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Review of Technologies and Architectures for UAV-Air Quality Monitoring in Hazardous Environments

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***Abstract* - Certain technologies enable remote monitoring in hazardous environments. These technologies range from wired and wireless communication, sensors, IoT, waste management, and cloud technologies. This paper reviews the technologies and architectures for Unmanned Aerial Vehicles' air quality monitoring systems in hazardous environments. It exposes the technologies and protocols associated with the UAV hardware, gas sensing, storage, and transmission. This paper identifies and discusses UAVs in air quality monitoring, IoT, wired and wireless communication technologies, choices, and applications in air quality monitoring in Hazardous environments.**

Indexed Terms - IoT, Monitoring, Hazardous environment, Gas sensor, cloud platform, IoT Architecture.

I INTRODUCTION

The fast-paced civilization is the primary cause of air pollution, which creates a hazardous atmospheric environment by the release of harmful particles from the automotive, chemical, fertilizer, and power generation industries. A hazardous environment is any area where the conditions or substances present can pose a threat to human health, safety, or the surrounding ecosystem. The hazardous environment with polluted atmospheric air poses a risk to environmental health, and causes damage to crop, buildings, and respiratory and cardiac diseases, responsible for 7 million deaths globally (Manisalidis et al., 2020). These extreme and inhospitable environments have a higher air quality index (AQI) than recommended, and areas contaminated by toxic chemicals, radiation, or biological agents. In a hazardous environment, the particulate matter (PM10 and PM2.5), nitrogen dioxide (NO2), sulfur dioxide (SO2), and carbon monoxide (CO) are the main pollutants causing an elevated air quality index (AQI). For instance, the current air quality index (AQI) in Nigeria for PM2.5 concentration is six and a half times higher than the value of the World Health Organization's 24-hour recommended air quality index, and causes problems around the globe. These prevalent air quality-related problems are fueling deployments of air quality monitoring technologies, which provide a means to assess the severity of the problems and measure the effectiveness of initiatives designed to tackle air pollution(Hossein Motlagh et al., 2023; Zaidan et al., 2022)

Traditionally, air quality measurement by fixed ground-based monitoring stations is not sufficient (Hossein Motlagh et al., 2023; Zaidan et al., 2022). Therefore, increasing the resolution of information, such as the use of low-cost sensors, manned aircraft, and satellites, is a possible alternative to supplement the resolution. However, deploying, operating, and maintaining these solutions is equally laborious (Hossein Motlagh et al., 2023; Zaidan et al., 2022).

In recent years, the use of Unmanned Aerial Vehicles (UAVs) has expanded significantly across various industries and applications. One of the areas where UAV technology shows immense promise is in environmental monitoring and surveillance, particularly in hazardous environments where human access is limited or risky. Within the realm of environmental monitoring, two critical aspects in hazardous environments are air quality monitoring and video surveillance. Air quality monitoring involves measuring pollutants, particulate matter, gases, and other airborne contaminants to assess environmental health and human exposure risks. Video surveillance, on the other hand, involves capturing visual data, monitoring activities, and providing situational awareness for safety, security, and incident response purposes. Combining air quality monitoring and video surveillance capabilities within a UAV platform offers a comprehensive solution for monitoring environmental conditions, detecting anomalies, and supporting decision-making in hazardous environments.

To efficiently monitor air quality and its associated hazards, unmanned aerial vehicles, technology, computing, and communication technologies must interact with the Edge of the network (sensors and actuators) and other physical systems to be controlled in what is known as a cyber-physical system (Jin et al., 2017). The advancement in embedded sensors, computation, and communication technologies has made control of complex dynamical cyber-physical systems made up of heterogeneous dynamic network components. An

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example is the UAV-air quality monitoring system, where the sensors are saddled with the responsibilities of data acquisition.
This paper focuses on reviewing IoT and cloud architecture, wired and wireless communication technologies, gas sensors and types, and their applications in a UAV air quality monitoring system in hazardous environments.

II INTERNET OF THINGS (IoT)

Many sectors are starting to consider the Internet of Things as part of their strategy. Because of the expansion of mobile devices, embedded and ubiquitous connectivity, cloud computing, and data analytics, the Internet of Things (IoT) was coined by a member of the RFID development group in 1999, and it has just recently become more prominent in the real world.
(Patel & Patel, 2019). The term "Internet of Things" refers to a broad concept of things, particularly everyday objects, that may be read, identified, located, and addressed via information sensing devices, and controlled over the Internet, regardless of communication method (whether via RFID, wireless LAN, wide area networks, or other means). Everyday things include not only the electronic devices we use or higher-tech products like automobiles and equipment, but also non-electronic commodities like food, clothing, and furniture.(Maier et al., 2017). For example, the idea of a "smart city" is gaining popularity. Smart urban systems incorporate smart transportation systems, smart grids, public lighting management, traffic light management, waste management, and environmental monitoring to improve residents' quality of life while also greatly increasing asset efficiency. Energy, water, mobility, buildings, and government are the five primary areas of smart city industries. The intelligent city's next granular step is to apply these concepts in a more confined physical setting. In the context of commercial buildings, space. Almost all intelligent city systems may be used to improve building management. (Kellow et al., 2019; Manjunath et al., 2018). The Internet of Things (IoT) uses the Internet to connect dissimilar objects. In this sense, and to make accessibility easier, all possible gadgets should be connected to the internet. To achieve this purpose, sensors can be developed at numerous locations to collect and analyze data to improve utilization. (Talha et al., 2018). A heterogeneous network of embedded electronic devices, mobile devices, industrial equipment, and other devices is used in robust waste management solutions. Devices may differ in terms of communication platforms, networking, data processing, data storage capacity, and transmission power. To share data, all these devices must be connected via networking and communication protocols that allow them to communicate and collaborate. Communication protocols are crucial in the Internet of Things. They act as the backbone of the IoT system, allowing IoT devices to communicate over the network. The data interchange format, data encoding, and device addressing mechanism are all defined by these protocols. Sequence control, flow control, and packet retransmission are among the various functions they provide. A multitude of communication protocols and standards are used in the Internet of Things. The most common IoT communication technologies are ZigBee, Bluetooth, Z-Wave, 6LOWPAN, and NFC. IoT application communication protocols such as HTTP, MQTT, CoAP, or XMPP, as well as routing protocols such as RPL and 6LoWPAN, are not secure by design. The next section provides a quick overview of Internet of Things (IoT) applications for smart cities.

