A Review Paper on Unmanned Aerial Vehicles for Vertical Profiling

Aneke Chikezie Samuel[1], Philip Michael Asuquo[2], Simeon Ozuomba[3], Okechukwu Collins Eze[4], Chetachukwu P Ogbu[5]

[1,2,3]Department of Computer Engineering, University of Uyo, Akwa Ibom State, Nigeria

[4]Washington University in St Louis, Missouri, USA

[5]Verizon Business Group, Richardson, Texas, USA

Corresponding Author: Aneke Chikezie Samuel, Department of Computer Engineering, University of Uyo, Akwa Ibom State, Nigeria. anekechikezies@uniuyo.edu.ng

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ABSTRACT
Technological advances in the implementation of unmanned aerial vehicles (UAVs) have drawn undue attention to various areas. Unmanned aerial vehicles, which can also be referred to as drones or autonomous vehicles, are devices that can be remotely controlled to fly. These UAVs have been rapidly integrated into meteorology and atmospheric science, specifically for capturing data in the atmosphere's lowest layer and the atmospheric boundary layer (ABL) because of their flexibility, mobility, effortless deployment, adjustability, and effective appraisal of real-world functions anytime and anywhere. The traditional means of capturing data such as satellites, balloons, and ground-based weather towers could not provide enough coverage. This paper has examined detailed UAV articles and journals to identify the different strategies and architectures used by researchers to obtain critical data in vertical atmospheric profiling.

Keywords: UAV, Weather, Atmospheric Parameter, Boundary layer, Forecasting

1. INTRODUCTION

Modern weather forecasting and climate models demand a steady and precise computation of the

atmosphere. Because the weather has an impact on our daily lives, meteorologists place a high value on weather forecasting. Cloud formation, weather creation, and the earth's rotation around the sun were once utilized to forecast weather. Accurate weather forecasting can help develop preventative measures for dangerous weather, and businesses including agriculture, maritime, and aviation all rely on accurate weather forecasts [1]. Due to current technological advancements, drones that were previously primarily used in the military sector are now

being seen in all industries [6]. Therefore, an unmanned aerial vehicle (UAV) will be deployed to fill the then gap in forecasting atmospheric wind data and atmospheric properties such as barometric pressure, air temperature, and relative humidity [3]. These UAVs are used in different fields of atmospheric research [4]. They are mostly utilized for remote sensing and data collection in this field due to their ability to convey sensors and cameras quickly and at a lower cost [87]. Hurricanes and other cyclonic storms aren't the only events for which weather drones are used. They can, however, be used in a wide range of atmospheric scientific studies, particularly in distant areas and regions of weather extremes [12]. Weather drones fly over the entire vertical layer to collect important data on temperature, humidity, barometric pressure, and wind speed and direction in the boundary layer, the lowest layer of the atmosphere. Weather drones increase observations by utilizing climatic remote sensing to provide vital information that is both faster and for a better understanding of atmospheric physics and dynamics, allowing for more accurate numerical prediction model findings. Drones must be used to take continuous and high-resolution observations of the atmosphere for these models to work correctly [5] The data collected by the drones' sensors is stored and used for weather forecasting, disaster forecasting and other purposes [7]. An applicable measuring model is used to monitor air quality [99] which is ever-changing as a result of advancements in technology and the expansion of compact detectors for measuring air at a low cost. Implementing wireless communication when compared to the use of wired communication

devices resulted in a 3 to 5 percent reduction in spending and annual operating cost in the United States [100] An aerial vehicle that is unmanned, often known as a drone, is a self-piloted aircraft that is controlled by embedded computers or remote control. These drones can be of any size or type, and they are frequently equipped with data-gathering accessories. To instantly register and monitor a particular area or object, they don't need any additional infrastructure. Another advantage is that they commission and fly in a relatively short period [11]. In addition, UAV takes less time and costs less money than other methods [17]

In this paper, a review of UAVs for weather forecasting is performed to examine and assess the relevant contributions to vertical atmospheric profiling. Consequently, types of UAVs and their applications have also been discussed. A survey of techniques and methods performed by researchers to obtain critical data in the atmosphere using UAVs is presented in this paper. This work is structured in such a way that Section II presents the background of UAVs, types of UAVs, applications of UAVs, UAV communication, and protocols. In section III, an extensive survey on the approaches and techniques implemented by researchers for vertical profiling using Unmanned Aerial Vehicles used for vertical profiling as well as a thorough review of related literature from researchers and academicians has been presented. Finally, an overview of open issues and challenges is provided in Section IV.

1.1. Types of UAV

Compared to alternative airborne technologies such as manned aircraft and satellites, UAVs are more adaptable and more visible when in operation. Small, lightweight UAVs are particularly useful for examining the atmosphere from a distance. It is critical to study the many sorts of drones to comprehend drones [97]., it is crucial to consider the types of drones in existence. In this section, their technical characteristics (types of drones) are discussed and the summary is given in Table 1.

1.1.1. Meteodrones

Meteodrones, also known as rotary-wing UAVs by Meteomatics, is 0.6 m wingspan hexacopters that measure vertical profiles of various meteorological parameters of the lower atmosphere at fixed locations with high temporal frequency [22]. Rotary-wing aircraft fly at slower speeds, swing for close inspection and follow irregular courses. Unlike fixed-wing aircraft, improved spatial resolution is possible at the expense of diminished geographical expanse. Recently, advancements in technology concerning these systems have made them more authentic and simple to operate, drastically reducing the occurrence of mishaps and sensory device damage. It does not require more space to be able to fly and land. Furthermore, its size will determine if it can be moved to any location at any time. It's important to double-check the sensor's attachment because it's not flexible and also higher payloads are likewise impractical to employ [97].

Figure 1: Meteodrone (Rotary Wings) UAV

1.1.2. CopterSonde

In aviation, this term is also known as fixed Wing UAV, which refers to drones that utilize fixed, static wings together with forward airspeed for take-off. Traditional airplanes and kites are examples of fixed-wing drones. The most critical feature of an aircraft to evaluate in the context of air quality monitoring is Capacity. Fixed-wing aircraft have a lot of options when it comes to sensor attachment. It covers a larger area for a specific quantity of time. For takeoff and landing, a short runway is required [22]. The main disadvantage of this type of aircraft is that it cannot hover and requires a minimum working height. While increased spatial coverage is achievable, it comes at the expense of lesser spatial resolution. Fixed-wing drones are appropriate for long distances and can fly faster than their multi-rotor counterparts [21].

Figure 2: CopterSonde (Fixed Wing) UAV

1.1.3. Multi-Rotor UAV

Multirotors are easy to fly, both for takeoff and landing and for autonomous flying [20]. The multirotor has a limited flying period, which limits the area of coverage, and they also have a small payload capacity. And the drone expands the majority of its energy battling gravity and maintaining stability in the air. Drones with several rotors are simple to control and maneuver [18]. To generate lift, this type of drone uses rotary wings. The classic helicopter is a good illustration of this sort of rotor drone. Because drones with multi-rotor have no requirement for a landing strip and may stay in the air, they produce very little noise than fixed-wing equivalents [21].

Figure 3: Multi-Rotor UAV

1.1.4. Fixed-Wing Hybrid VTOL

When fixed-wing aircraft with the capacity to take off and land are combined, the result is called Fixed-Wing Hybrid VTOL. These hybrid systems have characteristics of both fixed-wing and multi-rotor systems [25]. Landing and VTOL capabilities are similar to unmanned helicopters, and VTOL UAVs have high cruising speeds similar to conventional UAVs. As a result, VTOL UAVs can perform takeoff and landing operations in dangerous conditions where normal takeoff and landing would be impossible, while reaching target operation regions in a short time. In addition, a VTOL UAV can switch from cruise mode to hover mode and vice versa depending on operational needs [23] [24].

Figure 4: Fixed Wing hybrid VTOL UAV

1.1.5. Single-Rotor Drones

Single-rotor drones are powerful and have a structure and design similar to real helicopters. They have a large rotor that acts like a spinning wing and a smaller rotor at the tail for direction and stability. These gadgets can hover and launch vertically thanks to their reliance on rotors. They are often larger than their miniature counterparts, allowing them to transport heavier payloads. They are more systematic than multi-rotor variants because they do not have several motors. Because the larger blades can make them more dangerous, it's a good idea to receive sufficient training before investing. (110)

Figure 5: Single Rotor UAV

Table 1. Summary of Different Types of UAV Platforms and Their Features

Configuration/Hoover	Taking off/Landing	Payload(Kg)/Airspeed (m/s)
Rotary wing/Yes	Vertical	3/15.2
Fixed wing/No	Conventional	I/ up 22+
Multi-Rotor UAV/Yes	Vertical	up to 10/ up to 11
Fixed-wing Hybrid VTOL/Yes	Vertical	up to 5/30
Single-Rotor UAV/Yes	Conventional	I/ up 20+

1.2. Applications of UAV

The first distinction to make when using drones is between the drone and the sensory device that is attached to it. UAVs are commonly used for mapping, monitoring environmental changes, disaster response, resource discovery, and other purposes [13].

