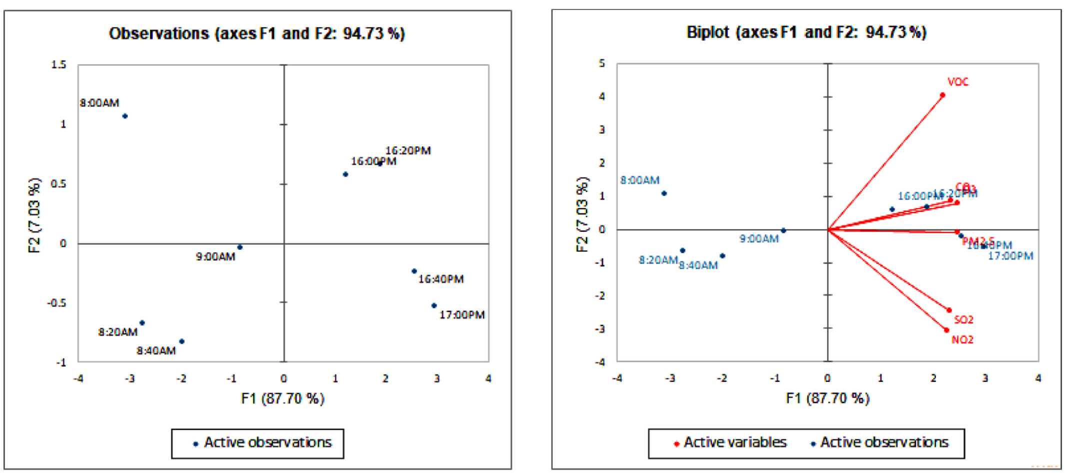
Table 6
Measurement of different Variables using Recorded Data.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
CO	8	0	8	7491.000	7501.000	7496.000	3.546
O_3	8	0	8	36.000	45.000	40.500	3.505
PM2.5	8	0	8	10.000	28.000	18.375	7.347
SO_2	8	0	8	1236.000	1246.000	1241.750	3.196
VOC	8	0	8	120.000	122.000	121.250	0.886
NO_2	8	0	8	98.000	105.000	101.500	2.449



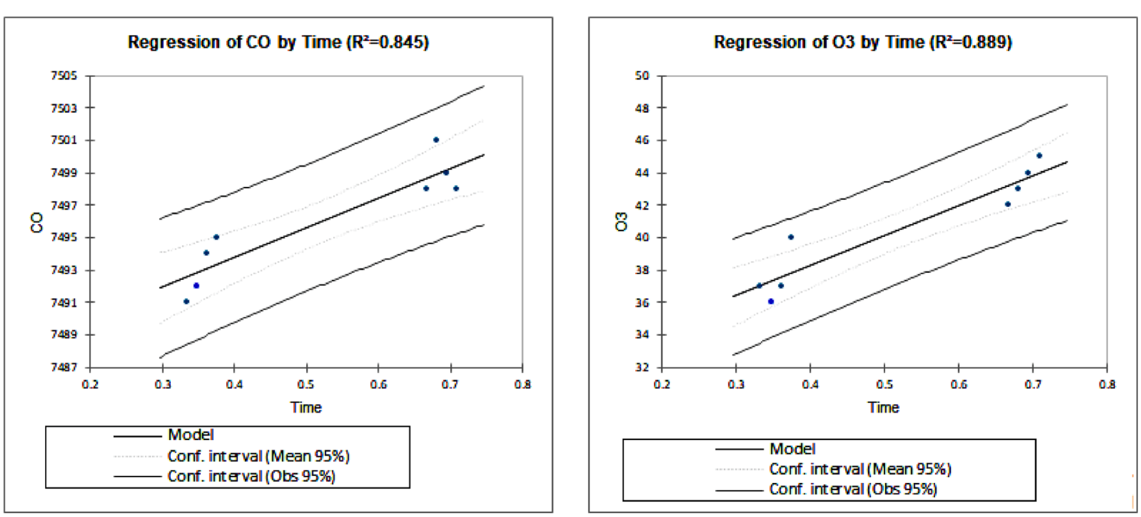
(a) (b)

Fig. 13. (a). Eigen value analysis, (b) Correlation in between recorded parameters.



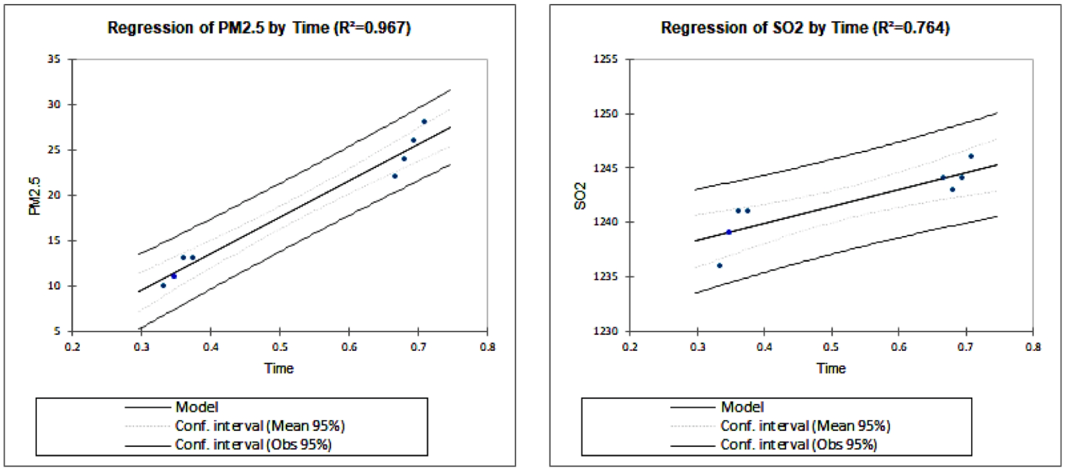
(a) (b)

Fig. 14. (a). Parameter observation, (b) Correlation in recorded parameters with time axis.