III APPLICATIONS OF THE INTERNET OF THINGS (IOT) NETWORK

The diversity of different devices that may be connected to the Internet, owing to the Internet of Things, has resulted in the emergence of a wide range of identity, data authentication and integrity, privacy, and secure communications applications and architectures for smart cities. The following are the key targets in the domain of knowledge relevant to our activity:
Smart communities and cities: The use of IoT can lead to the production of a variety of other services that interact with the environment. As a result, it may provide opportunities for contextualization and geo-awareness. Furthermore, pooled intelligence will improve decision-making processes and give citizens more authority. (Alenezi et al., 2018). In addition, a common middleware for future IoT-based smart city services may be offered.
(Jlassi et al., 2016; Parashar & Tomar, 2018; Sikder et al., 2018). Smart buildings and homes: Through the IoT platform in the house, heterogeneous devices will enable the automation of common activities. Services can be realized through web interfaces by changing objects into information devices that are connected to one another over the Internet. Sensor networks are used in a wide range of applications in homes and intelligent buildings. These applications connect intelligent gadgets to the Internet so that they can be monitored or controlled from afar.
(Pilloni et al., 2018; Tatnall & Davey, 2017; Wu et al., 2018). In recent years, for example, intelligent lighting has received a lot of attention (Tao et al., 2018). If lighting accounts for 19% of global electricity use in cities, it is responsible for 6% of greenhouse gas emissions. In this manner, clever lighting control methods might save up to 45 percent of the energy required for illumination. (Y. Xie, 2019). The attention of this work will be on the application of IoT in Hazardous environments.

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Waste Management: The use of IoT in waste management is growing more popular around the world, and some research studies have been conducted (Bughin et al., 2016). A strategy is provided that employs numerous solutions to address spillage and inefficient collection schemes. The system provides a monitoring platform for waste management institutions to manage alarm records by making orders for garbage collectors/drivers that may be accessed through a mobile application system. The suggested system includes a smart waste bin with a microcontroller-based system built into and attached to the top of the bins to detect bin level status and communicate it to drivers and management via SMS and an application system. A system framework comprising of smart bin, gateway, and a control station was proposed in (Ouda et al., 2017). Real-time data on the status of the bins was made available by incorporating a graphical user interface into the proposed system. Garbage management organizations can use this real-time access to bin status to more efficiently manage waste bins. This effort, on the other hand, focuses on bin status monitoring rather than delivering bin geolocation data. In
(Chaudhari & Bhole, 2018) Smart solid waste containers for both wet and dry rubbish were proposed and deployed at several locations, including monitoring and collection schedules. The hardware, software system in the cloud, mobile application, and routing information are the four major phases of this system. All of these components, as well as a desktop administration system, SMS on bin status, and geolocation information, are included in our solution.

Waste management systems based on the Internet of Things (IoT) were proposed in
(Aleyadeh & Taha, 2018; Ouda et al., 2017). In each scenario, a smart bin with a microprocessor, a waste level sensor, and an internet connectivity module was demonstrated. Both systems lacked a way to keep track of the garbage collectors on the job, but this would be rectified in ours. In recent publications, the need to solve waste management issues in smart cities has been highlighted.
(Aleyadeh & Taha, 2018; Ouda et al., 2017). The fundamental purpose of these works is to propose a framework for dealing with waste management by presenting a smart waste-bin that can manage waste in a smart city project. Sensors measure the weight of waste and the level of rubbish inside the bin in this system. The system may also adapt to a network environment to manage all waste management data.
(Abdullah et al., 2019; Ali et al., 2018; Alqahtani et al., 2020; Atayero et al., 2019; Catarinucci et al., 2020; Haque et al., 2020; Maksimovic, 2019; Talha et al., 2018). This study introduces a novel approach of smart waste city management that cleans the city's environment at a minimal cost. The sensor model detects, measures, and broadcasts waste volume data via the Internet in this fashion. Regression, classification, and graph theory are used to process the acquired data, which includes the location of the garbage bin and its serial number. Following that, a new strategy is proposed for managing waste collection in a dynamic and efficient manner by predicting waste status, classifying trash bin locations, and monitoring waste volume.
Waste management is a globally visible phenomenon. If not adequately supervised, it poses a significant environmental threat. There is a significant volume of trash disposal that has occurred without sufficient planning, posing both economic and environmental issues. Due to direct trash disposal, there is a great amount of damage in terms of environmental deterioration, health hazards, and economic decline. A geographic information system (GIS) is a tool that aids in the effective coordination of spatial data.
(Adedotun et al., 2020; El-hallaq & Mosabeh, 2019; Erfani et al., 2017; Kashid et al., 2015; Kiettitanabumroong et al., 2017; Prabhakaran et al., 2017; Ruiz-Chavez et al., 2019). However, in most African countries, particularly Nigeria, this useful planning technique has not been employed to manage trash disposal. On the technical side, existing systems are frequently closed and uncommercialized, forcing agencies to rely on GIS solutions that aren't designed for garbage disposal, limiting the environmental management efforts of developing countries.(Singhvi et al., 2019) A smart system that monitors the garbage and provides real-time status is required for the construction of smart cities. Municipal corporations in India do not yet have access to real-time information about trash cans. In order to address this issue, we are building an Internet of Things (IoT)-based system that can send a notification to a company about the overflow and toxicity level of the dustbins. A website is also being created to keep track of the data related to the trash cans. The dustbin status is updated on the website, and a message is sent to the mobile phone through GSM module. On this website, citizens can also submit complaints related to dustbins or waste management. Arduino is used as a microcontroller to interface between GSM/GPRS modules with sensors. Ultrasonic sensors and gas sensors are used for the measurement of the dustbin level and toxicity, respectively. In (Chu et al., 2018), Using an IoT prototype with sensors, show a garbage collection management solution centered on supplying intelligence to waste containers. It has the ability to read, collect, and send massive amounts of data across the Internet. When such data is placed in a spatio-temporal context and analyzed by sophisticated and optimized algorithms, it can be used to manage garbage collecting mechanisms dynamically. (Idwan et al., 2020; Saha et al., 2019). However, none of these studies focused on what happens at the edge of the devices of the IoT network, the problem of data quality and false data detection have not yet been studied in this domain. This study addresses the problem