1.2.1. Road Safety Traffic and Highway Infrastructure Management

UAVs have been proposed as a new traffic surveillance tool for collecting data on road traffic conditions. Less expensive than typical surveillance systems such as loop detectors, security video cameras, and microwave sensors, UAVs can monitor vast contiguous road segments or focus on a specific section of the road [77]. Police departments and auto insurance companies are currently investigating the use of UAVs to investigate traffic incidents [31]. There are many ways this technology can be applied to transportation systems [29]. The majority of its applications rely on data from UAV cameras to gather information about traffic and driving habits [28]. This collected data is then utilized in surveillance, recognizing traffic congestion, etc. [27]. Drones have been used by railway firms to monitor and inspect track issues in places with limited access [91].

1.2.2. Agriculture

The aim of accuracy in agriculture is to apply the right amount of input at the right time and place to get excellent results. Data gathering and variation in the mapping of agriculture fields are common precision farming procedures, as are data analysis, making farming management decisions based on results from the analysis, and lastly manage applications such as pesticide spraying and fertilizers [91]. Unmanned aerial vehicles (UAVs) have several advantages in agriculture. Correctly forecasting agricultural produce using geographic data obtained from sensors is a good example. It also lets farmers study their farms from above

for irrigation issues, soil variances, and fungal and pest infestations, among other things. Data on water access, changing climate, winds, and a variety of weather conditions are also available. [26].

1.2.3. Drones in Forestry, fisheries, and wildlife protection

Drones fill in the gaps left by limited satellite imagery availability and cloud cover by easily measuring tree canopy height, following forest types, assisting with forest management, detecting and controlling wildfires, surveying forests, and mapping canopy gaps [8]. Remotely operated fixed-wing UAVs with integrated thermal and hyperspectral sensors are used to identify and monitor forest fires. Poaching of animals and intense climate conditions have a negative influence on wildlife. UAVs equipped with thermal sensors [67] and satellites are being considered for monitoring, tagging, and counting animals, which will help reduce animal poaching and conserve biodiversity [9].

1.2.4. Weather Forecasting

UAVs are gradually becoming a feasible option for routine and reliable observations in the Atmospheric Boundary Layer (ABL). The goal of flying strong, lightweight atmospheric sensors on UAVs is to monitor atmospheric parameters such as wind speed, as well as air quality, pollution sources, and real-world exposures to gases of concern at ground level. This form of measurement can provide a detailed inventory of thermodynamic and kinematic data, as well as trace gases in the lower troposphere. Data collected in the lower part of the troposphere [43] throughout all flights is combined with GPS data to create maps of the ABL's state [10]. Their ability to fly to the Atmospheric Boundary Layer in a short amount of time and collect data horizontally and vertically complements ground-based measurements [93].

1.2.5. Aerial Mapping

Drones are utilized in urban planning and management, with aerial mapping being the most common activity. Drones have caught the interest of businesses across the board, from electrical corporations to the training industry. Electrical businesses choose drones for high-tension line inspections because they eliminate the risky task of climbs and power outages [14] [15]. Drones have been used by railway firms to monitor and inspect track issues in places with limited access. Software is used to conduct the survey and model the results. LIDAR and Synthetic Aperture Radar (SAR) data have been added to these updated UAVs [32]. UAV photogrammetry

combines close-range photogrammetry, aerial photograph mosaicking, and terrestrial photogrammetry for photogrammetric purposes [42] and they are embedded with user-friendly software [41].

1.2.6. Disaster Management

Response Time is critical in disaster management since it can save many lives. The most effective technique to achieve rapid situational awareness is to use unmanned aerial vehicles (UAVs). Responders can learn about the locations affected, the degree of the damage, and the state of transportation, among other things [38]. These UAVs can also provide recovery and mapping assistance, perform structural assessments, guide survivors to a safe location, and act as an ad hoc communications infrastructure [39]. The potential and usefulness of drones are demonstrated by a trial to identify people in the Donegal mountain range in Ireland and a rescue operation of 200 persons in a flood zone by Chennai police in India [91].

1.2.7. Medicine

Drones can be used to assess disasters when other methods of access have failed, such as providing secure transportation of disease test samples and test kits in the area; sending relief packages, medicines, vaccinations, blood, and other medical supplies to remote areas where the disease is highly contagious [34]. However, this application might be extended to domestic multi-casualty events. UAVs could be used to bring emergency medical supplies such as external fixator devices, automatic defibrillators, combat gauze, and tourniquets might also be delivered by UAV if necessary to local hospitals or even straight to injured patients on the scene in these situations [45]. Even in this COVID-19 pandemic, drones can be used to supply Personal Protective Equipment (PPEs), test kits, vaccines, medication, and laboratory samples [33].

1.2.8. Military

UAVs were first developed to carry out war operations such as espionage, spying, reconnaissance, vigilance, and target detection; later, they were used for civic and logistical purposes [49]. The United States, the United Kingdom, Russia, India, and Israel are the most advanced countries in terms of military drone development and deployment. In 2017, there was an increase in the proliferation of military and civilian drones, with the United States and the United Kingdom carrying out the most drone strikes. These UAVs are equipped with a trajectory planning module that allows them to adjust their direction based on the scenario [40]. Drones

in the military can save expenses and hazards to soldiers by being used for lethal surveillance and targeted kills [35];[36]. These drones are embedded with decision mechanisms [37].

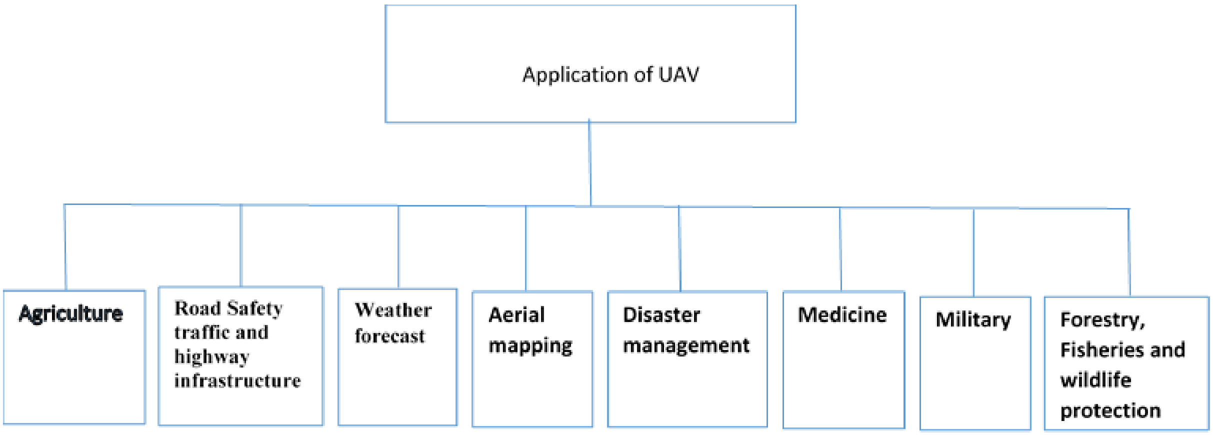

Figure 6. Applications of Unmanned Aerial Vehicles in Atmospheric Vertical Profiling

Table 2: Summary of UAV Applications

S/N	Category of Application	UAV Application
1	Civilian Usage	Photography
		Shipping and Delivery
		Disaster Management
		Rescue Operation
		Archeological Survey
		Geographic Mapping
		Human Health
		Livestock Surveillance
		Safety Inspection
		Life Observance
		Weather Forecasting
		Firefighting
		Emergency Rescue
2.	Military Usage	Bomb Recognition
		Military Surveillance
		Air Strikes
		Military Security
		Border Security
		Law Enforcement

3.	Agriculture Usage	Analysis of Soil
		Health Assessment of Crops
		Plant Prevention Spray
		Monitory Crop
		Irrigation System
		Crop Dusting
		Optimizing the Use of Resources