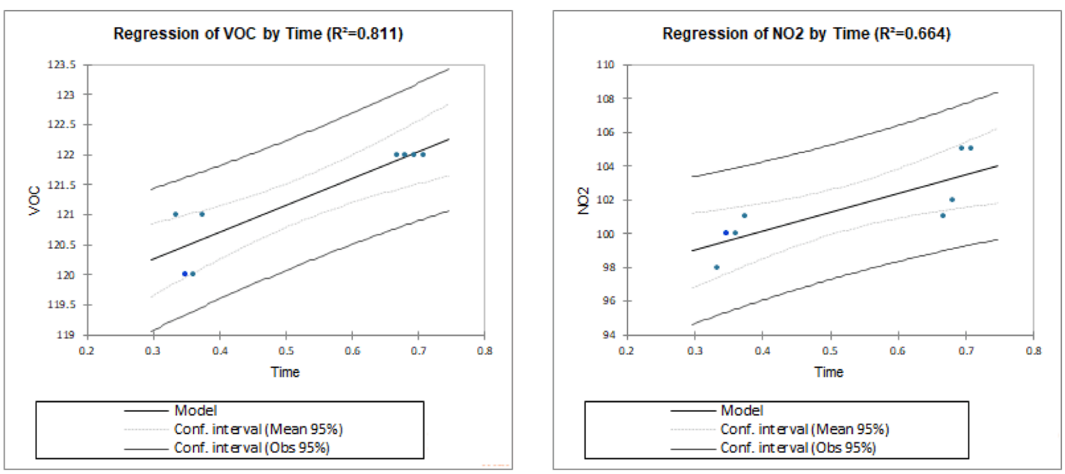
(a) (b)

Fig. 15. (a). Regression analysis of CO, (b) Regression analysis of O_3.



(a) (b)

Fig. 16. (a). Regression analysis of PM2.5, (b) Regression analysis of SO_2.



(a) (b)

Fig. 17. (a). Regression analysis of VOC, (b) Regression analysis of NO_2.

CRediT authorship contribution statement

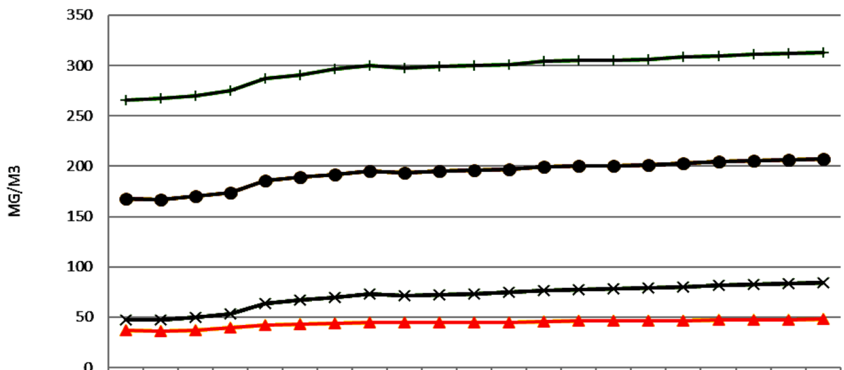
Rohit Sharma: Conceptualization, Methodology, Software, Visualization, Investigation, Data curation. **Rajeev Arya:** Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table 8
Comparison of proposed study with recent studies.

Research	Sensor node	connectivity	Gateway node	Area of implementation
(Bolla, 2018)	Yes (UAV)	Xbee	No	Outdoor
(Rohi et al., 2020)	Yes (UAV)	Xbee	No	Smart city
(Hernández-Vega et al., 2018)	Yes (UAV)	Xbee	No	Smart city
(Nasution, Muchtar, & Simon, 2019)	No	Wi-Fi	No	Smart city
(Jo, Jo, Kim, Kim, & Han, 2020)	Yes	Long term evolution (LTE)	No	Indoor
(Zakaria et al., 2018)	Yes	Inbuilt wi-fi	No	Smart city
(De Medeiros & Girao, 2020)	Yes	ESP 32 (Wi-Fi)	No	Outdoor
(Moharana, Anand, Kumar, & Kodali, 2020)	Yes	GSM & Wi-Fi	No	Indoor
(Karar, Al-Masaad, & Reyad, 2020)	Yes	Zigbee & ESP 8266 Wi-Fi module	No	Indoor
(Gu, Michanowicz, & Jia, 2018)	Yes (UAV)	Wi-Fi	No	Outdoor
(Angrisani, 2019)	Yes (UAV)	LoRa	Yes	Outdoor
Proposed	Yes (UAV)	LoRa and Wi-Fi	Yes	Outdoor



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
NO-2	98	100	100	101	101	102	105	105	104	104	104	104	105	105	105	105	105	105	105	105	105
VOC	121	120	120	121	122	122	122	122	122	122	122	122	123	123	123	123	123	123	123	123	123
PM2.5	10	11	13	13	22	24	26	28	27	28	28	29	31	31	32	32	33	34	35	36	36
O3	37	36	37	40	42	43	44	45	44	45	45	45	46	46	46	46	47	47	47	48	48

HOUR

Fig. 18. The forecast analysis for NO, VOC, PM2.5 and O3.

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