of data quality and false data detection by Sensors used in Hazard Management Alert System HMAS, which has not been addressed in literature in the waste management research domains. In (Nirde et al., 2017) suggested a wireless solid waste management system for smart cities that allows municipal corporations to remotely check the status of dustbins via a web server and maintain cities clean more efficiently by reducing the cost and time required.
(Salah & M., 2018; Yusof et al., 2018)
An IoT-based cost-effective solution has been designed, as shown. It uses smart technologies, such as WeMos and Ultrasonic sensors, to monitor refuse in real time. This system makes use of electronic devices as well as the ThingSpeak platform to reduce waste collection and transportation costs and time.
(Dev et al., 2018; Dubey et al., 2020; Rajkamal et al., 2014; Rao et al., 2020) based on their nature of composition, effective and efficient waste collection and segregation procedures at the residential level. Metal, plastic, and biodegradable garbage are all placed separately in different sections of the dustbin. A green bin model for separating dry and wet household garbage. In a circular pattern, five separate bins are organized. The garbage collection module is positioned above the bins, allowing rubbish to be emptied as needed (Rajkamal et al., 2014). This system is neither small nor cost-effective. Waste was segregated into metallic, moist, and dry waste using a segregation model. However, this method is inefficient since it categorizes materials solely based on dielectric constant values, and some dry trash is labeled as wet waste. A device that uses the sound resonance frequency produced when it hits a galvanized iron platform to distinguish between plastic bottles and tin cans (Sejera et al., 2017). This system separates and recycles plastic bottles and tin cans. A recyclebot has been created (Murugaanandam et al., 2018) It employs image processing techniques to separate recyclable and non-recyclable garbage. Also utilized is ZigBee. This system is complicated, and efficient operation necessitates communication between parts. Using an IoT-based system, a methodology for collecting and disposing of household waste was developed(Misra et al., 2018). The autonomous waste management system classifies waste into biodegradable and non-biodegradable categories using artificial intelligence and deep learning techniques. (Sharma et al., 2020). To achieve efficient results, the system must be well-trained. As a result, if the system is not well-trained before being used, its efficiency of operation will be quite low.

IV ARCHITECTURES OF INTERNET OF THINGS

Universally, there is no agreed-upon architecture for the Internet of Things due to its complexity and vast span of applications. The above are two of the basic architectures that have been defined by the researchers: the three-layer architecture and the five-layer architecture, respectively. To represent, organize, and arrange the IoT in a way that allows it to work successfully, architecture is required. The IoT's distributed, heterogeneous nature necessitates the use of hardware/network, software, and process architecture that can support these devices, their services, and the workflows they will affect. Several existing IoT architectures are described here. (Minoli et al., 2017) .

A Three-Level Architecture of Internet of Things

The three-level Internet of Things architecture is applied in a wide range of applications. In (Borges et al., 2017; Chamoso et al., 2018; Cirani et al., 2014; Ray, 2018) Various scalable architectures for large-scale IoT networks are presented. In most IoT networks, the following three tiers can be found: Sensors and actuators, as well as knowledge, are all internet-oriented. But in(Mahmoud et al., 2016), Perception level, network level, and application level are the three tiers of IoT architectures. The perception layer, the network layer, and the application layer are the three layers that make up the most basic Internet of Things architecture. The perception layer is the architecture’s most fundamental physical layer. It has sensors for detecting and collecting data, which are then utilized by the other layers to achieve a successful result. The layers detect the physical factors indicated, as well as any other intelligent items present in the surroundings. The network layer is the architecture's beating heart. It connects smart things to other smart items, network devices, and servers via the perception layer's smart objects. It also allows the information acquired in the previous layer to be shared. The network layer is also in charge of sensor data processing. The application layer oversees its namesake services, i.e., it oversees supplying application services to customers according to their needs. It specifies the many domains in which IoT can be used and how it can be used, such as smart cities, smart homes, smart transportation, and so on. The three-layer design serves its function and establishes the basic concept of the Internet of Things; it is not sufficient to research to arrange the finer parts and features of research. As a result, the five-layer architecture was created.

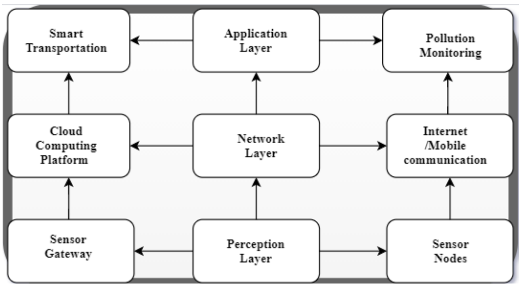

Figure 1: Three-Level Architecture of Internet of Things (IoT) network

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B. Five-Level Architecture Internet of Things (IoT) network

It has five layers: perception, transport, processing, application, and business. The perception and application levels function similarly to the three-layer architecture. As a result, the functionality of the last three layers has been outlined below.

(Sethi & Sarangi, 2017). The conveyance of information received and collected by the perception layer to the processing layer and vice versa is the primary purpose of the transport layer. It uses networks including WiFi, 3G, LAN, RFID, Bluetooth, and NFC to carry out this trade. Because it stores, processes, and analyzes the huge volumes of data received from the transport layer, the processing layer is sometimes known as the storage or middleware layer. Aside from that, the processing levels serve the lower layers by providing a variety of services. Many technologies are used, including databases, cloud computing, and big data processing modules. The business layers are responsible for all of the layers beneath them, as well as the overall IoT system, including services, data, and user privacy and profit models.