1.3. Block diagram of UAV

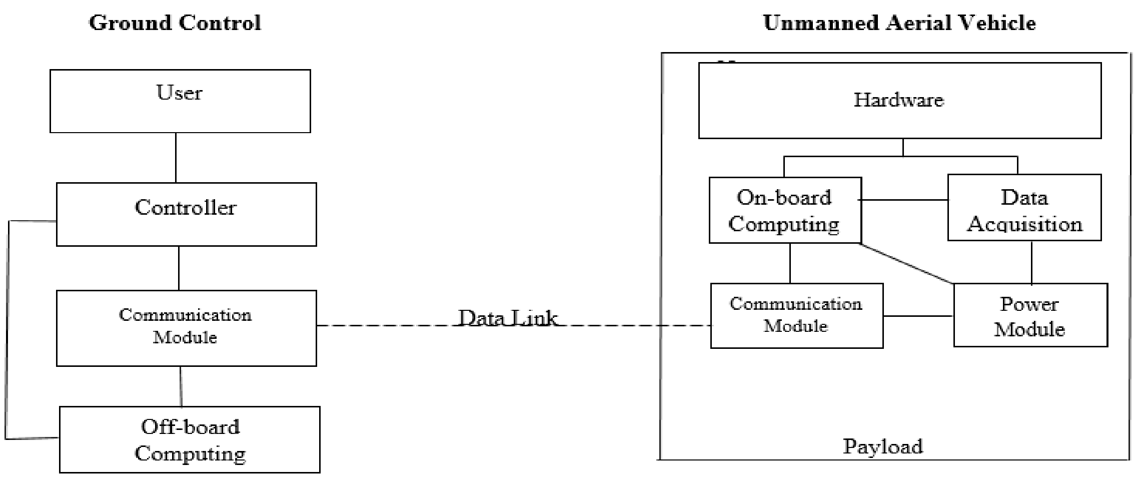

Figure 7: Block Diagram of Unmanned Aerial Vehicle

Table 3: Advantages, Disadvantages and Applications of UAV

UAV	Advantages	Disadvantages	Applications
Multi-Rotor	• Lower Price • Easy to control • It can Hover • Landing is Easy • High Payload capacity	• Less stable in the wind • Battery drain faster • Short flight time • Small payload capacity	Aerial Photography, Video Aerial Inspection, Security, Entertainment, and Agriculture.
Fixed- Wing	• 16 hours' flight time • Long endurance • Large area Coverage • Fast flight speed	• Take-off and Landing difficult • Do not hover • Harder to fly, need special training	Aerial Mapping, Inspection, Surveillance, Agriculture, and Security.

	• More massive and stable	• More Expensive	
Single-Rotor	• It can hover • Long Flight time • Heavier payload Capability • Very durable and robust	• More dangerous because of the blade • Harder to fly and operate • Very Expensive	Aerial Scanning, Exploration and Surveying.
Fixed- Wing Hybrid	• Long flight time • Large Area Coverage • Operates in a Hazardous environment	• Not Ideal for Hovering or forward flight • Difficult to operate • Less Stable • Small size may limit payload	Aerial Mapping, Surveillance, Remote sensing and Deliver.
Rotary-Wing	• It can hover • Easy to Operate • Take-off and Landing are easy • Less time to set up	• Less Efficient • Unstable • Very Complex • Small payload capacity	Detection of Harmful chemical, Filmmaking, Anti-piracy, Education

1.4 UAV Classification

The author in (116) opined that UAVs can further be classified based on the following:

(a) High Altitude Platform (HAP) Which is above 17km and is costlier.
(b) Low Altitude Platform (LAP) which basically contains tens of meters to a few kilometers and has quick deployment and mobility.
(c) Fixed-wing which must move forward to remain aloft.
(d) Rotary Wing which can hover

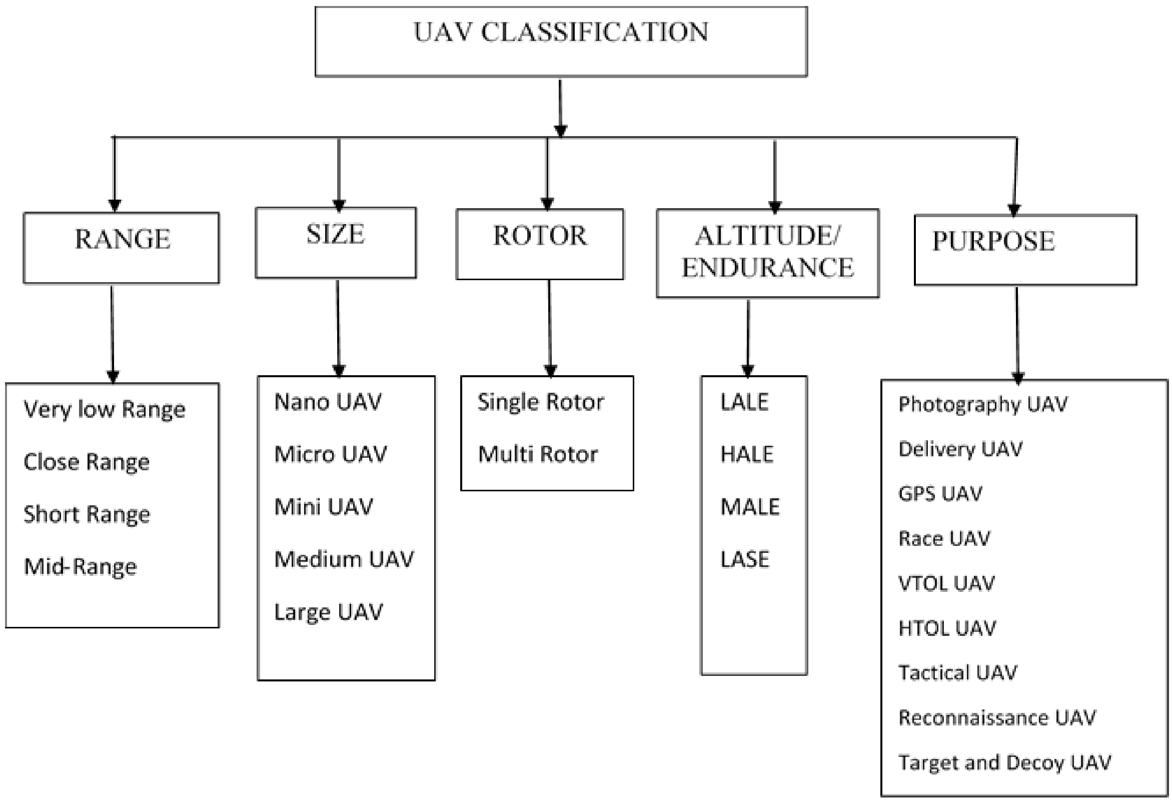

Figure 8: Classification of UAV based on Range, Size, Rotor, Altitude and Purpose

LEGEND

LALE Low Altitude, Low Endurance

HALE High Altitude, Low Endurance

MALE Medium Altitude, Low Endurance

LASE Low Altitude, Short Endurance

VTOL Vertical Take-off and Landing

HTOL Horizontal Take-off and Landing

1.5 Challenges in UAV Classification

The following Challenges were observed by (116)

(a) Deployment
(b) Channel Modeling
(c) Path Planning
(d) Performance Analysis
(e) Energy Constraints
(f) Resource Management

1.6. UAV Communication

Because UAVs move quickly and flexibly, using wired communication is impractical, and even when wireless communication is employed, the speed and altitude of the UAV are usually taken into account. Data connection (radio-frequency transmission) is used by UAVs to send and receive data. Its location, distance, and location to the target, as well as payload information, airspeed, altitude, and other factors, can all be included in the data. In addition, live video from the UAV can be relayed to the Ground Control Station. To bypass transmission range limitations, UAVs used air-to-air wireless communication to communicate among themselves and with the station on the ground. Ad hoc network architecture allows some UAVs to interact with one another [46]. Few UAVs can transmit data to the station on the ground, or satellites and other services [47]. These drones communicate using data link which employs a variety of frequencies, that are chosen based on the design and usefulness of the UAV. The summary of UAV data-link frequencies is given in Table 4.

1.6.0 The Data-link

The data link is actually the nervous system of the UAS, transmitting data from the operator's eyes and ears to his mind, which is then processed and transmitted over the data link to the UAV, which can be direct via line of sight or radio communication from the ground station, indirectly via satellite or via cloud-based multi-UAV networks. The communication path of the UAV with the operator and the ground station is shown in the data link diagram. It also shows how the operator controls, assess, navigates, and responds to the UAV during its mission. (117)

1.6.1. Data Link System

The most popular data link system frequencies are:

• 3Ghz Frequency: 3Ghz data link frequency can pass through barriers, with maximum data rates that are limited.

• 4Ghz Frequency: This frequency is very popular thus becoming overcrowded.

• 8Ghz Frequency: This is the shortest range although it has the maximum data range.

• 900Mhz Frequency: This frequency has limited maximum data rates and can pass through barriers. It enables devices to transfer a larger amount of data.