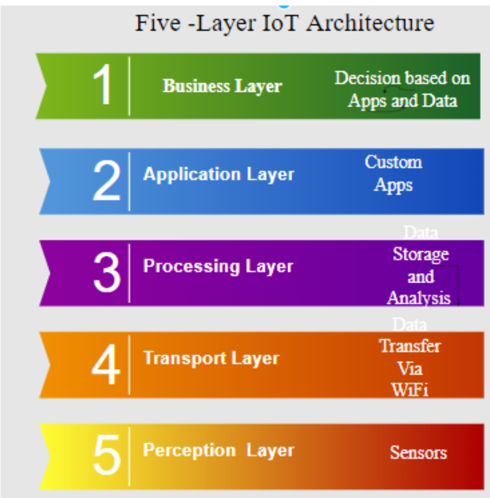

Figure 2: Five-Level Architecture of Internet of Things (IoT) network

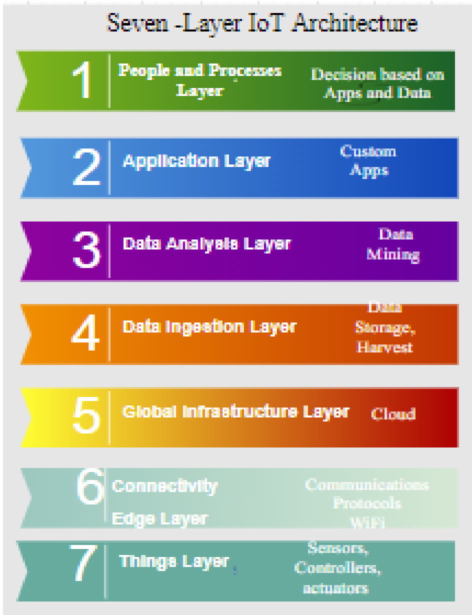

Figure 3: Seven-Level Architecture of Internet of Things (IoT) network

C. Software Defined Network-Based Architecture Internet of Things (IoT) network

In (Bekri et al., 2020; Dawoud et al., 2018; Iqbal et al., 2020; Karmakar et al., 2021; Nguyen et al., 2019; Pourvahab & Ekbatanifard, 2019; L. Xie et al., 2019; Yazdinejad et al., 2020) presented an IoT architecture based on SDN to improve service quality (QoS)(Casado-vara et al., 2018), provides a technique for enhancing the data quality that can be employed in IoT architectures, hence improving the QoS of IoT architectures with application to temperature data only.

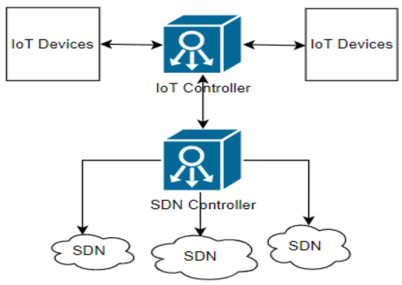

Figure 4: Software-Defined Network-Based Architecture Internet of Things

D. Quality of Service-Based Architecture of Internet of Things (IoT) network

Jin et al (2017); Abreu et al. (2017) suggest four alternative IoT architectures that allow several applications for intelligent cities to include their QoS requirements. These structures were enhanced in (Khan and Zeeshan, 2019; Matias et al., 2015; Rahimi et al., 2018; Sarwesh et al., 2019) to alleviate congestion and stress among nodes

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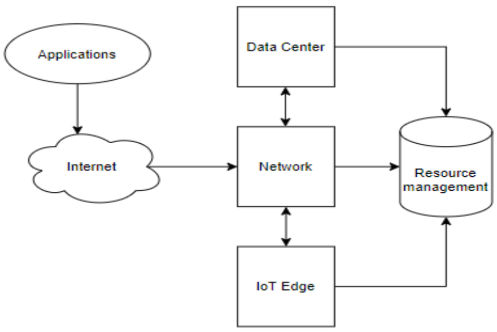

Figure 5: Quality of Service-Based Architecture of Internet of Things

E. SoA-Based Architecture of Internet of Things (IoT) network

SoA (service-oriented architecture) is a component-based methodology for connecting many services via applications and interfaces. (Atzori et al., 2010; Gupta et al., 2018; Shashwat et al., 2018). SoA architectures are made up of four layers that work together: the perception layer, the network layer, the service layer, and the application layer. It is used to store and analyze data from IoT devices at the fourth level of SoA-based architecture. (Leu et al., 2014, Tiburski et al., 2015).

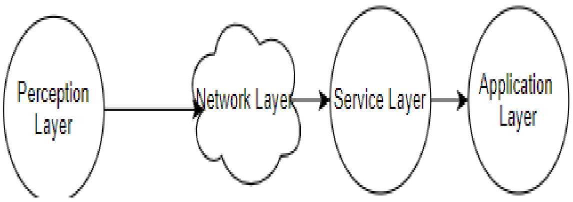

Figure 6: SoA-Based Architecture of Internet of Things

V. CLOUD THINGS ARCHITECTURE

In (Zhou et al., 2013), they examined the data clouds IoT that needs an IoT-enabled smart house scenario, a data-centric architecture that aims to improve the reliability of the next generation of Internet services (Yue et al., 2014). Most of these structures are used in industry or smart cities. (Manogaran et al., 2018, Samie et al., 2019). Even though these frameworks are effective for the time being, they must be re-examined to ensure that future problems do not compromise reliability. Integrating smart devices into physical infrastructure can help to increase infrastructure dependability and efficiency. These advantages can lower costs and improve a wide range of IoT applications, including smart infrastructure, healthcare, supply chains/logistics, social applications, surveillance, and more.

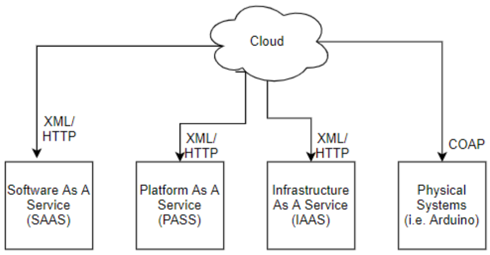

Figure 7: Cloud-Based Architecture of Internet of Things

VI. COMMUNICATION SYSTEMS

Technological improvement in the past years has been exponential. In order to efficiently provide solutions for solid waste management, technologies must play a very significant role in the areas of automatic data acquisition, identification, communication, storage, and analysis. The technologies and techniques to be adopted differ depending on what the researcher is set to accomplish, and in most scenarios, the applications of these technologies are made as stand-alone applications, and in some other cases, the technologies are networked. The technologies applied at the various stages in the UAV system (which include monitoring, collecting, transporting, transmitting, and analyzing) are grouped into spatial, identification, data acquisition, and data communication technologies.

The technologies whose applications are found in spatial analysis and environmental modeling are spatial technologies. It helps to capture, store, analyze, and map the spatial dataset. These technologies manage complex spatial information, platforms for the integration of various models, interfaces, and sub-systems. Examples of spatial technologies are geographic information systems (GIS), Global Positioning Systems (GPS), Visual Positioning Systems (VPS), and Remote Sensing (RS). The communication technologies, which began as wired communication, have today developed into a more convenient wireless communication technology. Wireless communication is vital to the sharing of information or commands between nodes of automatic acquisition. Wireless communication technologies used in Solid Waste Management applications are either for long-range communications GSM, GPRS, RF, and VHFR or for short-range communications Wi-Fi, ZigBee, and Bluetooth, for short-range communication and computing technologies, which include cloud, fog, and edge computing. For the sake of this study, attention will be given to wireless communication technologies, computing technologies, and the Internet of Things network.

A. GSM/GPRS

The Global System for Mobile Communications (GSM) is a 2G network that first launched in Europe in 1982. It is now a

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widely established standard for digital cellular communication technology, which is mostly utilized for mobile voice transmission. Furthermore, GSM facilitates data transmission service, with data transmission rates limited to 9.6 Kbps and connection setup taking several seconds. The General Packet Radio Service (GPRS) is a 2.5G network that is a GSM bearer service that greatly enhances and abridges wireless access to packet data networks and the Internet. GPRS uses the packet switching mechanism to transfer data packets. The packet switching mechanism used by GPRS allows packets to be routed directly from GPRS mobile stations to packet switched networks. The Internet Protocol (IP) and X.25 networks are supported by GPRS. (Singhvi et al., 2019) worked on the GSM/GPRS system for waste management, so also
(Jain & Bagherwal, 2017; Kumar et al., 2020; Mahmood & Zubairi, 2019; Xenya et al., 2020)

B. ZigBee

The ZigBee Alliance created the ZigBee protocol, which is a low-power wireless IEEE802.15.4 networking standard. The ZigBee protocol attempts to build a low-cost communication technology that can be used to create personal area networks (PANs). In applications that demand a low data rate, longer battery life, and secure networking devices, the ZigBee protocol, which can operate in three license-free industrial, scientific, and medical (ISM) frequency bands, is recommended over other communication protocols. These can handle data speeds of up to 250 kbps over the air. For the three separate frequency bands, 802.15.4 allocates a total of 27 channels.
(Song & Wang, 2020)
worked on waste battery recycling and management using ZigBee,(Ravindhiran et al., 2018), smart garbage (Abdul Khadar et al., 2018) (Karthikeyan et al., 2018)

C. Wi-Fi

Wireless Fidelity (Wi-Fi) is a flexible and mobile short-range wireless communication technology mainly used to connect homes and small offices to a mobile network. Wi-Fi access point (AP) usage is increasing because of its efficiency and convenience. The IEEE 802.11 standard specification, which has up to 20 variant standards, each of which is differentiated by an alphabetical suffix at to the end of the name. The chief among them are 802.11b and 802.11g with an operating frequency of the 2.4 GHz band, 54 Mbps maximum data rate, and 250 m coverage area, 802.11a with 5 GHz band operating frequency and maximum data rate of 11 Mbps, and 250 m coverage area, find application in some electronic devices. Some scholars, such as
(Hassan et al., 2018; Khan & Naseer, 2020; Lyu et al., 2019; Mujkic & Aksamovic, 2018; Saha et al., 2019; Zhang et al., 2019)
, have worked with Wi-Fi to solve waste management problems.

D. Bluetooth

Bluetooth is a non-line-of-sight, short-range communication protocol. It has the operating frequency of 2.4–2.5 GHz ISM bands, coverage distance of 30m, and bandwidth of 1MGHz. a variant known as Bluetooth low energy finds application in IoT-enabled systems and offers minimal power consumption, and is incorporated into smartphones, PDAs, and notebook PCs.
(Aggarwal et al., 2020; Dhayalini & Mukesh, 2018; Hasan & Hasan, 2020; Sugawara et al., 2016)
have used Bluetooth to solve waste management problems.

E. VHFR

Very high frequency radio (VHFR), which has a 30–300 MHz bandwidth, 10–1 m wavelength, 64 kbps maximum data rate, covers 10,000 m maximum distance, is an ITU-8-designated communication technology. Long-range data communication, marine communication, television broadcasting, and private, business, or military communication are some of the other applications. (Liu et al., 2015)

F. Z-Wave

As a low-power radio frequency communication protocol, Z-Wave is mostly used in home automation. It provides a scalable, reliable, and low-latency communication protocol with short data packets and data rates up to 100kbit/s, as well as full mesh network topology compatibility. Z-Wave is a simplified protocol that allows for quicker and easier development.

G. Near Field Communication (NFC)

NFC is a short-range wireless communication technique that enables simple and secure two-way communication between electronic devices, particularly smartphones. It also allows users to make contactless payments, access digital content, and connect their smart devices. NFC makes it simple to share data, connect, and control IoT devices over a distance of less than 4cm (Lee & Wu, 2014).

H. 6LoWPAN IPv6 over

6LoWPAN (Low Power Wireless Personal Area Network) is an IP-based standard that uses no gateways or proxies to connect to another IP network. The 6LoWPAN communication protocol is the most extensively used IoT protocol. It wraps IPv6 headers in 128-byte IEEE802.15.4 packets. 6LoWPAN offers a range of topologies, including star or mesh and length addresses, as well as low bandwidth. It also supports low power consumption, low cost, scalable networks, mobility, unreliability, and long sleep times.