1.6.2. Data-Links for UAV Control

Some of the data links used for controlling UAVs are:

• 4Ghz Frequency: This frequency can span up to 1 mile, but cannot be used in places that are full of mountains or woods.

• 900Mhz Frequency: It can cover more than 60 miles, and is used in areas where there are mountains and woods. It lacks the necessary data transmission speeds for video. Around 20 kilometers away, transmission is possible.

1.6.3. Data-Links for UAV Video Transmission

• 3Ghz Frequency: It has a range of 40+ miles. The drawback is poor video quality caused by minimum data rates. Because the wavelength is rather long, it has a higher penetrating potential.

• 4Ghz Frequency: It has a range of 15+ miles. The drawback is that many UAVs are controlled using this frequency and using it for control and video will cause interference.

• 8Ghz Frequency: It is used for video. Its drawback is that it has a short wavelength that can cover up to 5 miles and cannot pass through most barriers. Because of its short wavelength and high data rate transfer capabilities, it is the most preferred frequency.

Table 4. Summary of UAV Data-link Frequencies

UAV Data-link System	Characteristics	Uses/Drawbacks
3GHZ	It can pass through barriers with range of 40+	Use for video transmission but have poor video quality
4GHZ	Very popular and is overcrowded	For UAV control, however it causes interference
8GHZ	Shortest range	For video transmission with minimum data range of 5miles
900MHZ	It has limited data-rates	For UAV Control and can cover more than 60 miles.

1.7. UAV Protocols

For drone networks, several routing methods have been proposed [48]. Unmanned aerial vehicles routing protocols are classified as network architecture-based routing protocols, data forwarding routing protocols, and centralized and distributed algorithms.

1.7.1 Networking Protocol

These protocols are categorized into topology-based routing protocol, Position-based routing protocol, and Hierarchical routing protocol.

A. Topology-based Routing Protocol: Topology-based routing protocol is divided into tree-based, mesh-based, and hybrid routing. Tree-based routing is subdivided into core-rooted-based routing and source-rooted. The source node is the root of multi-cast trees and maintains tree formation and distribution in source-rooted tree routing. Core-rooted tree routing comprises of Core which are nodes that have specific functions such as distributing multi-cast data and managing membership. Source-based routing eliminates the requirement for intermediary nodes to keep current routing information to route packets. Overhead is the most significant drawback of source routing. In source routing, the routing table is extensive for a big network, and all packets must have the complete route information in their header file, leading to waste in the network capacity. In hop-by-hop routing, the next hop distributes the route to the destination. When packets for the destination node are sent to another node, the node transfers it to the next hop corresponding to the destination node. Mesh-based routing disseminates packets between all associated nodes in a mesh structure. Route discovery and Mesh building can be accomplished in two ways: route discovery can be done using the broadcasting approach, and mesh construction can be done using the core point method. In a high mobility network, mesh routing outperforms tree-based routing, mesh-based routing, on the other hand, enables several paths for data packets to be sent from source to destination. Mesh-based routing requires control packets to sustain and control the routing topology, resulting in routing overhead and power inefficiencies. Hybrid routing methods are a combination of tree and mesh-based routing techniques. The main benefits of hybrid routing are the multiple route paths [65].

Conventional routing protocols that were initiated for low-speed ad hoc networks based on networking protocol (topology-based Routing) were:

• Static routing protocols have fixed routing in topology-based protocols. They were designed for slow networks with varying topologies or static networks. This means that the best end-to-end path for source-destination pairing is static for some time. [92] Before each flight, a routing table is calculated and uploaded to the UAVs, and it is not feasible to alter or modify it while they are in flight. This routing protocol is not fault-tolerant and is not dynamic [66].

• A routing table is used by the Proactive Routing Protocol (PRP) to keep all of the routing information in the communication network. These routing tables are updated and shared across the nodes regularly. Tables must be updated when the topology changes. The main benefit of PRP is that it consistently contains the most current information. Routing messages are interchanged among the communication nodes to ensure that the routing tables are updated. However, this consumes too much bandwidth, rendering the network ineffective [67].

• In reactive routing protocol (RRP), when a pair of nodes communicate with one another, the route between them is saved. The primary goal of RRP is to eliminate the overhead associated with proactive routing methods. Due to the length of time required to select the best route, excessive latency may arise throughout the routing process [16]. RRP is divided into two categories: hop-by-hop routing and source routing. With source routing, the packet has the full source-to-destination address, so this packet can be easily transmitted by the intermediate nodes. In the hop-by-hop routing system, it includes the destination and next hop addresses in the packet. An intermediate node is in charge of maintaining the routing tables to forward the data.

• Hybrid Routing Protocol (HRP) was developed to reduce the overhead concerns associated with proactive and reactive protocols. RRP requires a longer period to identify routes, though PRP has a high control message overhead. The Route in the hybrid protocol is first determined using a proactive protocol but the reactive routing protocol is initiated when the essential network topology is detected or the initially established route is broken [92]. HRP is appropriate for large-scale networks with multiple sub-network areas, Interzone routing utilizes PRP and inter-zone routing employs R P [65]

Irrespective of the topologies used, the routing algorithm can also be divided into centralized and distributed algorithms. In centralized algorithms, the central node is shared with network members. Hence, the local algorithm can be executed by the source node to discover the end-to-end optimal path. For distributed algorithms, the nodes are kept hidden from the entire network topology, and also they do not fully know about their local sub-network topology [92].

B. POSITION-BASED PROTOCOL

Position-based routing systems discover the best route based on the user's location. For instance, one could pick the next node based on its proximity to the present node or the destination. Instead of using link information for routing, it uses GPS to find the optimum path. The packet source is thought to have position information for itself and its neighbors, as well as the packet destination node. It performs better and has robustness against frequent topological changes and superior scalability because of the usage of location services and forwarding techniques (115).

- Greedy Perimeter Stateless Routing (GPSR)

GPSR is a wireless routing protocol suitable for wireless datagram networks. In GPSR, greedy packet forwarding decisions are made based on the neighboring information table. However, GPSR selects a coordinator node based on geographic information but in a situation where greedy forwarding is not attainable, an algorithm is used to recover it by routing around the perimeter of the region (83).

- Greedy Hull Greedy(GHG)

GHG is a wireless routing protocol suitable for forwarding messages very close to their destination and is similar to GFG in terms of routing algorithm and recovery algorithm. To restrict the local recovery process, the protocol divides the network space into multiple closed subspaces (69)

- Greedy Random Greedy(GRG)

In GRG, the message is greedily passed on until it reaches a minimum in the routing protocol. For the local minima to be resolved, a randomized recovery algorithm is used. More so, the recovery technique should be randomized and the recovery part should be memoryless and local. (50)

- Greedy Forwarding (GF)

This algorithm is identical to the Greedy Random Greedy algorithm, with the exception that it does not perform any predictions and instead simply checks the node location at each step. Then, based on the shortest distance, it chooses the optimal node to transmit the packet to. GF is a technique that permits drivers to communicate seamlessly in the network. (51)

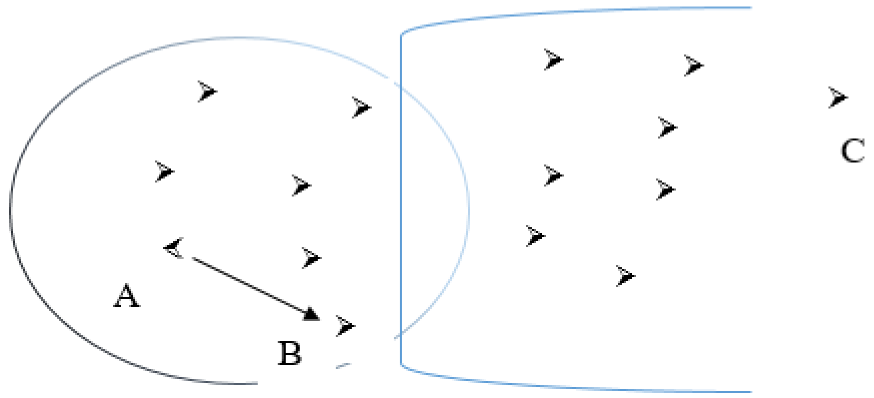

Figure 9: Greedy forwarding Example B is A is the closest neighbor to C

- Energy Balanced Greedy Forwarding Routing (EBGR)

The forwarding area is separated into four 24 sub-regions in this routing protocol. The candidate sub-regions next-hop node is chosen based on the node's residual energy level and from the next node's remaining hops to the destination node. It makes use of geographical routing protocols to get the energy estimate of the routing paths balanced thereby preserving good scalability and efficiency for an arranged wireless sensor network. (52)

- Greedy Distributed Spanning Tree Routing (GDSTR)