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Table 1: A comparison between common data communication protocols

Characteristics	ZigBee	NFC	GSM	GPRS	Z-wave	6LOWPAN	Bluetooth	VHFR	Wi-Fi
Band width	0.3/ 0.6 MHz, 2 MHz		200 kHz	200 kHz	1GHz		1 MHz	30–300 MHz	22 MHz
Standard (IEEE)	802.15.4	ISO/IEC 18000-3	2G	2.5G	Z-wave	802.15.4	802.15.1		802.11
Network type	WPAN	P2P	GSM	GPRS	WPAN	WPAN	WPAN	VHFR	WPAN
Frequency	2.4 GHZ	13.56 MHZ	900MHZ	900MHZ	900MHZ	2.4 GHZ	2.4 GHZ		2.4 GHZ
Range (M)	100–400	Upto 200M	35,000	25,000	100	100	30	10,000	250
Data Rate	250kbps	100-420Kbps	9.6 kbps	76– 172 kbps	100kbps	250kbps	1 Mbps	16–64 kbps	54 Mbps
Power	30mA	50mA			2.5mA	VLP	30mA		
Topology	S, M	P2P			M	M, S	S, B		
Security	AES	AES & RSA	AES	AES	AES	AES	AES	AES	AES

Table 1 compares common data communication protocols that can be used in Waste Management. The properties of interest for the ideal communication protocol should include security, power consumption, Advanced Encryption Standard (AES) platform, and a member of the Wireless Personal Area Network (WPAN). With regards to the properties outlined, 6LoWPAN will emerge as the future protocol owing to IPv6, which allows a large number of IoT devices to be effortlessly deployed over the internet

I Wired Communication Technology

Wired Communication Technology is adopted in an IoT system to interface the sensors and actuators to the embedded controllers' input/output ports using physical wires. Wired Communication Technology may adopt any of these protocols: Serial Peripheral Interface (SPI), Inter-Integrated Circuit (I2C), and Controller Area Network CAN protocols, depending on the researcher's need.

A. Serial Peripheral Interface (SPI)

In the 1980s, **the** Serial Peripheral Interface (SPI) serial synchronous protocol was designed for short-distance transmission. This made its application in embedded system communication possible, and it is used widely to communicate ICs, especially in embedded systems applications. It uses a master and slave full-duplex communication system as shown in Figure 2.1. There have been improvements on the SPI protocol in recent times; lightweight SPI master IPs were designed by (Aykenar et al., 2020).

(Hafeez & Saparon, 2019) worked on the IP core of APB interfacing with SPI. Protocol Conversion Unit (PCU) for seamless communication between the two widely accepted serial communication protocols, SPI and I2C (Trivedi et al., 2018).

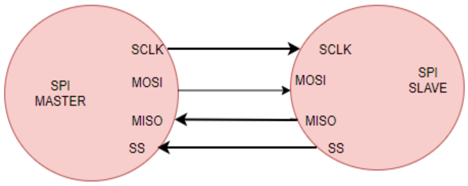

Figure 8: Serial Peripheral Interface (SPI) Master to Slave Configuration

B. Inter-Integrated Circuit (I2C)

In 1982, the Inter-Integrated Circuit was designed for interconnecting low speed, short-distance communication peripherals to microcontrollers. It uses a two-wire system for serial data and synchronous clocking of the signal. See Figure 2.2. I2C still attracts research interests

(Deepika & Yadav, 2018) designed Dual Master I2C Bus Controller and Interface, I2C Controller on FPGA

(Bagdalkar & Ali, 2020) and I2C with specific tasks on Internet of Things (IoT) based context - web server access (Pintilie et al., 2019).

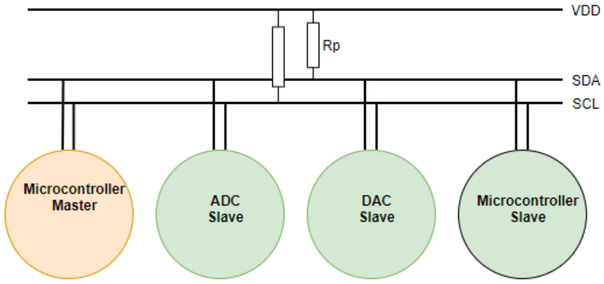

Figure 8: Inter-Integrated Circuit (I2C)

C. Controller Area Network (CAN) Protocols

A wide range of embedded and automated control systems use the serial bus system Controller Area Network (CAN). A CAN network is built over a shared serial bus using a carrier-sense multiple access with collision avoidance (CSMA/CA) technique with deterministic collision resolution. An Intrusion Detection System (IDS) has been proposed for the Controller Area Network (CAN) bus of current automobiles. (Shahrajabian & Bijami, 2019) offer a model that can manage CAN buses connected by a gateway (Ivkovic et al., 2019) (Macayana et al., 2019). A hybrid sensor network system with both wireless (6LoWPAN) and wired (CAN Bus) components was studied.

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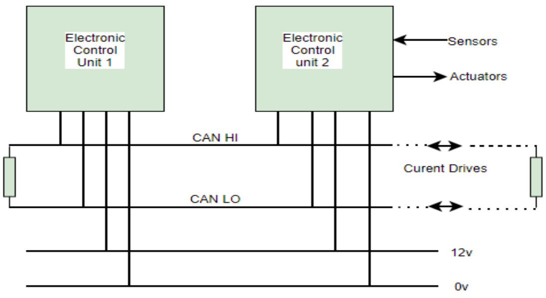

Figure 10: Controller Area Network (CAN)

I. COMPUTING TECHNOLOGIES

The prime aim of computing technologies is to push the intelligence of data storage and analysis either to the cloud, edge, or fog. If the computing resources are in the cloud, it is known as cloud computing, if it's at the network edge, it is called edge computing, and if the computing resources reside at the Fog, it is fog computing. Further description of these computing technologies is found in the subsequent section.