During greedy forwarding, an individual node keeps a record of 2-hop neighbor information to limit the possibility of local minima. It forwards packets greedily to a destination other than the current one so far it can find a neighbor close by. Assuming the packets end up in a local minimum, the node will look for a neighbor close by other than itself to forward the packets. The packets are forwarded by the sides of a spanning tree that sums up the location of the nodes in its subtree. (53)

- Cross-Layer Link Quality and Geographical Beaconless Opportunistic Routing (Xlingo)

This technique takes neighboring link quality into account and chooses the following node depending on geographical factors. For routing decisions, the article makes use of a combination of human-related and cross-layer characteristics, including packet delivery ratio, quality of experience, link quality, queue duration, residual energy, and geographical location. It also examines a route failure recovery method, allowing for smoother functioning in difficult conditions and mobile networks. (54)

- Adaptive Forwarding Protocol (AFP)

This route presents a forwarding method based on forwarding probability and the construction of forwarding zones. To eliminate redundant broadcasts, the forwarding probability is employed. It aids in adaptively calculating forwarding probability to boost forwarding efficiency. Nodes closer to the destination and a longer distance to the last hop forwarder rebroadcast the message with a higher prospect. A forwarding zone criterion has also been created to regulate the forwarding range, with the main goal of reducing wasteful retransmission and reducing collisions between neighbor nodes. (55)

- Reactive- Greedy- Reactive (RGR)

To discover the optimum path, this greedy method uses Route Requests (RREQs) and Route Replies (RREPs), which contain Route Errors (RERRs), hello messages, and location information. A RERR message is returned to the source in the event of a link failure. This protocol increases the packet delivery ratio while lowering latency. Because of the UAVs' high mobility, a packet loss error will occur if the next hop's geographic position information is not updated in a timely manner. (56)

- Scoped Flooding and Delayed Route Request

This protocol suggests a way to enhance the RGR algorithm in order to reduce the routing overhead generated by multiple route request messages. To improve the original RGR protocol's performance and the location information, the velocity vector of the nodes is used by this technique to estimate their present locations. (57)

- Beaconless Opportunistic Routing

Video recording applications use this routing protocol. This technique provides a geographical beaconless Opportunistic Routing (OR) and a link quality protocol that makes routing decisions based on numerous parameters such as connection quality, geographic position, and energy. (58)

- Location Oriented Directional MAC (LODMAC)

To boost spatial reuse, communication range and capacity in FANETs, this technology uses directional antennas. Within the MAC layer, the location of adjacent nodes is estimated and this includes the use of directional antennas and location estimation of surrounding nodes. (59)

- Extremely Opportunistic Routing (ExOR)

The source node uses multi-paths to send packets to the port of call while utilizing a forwarder preference list in this routing protocol. Identical data packet transmissions are reduced with this strategy, MAC technique, and an integrated routing for multi-hop wireless networks that boosts the speed of big unicast transmissions. (60)

- Location –Aided Routing (LAR)

This technique reduces the look for a route to a smaller and more constrained request zone. When compared to the flooding approach, the quantity of routing messages is reduced. Nevertheless, it doesn't provide the shortest route. The protocol restricts route discovery to the "request zone," which is determined by the anticipated location of the destination node at the time of route discovery. When compared to a routing method that does not use location information, simulation findings show that adding location information reduces routing overhead dramatically. (61)

C. Hierarchical Routing Protocols Hierarchical routing protocols take into account nodes that are organized in a hierarchy, with the lower layers forming clusters. In most cases, each node just stores details about its neighbors in a table that is modified via hello packets. For the best path, each cluster head interacts with the others in the cluster [92]. A list of newly developed techniques for UAV networks is as follows:

• Cluster-Based Routing Protocol (CBRP): In a distributed fashion, this routing technique separates the nodes into numerous disjoint or overlapping clusters. The cluster membership information saved at each cluster head is used to discover inter-cluster paths dynamically [92]

• Enhanced Cluster head Gateway Switch Routing [62]: This algorithm based on AODV has a congestion control technique. The congestion is monitored by the cluster head by lowering the number of transmissions and creating routes on a per-need basis during this procedure.

• Fisheye State Routing (FSR) [63]; [64]: This routing system constantly updates a topology map that is utilized to find the shortest path. It performs neighbor discovery by allowing nodes to send a Hello message every second disseminates information by allowing nodes to use Link State Announcement(LSA) every second and finally computes route from LSA.

2. ATMOSPHERIC PARAMETERS VERTICAL PROFILE USING UAV: APPROACHES

This section discusses the proposed UAV schemes and techniques used to obtain atmospheric parameters. In [68], the authors employed autonomous Environmental Drones (E-drones) to observe the status of the air in a certain area by flying the E-drone at a predetermined height (Altitude) at hourly intervals and collecting data on the air pollutants in that area. A solution to reduce pollution is mounted as a payload on the UAV and is deployed for the pollutant (CO2, CO, NH3, SO2, PM, O3, and NO2) above a prescribed level. The UAV then returns to its ground position after that. Tailored software is used by multiple E-drones in different areas to produce an Air Quality Health Index (AQHI) chart of that area, which is subsequently utilized

to analyze the current surroundings and also over a long period.

Witte et al. used Unmanned Aerial Vehicles for pressure, temperature, humidity, and wind velocity measurement [71]. The UAV was constructed to monitor turbulence in the lower air boundary using a technique for computing time-dependent wind speed from moving velocity sensor data. During the transition from a stable to a convective situation, three flights of two unmanned aerial vehicles (UAVs) were used to measure the lower atmospheric boundary layer. When the results were compared to those from a ground-based meteorological measurement station, it was discovered that this method efficiently retrieves the wind vector as well as scalar

temperature and humidity statistics.

Observations were made by the authors in [72] with more than 150 flights made by various Unmanned Aerial Vehicles (UAVs). These flights were conducted during largely steady and highly stable boundary layer conditions, using ground-based eddy-covariance (EC), automated weather stations (AWS), and remote sensing instrumentation. Temperature, humidity, and wind were measured using an eddy covariance (EC) device. Several varieties of fixed and rotary-wing UAVs, as well as a scanning wind LIDAR and a vertically profiling SODAR, were used to supplement the ground-based in-situ observations. Except for the wind, which was retrieved at the ground station, all measurements were retrieved using the UAV.

Vertical profiles of wind, temperature, and moisture in the lower atmospheric boundary layer (ABL) at high spatial (space) and temporal (time) resolutions were captured by authors in [73].

The authors employed a UAV to acquire wind speed and temperature at a suitable height. The authors measured the speed of the Wind and sensible thermal flux indirectly using the UAV data, and height was calculated using the sensible heat flux data captured. The use of a UAV to capture surface temperatures was a major constraint of this study. The results showed that UAV-observed temperatures and relative humidity were in good agreement with AWS-observed temperatures and relative humidity, with correlation coefficients of 0.98 and 0.9 and mean biases of -1.05 C and 6.66 percent.

Authors in [74] employed three unmanned aerial vehicles (UAVs) that had been customized for usage in harsh polar conditions. These UAVs were employed to gather meteorological observations under difficult situations, such as taking off and landing on ice, low temperatures, icing, and, in the case of the quadcopter, rotor downwash. The three UAV results highlighted the value of flexible small-scale high-resolution measurements, which are only attainable with UAVs. Guimar˜aes et al. in [75] captured nighttime vertical during the dry season of 2018, a copter-type UAV was used to collect vertical profiles of ozone, PM2.5, and PM10, as well as other data, above the city of Manaus, Brazil, in the center Amazon. These captured data were analyzed to learn more about the structure of the urban nighttime boundary layer (NBL) and pollution within it, demonstrating the ability to emerge sensor payload technologies on UAVs to provide new checks and understanding into pollution dynamics in urban nighttime boundary layers.

[76] undertook an experiment to capture meteorological characteristics, which indicate the state of the atmosphere at lower levels, using an unmanned vehicle with rotary wings and an electrical engine weighing less than 7 kg. Data collected from the drone at a fixed location was compared to data collected from a meteorological station, while data collected during the flight was compared to balloon sounding and data collected from sensors attached to a 250-meter-high mast. The temperature measurement resulted in an optimistic outcome, even though the reading changed at times.

These authors [78] developed a small drone called OVLI-TA for atmospheric boundary layer research. This OVLI-TA could profile the speed, direction, temperature, and humidity of wind up to 1 km altitude, and also measure turbulence. The findings of the flight tests were compared to the measurement of a 60 m tower as well as the radiosonde profiles. The average values of wind, temperature, humidity and turbulence parameters showed good agreement in these comparisons.

[80] used an unmanned aerial vehicle to analyze the vertical distribution pattern of PM2.5 in Hangzhou, China. The PM2.5 mass concentration was measured using a Sidepak AM510 PM Detector. The HOBO U12 Temp/RH Data Logger, which is positioned outside the UAV body, was used to capture the temperature and relative humidity. It measures temperature with a 0.03 °C resolution and relative moisture with a 0.03 percent resolution every 2 seconds. It was determined that as altitude increases, the amount of PM2.5 in the air decreases. Climatological parameters like Air temperature, moisture, and atmospheric pressure are all influenced the vertical profile of PM2.5 levels. In the morning, ambient air temperature and relative humidity have a greater impact on the vertical profile of PM2.5 concentrations than in the evening.

To record the Instrument Landing System (ILS) signal, Demule et al. in [81] utilized UAV multicopters. The author's purpose was to undertake elevation profile trials in the far field region and, as a result, provide answers to sky guide engineers' problems. This was carried out in the airport area, with regulated and compulsory flying checks. The results revealed that measuring Instrument Landing System signals using an unmanned aerial vehicle was both possible and lucrative. The measurements were accurate and repeatable, which met the requirements. The precision, repeatability, and correlation with flight check and ILS theory of this new measurement approach demonstrated its promise.

[82] provided a mapped estimate of crop evapotranspiration (ET) based on the METRIC model (Mapping Evapotranspiration at High Resolution with Internalized Calibration) for calculating consumptive use utilizing high-resolution multi-spectral pictures from a UAV. A multi-spectral band and a thermal camera were used by the UAV to obtain the image. In certain flights, relative humidity and air temperatures were also recorded. The data were then interpolated and mapped, providing additional information for comparison with the METRIC map, enabling the scheduling of a high-frequency flight program during the growing season, resulting in data that may be used to track crop water usage and the likelihood of drought.

To solve the problem associated with capturing atmospheric data and fire, these authors [84] proposed using a UAV capable of managing wildland fire to sample the vertical wind profile of 3-dimensional (3D) winds captured by several sonic anemometers for fire weather observations to solve the problem of capturing atmospheric data and fire. To measure wind, the authors employed an Anemoment, LLC TriSonica Mini Weather Sensor. At speeds of up to 5 Hz, these sensors recorded humidity, magnetic heading, pressure wind direction, sonic temperature, pitch, and roll. The results revealed that UAVs are important in the recording of vertical profiles of climatic parameters and that meteors can be used instead.

Atmospheric gas sensing using UAVs was employed for airborne gas sensing by authors in [85]. This drone-based broadband infrared atmospheric spectroscopy was capable of swiftly capturing several gas species data while in flight. A broadband Fourier-transform infrared spectrometer was fitted into the autonomous UAV to provide rovibrational spectroscopy and allow the quick quantitative aerial study of several species together with a minimal noise performance estimate. The UAV's sensing capabilities were improved by employing a novel gas mapping strategy based on machine learning methods to derive concentration maps from spatially sparse sets of data and quantifying unpredictability.

A drone equipped with meteorological components sensors such as the ultra-light Air Dust measurement system for relative humidity, temperature, particulate matter, atmospheric pressure, and GPS position equipped with a data logger was used to perform measurements in the atmosphere in this article [86]. Data processing methods were also tweaked to improve the UAV sensor measurement response time during the aircraft mission's ascent and descent. Using an I2C interface, the digital humidity, pressure, and temperature sensors communicate with the microcontroller. A thermocouple type T was also installed on this UAV to monitor rapid temperature changes.

The canopy boundary layer and the lower atmosphere stability were profiled using an unmanned aerial system [88]. The UAS was built out of a small multi-rotor unmanned aerial vehicle (UAV), a Kestrel DROP D3FW Fire Weather Monitor (Kestrel Meters, Boothwyn, PA, USA), and a basic rope that connected these elements. The fast variation in relative humidity and temperature in the course of the taking-off and landing of the UAS in three different environments was visualized by the authors to highlight the system's capability to acquire data. Due to the complexity of the atmosphere, minute changes in vertical profiles were noticed over small scales of space and time.

In [89], a lightweight UAV with monitors attached was used to measure the vertical variation of PM2.5 concentration and meteorological factors up to an altitude of 1000 m. The measurements taken with this UAV followed the same spiral path. The UAV's three-dimensional sampling data revealed the PM2.5 distributions which were more homogeneous horizontally than vertically, and that the PM2.5 concentration decreased as the height increased. Also, the vertical gradient from morning to afternoon was reduced, which was less in winter than in summer and fall. These findings could serve as a foundation for more intelligent and targeted air pollution regulation and governance, as well as a standard for analyzing and forecasting PM2.5 pollution.

Martin et al. in [90] proposed the use of a Meteorological Mini Aerial Vehicle (M2AV) to measure wind direction and speed, temperature, and humidity. A three-dimensional GPS was also employed to measure and store data on the precise time, aircraft position, altitude, and speed. Although it was auto-piloted throughout the flight, a human pilot handled the take-off and landing of this UAV. In comparison to ground-based in-situ systems, which only offered temporally averaged data, the data obtained by UAV had point measurements in space and time, according to the scientists.

A Multi-Purpose Airborne Sensor Carrier (MASC-3) was proposed in [93] for detecting wind and turbulence. The UAV can collect data, process it, and provide a flight platform. The measurements were taken during two UAV flights in a steady boundary layer, and they were compared with those taken by the tower and the Sodar system. The results revealed that the data collected on the direction and speed of the wind, as well as turbulence, were accurate. The mean values, integral length scale, turbulent kinetic energy, variances, co-variance, and mean values obtained from the data recorded by the UAV were all consistent with the meteorological measurement tower.

This article [94] provides a conventional notion of acquiring data utilizing tandem flying multi-copters as a distributed sensor platform. Gimbal stabilization methods were introduced by the authors to achieve high payload pointing performance. Different flight experiments were carried out in various wind situations to test the accuracy of sensor and position control measurements. However, no proof of concept was provided, and the relative position controller was not used on flights. To evaluate the performance of the single UAV in this idea, flight tests were conducted with each UAV.

[95] presents a methodology for Urban Boundary Layer investigations making use of meteorologically instrumented UAVs, as well as best practices and lessons learned from a

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proof of concept field campaign that focused on the urban canopy layer and roughness sublayer of a large modern city with a high-rise urban canopy. A mixed fleet of multi-rotor and fixed-wing UAVs were engaged to conduct simultaneous observations. Following the field demonstration, the Roughness Sublayer of a large modern city with a massive urban canopy were discussed.

An Unmanned Aerial Vehicle was employed by the authors of [96] to conduct a study on simple three-dimensional fluctuations in vehicle pollution. The concentration of Particle number(PN), particle mass (PM), and black carbon (BC) were all measured by the UAV. Most air contaminants rise with the altitude of highways, according to the results of these vertical profiles near the highway. When compared to earlier investigations, practically all pollutants dropped below background levels, which is in line with prior research, while the vertical profile revealed that PNs and BC increased above ground than previously documented ones.

[104] used a quadcopter-based setup to measure particulate matter and carbon dioxide concentrations with a high space resolution of 1 m both horizontally and vertically inside a 0–100 m atmospheric layer. To distinguish the aerosol plume, the UAV system flew horizontally up to 25 m above ground level at a 5 m interval from the sea to the surf zone, delivering the aerosol profile vertically and horizontally. Researchers were able to calculate the emission

rates of surrounding humidity for small and large surf zone particles using these horizontal and vertical aerosols profiles.

[106] investigated airborne particle variability using aerial remote-control vehicles. Four different flights were performed using a fixed-wing UAV at different heights. For clean, uninterrupted operation, the UAV was made up of an aerosol spectrometer with the input probe hidden under a covering. The average PM2.5 concentrations was determined to be 36.3 g/m3 for three flights at various altitudes, with the highest concentration reported below 10 m above ground level. The outcome showed a normal deviation of just 3.6 g/m3 and a 3.6 g/m3 general vertical variance.

The authors' goal in [108] was to use a hexacopter-type unmanned aerial vehicle (UAV) to show the vertical distribution regular pattern of PM2.5 over urban underlying surfaces near the ground in winter. Throughout the day, PM2.5 was shown to be inversely connected with height and temperature and favorably correlated with RH. PM2.5 concentrations peaked at 11:00 a.m. Furthermore, due to the relatively steady climatic conditions with a vertical temperature difference of 1.05 °C, the vertical gradient of PM2.5 in the morning was the most significant. In addition, air temperature, relative humidity, and height were chosen as independent variables in the linear regression model, whereas PM2.5 concentrations was chosen as a dependent variable.