A. Cloud Computing

Cloud computing centralizes complex technology that requires network allocation in a dynamic manner, the use of resources in a flexible way, high speed, and high performance (Basir et al., 2019). As future application demands that reliable communication should offer low latency, high speed, Privacy and security, efficient resource allocation, and energy-saving communication technology are all important considerations. However, there are certain drawbacks to cloud computing, which are as follows:

Outsiders should not be given access to an industry's confidential data or personal information. (Privacy of personal and confidential information is not guaranteed) A cloud service provider's security and privacy are in high demand by the industry. The location of data based on geography is governed by rules and regulations. It also aids with information security. High load necessitates high-speed internet access. Communication is delayed because of this process. Because multiple apps are accessing a single cloud server at the same time, memory and storage capacity may be depleted. For quick procedures, context awareness is essential. Different standards make it difficult to exchange data, information, services, and applications between clouds in different regions. For industrial processing and decision-making, recovery and backup updates are essential; cloud computing will cause a delay.

A. Fog Computing Technology

Fog computing, commonly known as "fogging," is a method of extending cloud computing to autonomous heterogeneous devices within an industry, in response to the demand for low-latency and high-processing applications and services. (Basir et al., 2019; Garach & Thakkar, 2017; Lin et al., 2017). Fog computing is defined as having processing, storage, maintenance, and intelligence control near the network of data devices (LAN level of network architecture, processing data in a fog node or gateway). When compared to cloud computing, fog computing better satisfies the needs of the industry 4.0 environment, such as real-time services, high data processing, maximum capacity, and scalability. By introducing the network fog computing concept, it reduces the burden on clouds. Real-time services and decision-making processes in industrial automation necessitate reduced latency and increased cache memory. Mobility and real-time applications are required performance parameters. Because of geographical dispersion, low-latency, location-awareness, number of nodes, and cache-enabled edge devices are all important. It typically uses cloudlets or fog nodes, which are virtualized nodes that sit between internet clouds and end-user devices. Fog computing services and applications outperform cloud computing in terms of QoS metrics, fulfilling crucial IoT requirements.

Merits of fog computing

By removing the need to retrieve data from far-away clouds, data storage on network edge nodes eliminates transmission delays. Fog computing allows IoT applications to handle and analyze data at a faster rate. The processing and computing delays will be reduced by storing data on edge nodes. Cache-enabled nodes will prevent the transmission of useless data throughout the network.

Using the edge networking idea, it is possible to enable all IoT applications, such as smart grids, smart cities, D2D, and Vehicular Ad-hoc networks (VANETS). Interaction between end devices and cloud service providers is filtered and necessary.

B. Edge Computing Technology

Edge computing further extends fog and cloud computing technologies to the edge of the data acquisition point (points where data emanates from)(Lin et al., 2017). It utilizes embedded automation controllers at the edge node (E-Node) to offer intelligence, low processing power, and hardware security. It consists of a peer-to-peer networking system, a self-organizing network, and a server that can be managed remotely. PLCs (programmable logic controllers), PACs (programmable automation controllers), and EPICs (edge programmable industrial controllers) are used to delegate the intelligence, processing power, and communication capabilities of an edge gateway or appliance to controllers such as PLCs, PACs, and EPICs (edge programmable industrial controllers). Sensors and actuators are integrated into a control system in edge computing, but the system is managed by an edge programmable industrial controller. It can collect, analyze, and process data from physical assets while simultaneously running control system programs. It

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makes use of the capabilities of edge computing to identify whether data should be saved locally or transferred to the cloud for further analysis. By speeding IoT connectivity, reducing system and network design complexity, and minimizing the number of potential failure points in an IoT application, edge computing saves time and money. The following is how Edge Computing works:

First, electrical signals from things are conventionally linked to an automation controller's I/O terminals (PLC or PAC). To automate the items, the automation controller runs a control system program.

The data from the control system program is then sent to an OPC server or protocol gateway, which converts it to a protocol that Internet systems can understand, such as MQTT or HTTP, and then to another system on the LAN, such as a fog node or IoT gateway, which collects the data and performs higher-level processing and analysis. This system filters, analyzes, processes, and perhaps stores data for eventual transmission to the cloud or WAN.

The following are the Merits of Edge Computing:

Encourages real-time connectivity and decreases overall network traffic by doing some processing at the network's edge. Increases network security by encrypting data near the network core. Optimize the use of resources.

IoT applications have critical communication requirements. Cloud computing, fog computing, and edge computing platforms need to be optimized for better, efficient results. Cloud computing can be used where there is no high requirement of real-time connections, privacy, and security. On a local area network, fog computing uses a centralized system that interacts between the network and cloud server, whereas edge computing does computation on embedded systems of the network. Edge computing has direct interaction with sensors and actuators. The need for cloud, fog, and edge computing architectures is increasing with the growth of the IoT application. To increase the use of IoT smart devices, researchers are focusing on fog or edge computing paradigms, which results in industrial development.
The UAV-AQMVS in this research requires Cloud computing, fog computing, and edge computing integrated together for optimal, better, efficient results. Fog-Edge-Cloud computing technique will leverage the advanced processing abilities of cloud computing, sandwiched with the security and timely processing of fog and edge computing, to birth a robust architecture for this work.

VI. GAS SENSORS

Gas sensing is as old as the first decade of the 21st century, when the use of coal was abolished in 1273, in London, as “prejudicial to health”. In 1863, the first “Alkali Works Regulation of coal Act” was (Dhall et al., 2021) assed and in 1876, the hydrogen chloride emissions discharge limit was set not to exceed 0.446 gm. This birthed variety of sensors to monitor the set limits on the environmental pollutants and to verify compliance with legislation (Dhall et al., 202). These pollutants are classified as primary pollutants (CO2, CO, Benzene, toluene & so on) and VOCs and industrial secondary pollutants (H2S, NOx, H2, and SOx). These pollutants sources are classified into anthropogenic and natural sources. Human activity including smoking, industry waste, vehicles and so on come under the category of anthropogenic source. Anthropogenic source is further classified into two; stationery and mobile source (Yi et al., 2015). Stationary sources include. Natural sources include Emission of methane (CH4) gas by food digestion of animals, Radon gas from radioactive decay within the Earth's crust, Smoke and CO from wildfires, and Volcanic activity that is main cause for the emission of sulfur, chlorine and ash particulates [20]. Increase in population and urbanization has significantly deteriorate activities and makes the atmospheric environment hazardous. Therefore, the design of UAV with on-board sensors for air quality monitoring, air pollution sources detection and video surveillance is important