Table 5. Summary of related work on UAV for Atmospheric Profiling

References	Applications	Limitations
(68)	Air pollution detected and abatement	Only N02 abatement was performed
(71)	Turbulence research	flight profile did not resolve long-wavelength motions while flying
(72)	Arctic ABL investigation	unresolved turbulence near the surface
(73)	Estimating sensible heat flux in ABL	could not determine the surface temperature
(74)	Polar ABL investigation	Did not consider stability, wind field, and turbulence
(75)	Profiling Atmospheric Species Concentrations	High heat capacity of the urban canopy
(76)	Profiling Lower Atmosphere	vertical component of force was ignored
(78)	Measuring profile and Turbulence in ABL	Utilized slow temperature and moisture sensors
(80)	Vertical distribution of PM	High configuration and interval
(81)	ILS ground measurement	unfiltered/filtered signals not displayed
(82)	Evapotranspiration estimation	characterizing crop water consumption at field scale not captured
(84)	Profiling in the fire environment	errors are introduced by the movement of the platform or prop wash
(85)	Gas Sensing	not permitted to operate beyond the visible line of sight
(86)	Measurement of urban boundary layer dynamics	Drone Fluctuation was observed and TKE parameter noisy
(87)	Measurement of Canopy Boundary layer	Equipment configuration and UAV not operational in rainy condition

(89)	Measurement of three-dimensional PM2.5	payload, battery, and monitors affected the duration of measurement
(90)	Lower troposphere profiling	No reliable measurement of the lower troposphere flight strategies
(93)	Atmospheric boundary layer measurement	week turbulent fluxes that require high accuracy measurement
(94)	Optical atmospheric measurement and quadcopter	No implementation of relative position compiler
(95)	Urban boundary layer measurement	No use of infrared thermal imaging camera
(96)	Particulate Matter and Blank Carbon profiling	Dataset obtained was small
(104)	Aerosol –particle –concentration measurement	dense nature of the atmosphere affects the reading/capturing of data
(106)	variability of airborne particulates	Multiple vehicles to validate mission
(107)	Measurement of PM2.5	Dataset obtained was small

3. OPEN ISSUES AND CHALLENGES

Despite the potential of UAVs, this field is still relatively new and under-explored. Many challenges need to be addressed before UAVs can be effectively deployed to offer robust and reliable context-specific networks. While it promises improved performance and capacity, it is difficult to establish and maintain efficient communications between UAVs.

All of the components of UAV communication networks face difficult problems that must be solved including sensors that are mounted on-board UAVs must be calibrated and validated for the observations acquired to be reliable. While the UAV accuracy standards will vary depending on the intended application of the observations, the calibration and validation (cal-Val) processes should be universal. The importance of the sensor response in describing the atmospheric boundary layer is examined by asking: What sensor response is required to represent key meteorological phenomena relevant to the accurate prediction of critical atmospheric phenomena such as convection initiation (CI)? Simulations of a convection boundary layer- and air mass limit with large eddy simulations (LES). There are still many unanswered questions when it comes to the use of UAVs in many industries. UAV routing protocols are still in the prime stages of development.

The following are the challenges faced in the use of UAVs for different applications:

• The topology of UAV networks unlike many other wireless networks, is dynamic, with the number of nodes and links altering as well as the relative placements of the nodes. The necessity for a communication infrastructure that can tolerate rapid network topology changes is a significant problem in implementing UAV networks.

• The routing protocol cannot just be a simple proactive or reactive scheme implementation. When UAVs malfunction, the inter-UAV backbone must constantly rebuild itself. Frequent link failures, packet loss, constrained bandwidth, high routing overhead, triggered routing table updates, and low network convergence rate are the main routing difficulties for UAV networks. The majority of the routing protocols presented so far are based on MANET and VANET routing protocols which are not fundamentally suitable for UAVs and have thus failed to deliver satisfactory performance in UAV networks.

• Energy conservation is also a challenge. A UAV's ability to use energy efficiently is critical to its operation, as it is frequently required to meet operational goals such as range, endurance, and other mission requirements. There must be strategies to conserve energy in power-deficient UAVs to extend the network's life by discovering a way to use larger capacity batteries in UAVs with a small footprint. Solar photovoltaic cells for powering UAVs, such as the hybrid fixed-wing, could be a potential avenue to explore.

• Flight longevity, the capability of payload, precision, and sizes of sensors must be resolved by Enhancing aerodynamics, lowering weight, and improving battery or propulsion system performance to increase travel distances and carrying capacity. The duration of a UAV's flight is largely determined by its battery life. Some UAVs, particularly multi-rotors, have batteries that can only maintain a flight length of 10 to 30 minutes at best, and even less when flown in at strong wind speeds. They are less efficient for jobs that involve more time, and distance, or in regions where some other equipment cannot be reached easily.

• The costs of manufacturing these devices are not a substantial barrier, but because of the technological nature of UAVs, the cost of integration, deployment, maintenance and training and data analysis can be expensive. Although they are presently not competitive against planes and satellites, their cost must be reduced to enable the use of UAVs in all sectors.

• Cyber-liability and hacking are the key problems of using UAVs for data collection and wireless distribution. UAVs that collect sensitive data could become targets for malicious software looking to take information. A hacker may potentially take command of the UAV itself and use it for unlawful purposes such as stealing goods or data, invading privacy, or smuggling. The majority of existing routing protocols have not worked well with UAV networks and are unable to meet security needs.

In addition, these challenges aren't just only technical; legislation and policies that differ from country to country currently represent a substantial barrier towards the widespread use of UAVs in air quality and monitoring investigations. Regulations are either non-existent or a loose adaptation of aviation laws that are not a perfect fit for UAVs. Countries like the United States, Germany, the United Kingdom, and Spain [109] are paving the way in this regard by creating standards for unmanned aerial vehicles (UAVs) usage and the territories over which they can fly. Other countries around the world, on the other hand, are still lagging. There is the need for legislation that will guide and regulate the new possibilities and application areas of UAVs.

4. CONCLUSION

A thorough analysis of this literature showed that different drones embedded with sensors were utilized to monitor air quality parameters like temperature, pressure, humidity, wind, CO, SO2, NO2, O3, PM2.5, PM1.0, and black carbon. UAVs are more adaptable and operationally conspicuous than ground-based approaches or other aerial systems like manned planes and satellites. These have several characteristics that make them ideal for air quality monitoring, including minimal size, weight, and energy requirements, as well as lower platform and instrumentation costs. At the same time, new techniques are rapidly developing, resulting in lighter and smaller appliances with increased sensitivity and the ability to operate remotely. The

potential of UAVs for air quality research has been discovered. UAVs are adaptable, allowing different sensors to be transported and operated in different flight modes. Unmanned aerial vehicles (UAVs) have a bright future in air quality measurement and applications due to their capacity and versatility. Other aspects of air quality control, such as humidity, temperature, and other relevant variables, could be improved/modified with these systems. Working with collaborators from all around the biosphere to create a specialized network that includes many aspects of UAVs has proved the ability to sample spatial and temporal data over large areas

or in site-specific regions. Because of increased efforts by researchers and sensor manufacturers, as well as developments in wireless automatic devices, vertical profiling is now possible.

REFERENCES

[1] Illingworth, A., Cimini, D., Gaffard, C., Haeffelin, M., Lehmann, V., L¨ohnert, U., et al. Exploiting existing ground-based remote sensing networks to improve high-resolution weather forecasts. Bulletin Of The American Meteorological Society. 96, 2107-2125 (2015)

[2] Bauer, P., Thorpe, A. & Brunet, G. The quiet revolution of numerical weather prediction. Nature. 525, 47-55 (2015)

[3] Gonz´alez-Rocha, J., De Wekker, S., Ross, S. & Woolsey, C. Wind profiling in the lower atmosphere from wind-induced perturbations to multirotor UAS. Sensors. 20, 1341 (2020)

[4] Holland, G., Webster, P., Curry, J., Tyrell, G., Gauntlett, D., Brett, G.,et al. The Aerosonde robotic aircraft: A new paradigm for environmental observations. Bulletin Of The American Meteorological Society. 82, 889-902 (2001)

[5] Alley, R., Emanuel, K. & Zhang, F. Advances in weather prediction. Science. 363, 342-344 (2019)

[6] Kar´asek, M. Robotic hummingbird: Design of a control mechanism for a hovering flapping wing micro air vehicle. Universit´e Libre De Bruxelles. (2014)

[7] Krishna, G. An integrated approach for weather forecasting based on data mining and forecasting analysis. International Journal Of Computer Applications. 120 (2015)

[8] Rufino, G. & Moccia, A. Integrated VIS-NIR hyperspectral/thermal-IR electro-optical payload system for a mini-UAV. Infotech@ Aerospace. pp. 7009 (2005)