A. Types of Gas Sensor

Different types of gas sensors have been reported in various literature, some are grouped based on their working principles, such as infrared (IR), Metal oxide semiconductors, electrochemical, and optical (fluorescence) sensors (Dhall et al., 2021). More attention has been given to chemi-resistive and electrochemical sensors due to their wide applications. However, more successfully developed at research laboratory and industrial levels is the metal oxide semiconductor-based environmental sensor (Dhall et al., 2021; Hanafi, Mayasari, Masmui, Agustanhakri, Raharjo, & Nuryadi, 2019). They have been used to detect a variety of gases such as CO, H2S, NH3, SOx, NOx, etc., with varying degrees of commercial success. These sensors are being widely used in various applications such as automotive, consumer, commercial, industrial, and environmental monitoring. Although electrochemical sensors have low power consumption as their merits, this work will adopt semiconductor metal oxide sensors due to their low cost, easy fabrication, availability, and low detection limit in PPM. (Aprilia et al., 2016; Hanafi et al., 2019).

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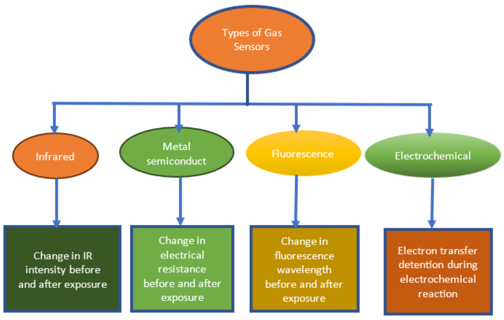

Figure 11: types of sensors *(Dhall et al., 2021)*

VII RESEARCH GAP AND OPEN ISSUES

A drone operator, other UAVs, and ground-based control stations may all share data due to the main components of UAV (unmanned aerial vehicle) communication systems. These technologies are crucial for managing the drone, gathering telemetry data, and occasionally, relaying gathered data back to the operator or other important parties. The essential features of UAV communication systems will be covered in this presentation. Zulfiker et al. (2019), Communication between the operator and the UAV is frequently done via radio control technologies. In addition to other operational orders, this also comprises directions for take-off, landing, and changing the flight route. Aviation authorities oversee the operation of these systems, which run in certain frequency bands. The drone's status is updated in real-time via telemetry systems, which also offer information on the drone's position, altitude, speed, battery life, sensor readings, and other factors. The operator's ground control station receives this data, enabling real-time observation and decision-making. Numerous UAVs include cameras that record photos or video while in flight. Real-time transmission of these streams to the operator's ground control station enables visual monitoring and information gathering.

According to Murtaza et al (2021), a crucial aspect of UAV operations is the communication system's practical range. It establishes the drone's maximum distance from the pilot while preserving a trustworthy connection. For tasks like long-distance surveying or search and rescue operations, longer-range communication technologies are crucial. Frequency bands for telemetry and video transmission are used by UAV communication systems, together with 2.4 GHz and 5.8 GHz for radio control. Frequency requirements must be understood and followed in order to operate safely and without disturbance. Some unmanned aerial vehicles (UAVs) use redundant communication systems to increase dependability. This implies that in the event of interference or signal loss on the primary communication channel, the drone can switch to a backup communication link. When communicating sensitive information, data security is very important. Between the UAV and the ground control station, data is protected against unauthorized access via encryption techniques. Santiago et al. (2022), using many antennas and the selecting of the one with the best reception, diversity antennas are intended to enhance signal reception. This improves communication dependability, especially in situations when there is signal interference. To go beyond line-of-sight restrictions, several UAVs employ satellite communication systems to increase their operational range. These devices offer worldwide coverage and are appropriate for far-off and distant missions.

Lee et al. (2021), dedicated command and control networks may be necessary for UAVs engaged in swarm operations or cooperative missions in order to allow communication and coordination among several drones. Regulations established by aviation authorities, such as frequency allotments, power caps, and other communication-related laws, must be complied with by UAV communication systems. In Maher et al (2020), UAVs may include established procedures for automatic operations in the event of signal loss or emergency, such as commencing a controlled fall or returning to a predetermined home point. For drones to operate safely and effectively in a variety of applications, from aerial photography and recreational usage to agricultural, surveillance, and other uses, UAV communication systems are crucial. The capabilities and dependability of UAV systems continue to be enhanced by developments in communication technology, enabling more complex and autonomous missions.

In the course of literature research, the following gaps have been identified in the various journals and conference papers reviewed so far in this thesis:

1. Non-existence of an artificial intelligence algorithm for state prediction of edge devices.
2. Non-existence of blockchain technology and control algorithms to bring security and confidentiality to the data of edge devices.
3. Limited ability to detect an imprecise or malfunctioning edge node from a hot (cold) real-time scenario.
4. The nonexistence of localized rapid response air quality monitoring and video surveillance

VIII CONCLUSION

This paper reviewed the available technologies, such as the Internet of Things, cloud, and gas sensors, and their applications in hazardous environments and waste management. These technologies are categorized into four classes, including spatial technologies, identification technologies, data acquisition technologies, and data communication and storage technologies. Among the four classes, waste management systems are mainly developed based on the first three classes, and the last one is used with almost every system. The spatial technologies include GIS, GPS, and RS; the identification technologies contain barcode and RFID; the data acquisition technologies include sensing and imaging technologies; and the data communication technologies comprise both the short-range and long-range communication technologies. The basic introduction with structure, working principle, functionalities, and salient features for every technology of each class was discussed. The detailed examination of these technologies provides a comprehensive foundation for understanding their capabilities and limitations. The paper successfully identifies a critical, unaddressed challenge in the specific application of technologies in hazardous environments. The proposed research direction is to fill this gap by developing a framework or system that uses technologies for effective UAV air quality monitoring in a hazardous environment.

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