[9] Ward, S., Hensler, J., Alsalam, B. & Gonzalez, L. Autonomous UAVs wildlife detection using thermal imaging, predictive navigation, and computer vision. 2016 IEEE Aerospace Conference. pp. 1-8 (2016)

[10] Jacob, J., Chilson, P., Houston, A. & Smith, S. Considerations for atmospheric measurements with small unmanned aircraft systems. Atmosphere. 9, 252 (2018)

[11] Kardasz, P., Doskocz, J., Hejduk, M., Wiejkut, P. & Zarzycki, H. Drones and possibilities of their use. Journal Of Civil Environmental Engineering. 6, 1-7 (2016)

[12] Darack, E. UAVs: The new frontier for weather research and prediction. Weatherwise. 65, 20-27 (2012)

[13] Ludeno, G., Catapano, I., Renga, A., Vetrella, A., Fasano, G. & Soldovieri, F. Assessment of a micro-UAV system for microwave tomography radar imaging. Remote Sensing Of Environment. 212 pp. 90-102 (2018)

[14] Floreano, D. & Wood, R. Science, technology and the future of small autonomous drones. Nature. 521, 460-466 (2015)

[15] Gonz´alez-Jorge, H., Martınez-S´anchez, J., Bueno, M. & Others Unmanned aerial systems for civil applications: A review. Drones. 1, 2 (2017)

[16] Gupta, L., Jain, R. & Vaszkun, G. Survey of important issues in UAV communication networks. IEEE Communications Surveys Tutorials. 18, 1123-1152 (2015)

[17] Martınez-Carricondo, P., Ag¨uera-Vega, F., Carvajal-Ramırez, F., Mesas-Carrascosa, F., Garcıa-Ferrer, A. & P´erez-Porras, F. Assessment of UAV-photogrammetric mapping accuracy based on a variety of ground control points. International Journal Of Applied Earth Observation And Geoinformation. 72 pp. 1-10 (2018)

[18] Shahbazi, M., Th´eau, J. &M´enard, P. Recent applications of unmanned aerial imagery in natural resource management. GIScience Remote Sensing. 51, 339-365 (2014)

[19] Cai, G., Dias, J. & Seneviratne, L. A survey of small-scale unmanned aerial vehicles: Recent advances and future development trends. Unmanned Systems. 2, 175-199 (2014)

[20] Thamm, H., Brieger, N., Neitzke, K., Meyer, M., Jansen, R. & M¨onninghof, M. SONGBIRD-an innovative UAS combining the advantages of fixed wing and multi-

rotor UAS. International Archives Of The Photogrammetry, Remote Sensing Spatial Information Sciences. 40 (2015)

[21] Vergouw, B., Nagel, H., Bondt, G. & Custers, B. Drone technology: Types, payloads, applications, frequency spectrum issues, and future developments. The Future Of Drone Use. pp. 21-45 (2016)

[22] Leuenberger, D., Haefele, A., Omanovic, N., Fengler, M., Martucci, G., Calpini, B., Fuhrer, O. & Rossa, A. Improving high-impact numerical weather prediction with lidar and drone observations. Bulletin Of The American Meteorological Society. 101, E1036-E1051 (2020)

[23] Ahn, O., Kim, J. & Lim, C. Smart UAV research program status update: achievement of tilt-rotor technology development and vision ahead. 27th Congress Of International Council Of The Aeronautical Sciences, ICAS. 6, 2010 (2010)

[24] Smith, K. & Belina, F. Small V/STOL Aircraft Analysis. (National Aeronautics,1974)

[25] Lee, C., Kim, S. & Chu, B. A Survey: Flight Mechanism and Mechanical Structure of the UAV. International Journal Of Precision Engineering And Manufacturing. pp. 1-25 (2021)

[26] Yinka-Banjo, C. & Ajayi, O. Sky-farmers: applications of unmanned aerial vehicles (UAV) in agriculture. Autonomous Vehicles. (2019)

[27] Barmpounakis, E., Vlahogianni, E. & Golias, J. Unmanned Aerial Aircraft Systems for transportation engineering: Current practice and future challenges. International Journal Of Transportation Science And Technology. 5, 111-122 (2016)

[28] Gu, X., Abdel-Aty, M., Xiang, Q., Cai, Q. & Yuan, J. Utilizing UAV video data for in-depth analysis of drivers' crash risk at interchange merging areas. Accident Analysis Prevention. 123 pp. 159-169 (2019), Available: https://www.sciencedirect.com/science/article/pii/ S0001457518309631

[29] Menouar, H., Guvenc, I., Akkaya, K., Uluagac, A., Kadri, A. & Tuncer, A. UAV-Enabled Intelligent Transportation Systems for the Smart City: Applications and Challenges. IEEE Communications Magazine. 55, 22-28 (2017)

[30] Pham, H., Camey, M., Pham, K., Pham, K. & Rilett, L. Review of unmanned aerial vehicles (UAVs) operation and data collection for driving behavior analysis. CIGOS 2019, Innovation For Sustainable Infrastructure. pp. 1111-1116 (2020)

[31] Outay, F., Mengash, H. & Adnan, M. Applications of unmanned aerial vehicle (UAV) in road safety, traffic and highway infrastructure management: Recent advances and challenges. Transportation Research Part A: Policy And Practice. 141 pp. 116-129 (2020)

[32] Meixner, P. & Leberl, F. 3-Dimensional building details from aerial photography for Internet maps. Remote Sensing. 3, 721-751 (2011)

[33] Ramadass, L., Arunachalam, S. & Sagayasree, Z. Applying deep learning algorithm to maintain social distance in a public place through drone technology. International Journal Of Pervasive Computing And Communications. (2020)

[34] Balasingam, M. Drones in medicine—the rise of the machines. International Journal Of Clinical Practice. 71, e12989 (2017)

[35] Bousquet, A. The eye of war: military perception from the telescope to the drone. (U of Minnesota Press,2018)

[36] Hunt, B. Targeted killings of ‘suspected terrorists carried out by US drones–an analysis of the applicability of international humanitarian law. (2017)

[37] Kindervater, K. The emergence of lethal surveillance: Watching and killing in the history of drone technology. Security Dialogue. 47, 223-238 (2016)

[38] Erdelj, M., Natalizio, E., Chowdhury, K. & Akyildiz, I. Help from the Sky: Leveraging UAVs for Disaster Management. IEEE Pervasive Computing. 16, 24-32 (2017)

[39] Cˆamara, D. Cavalry to the rescue: Drones fleet to help rescuers operations over disaster scenarios. 2014 IEEE Conference On Antenna Measurements Applications (CAMA). pp. 1-4 (2014)

[40] Roberge, V., Tarbouchi, M. & Labont´e, G. Fast Genetic Algorithm Path Planner for Fixed-Wing Military UAV Using GPU. IEEE Transactions On Aerospace And Electronic Systems. 54, 2105-2117 (2018)

[41] Samad, A., Kamarulzaman, N., Hamdani, M., Mastor, T. & Hashim, K. The potential of Unmanned Aerial Vehicle (UAV) for civilian and mapping applications. 2013 IEEE 3rd International Conference On System Engineering And Technology. pp. 313-318 (2013)

[42] Eisenbeiß, H. UAV photogrammetry. (ETH Zurich,2009)

[43] Hemingway, B., Frazier, A., Elbing, B. & Jacob, J. Vertical sampling scales for atmospheric boundary layer measurements from small unmanned aircraft systems (sUAS). Atmosphere. 8, 176 (2017)

[44] Rautenberg, A., Sch¨on, M., Zum Berge, K., Mauz, M., Manz, P., Platis, A., Kesteren, B., Suomi, I., Kral, S. & Bange, J. The multi-purpose airborne sensor carrier MASC-3 for wind and turbulence measurements in the atmospheric boundary layer. Sensors. 19, 2292 (2019)

[45] Thiels, C., Aho, J., Zietlow, S. & Jenkins, D. Use of unmanned aerial vehicles for medical product transport. Air Medical Journal. 34, 104-108 (2015)

[46] Wan, J., Zou, C., Ullah, S., Lai, C., Zhou, M. &Wang, X. Cloud-enabled wireless body area networks for pervasive healthcare. IEEE Network. 27, 56-61 (2013)

[47] Uluskan, S., G¨okc¸e, M. & Fılık, T. RSS-based localization of an emitter using a single mini UAV. 2017 25th Signal Processing And Communications Applications Conference (SIU). pp. 1-4 (2017)

[48] Choi, S., Hussen, H., Park, J. & Kim, J. Geolocation-based routing protocol for flying ad hoc networks (fanets). 2018 Tenth International Conference On Ubiquitous And Future Networks (ICUFN). pp. 50-52 (2018)

[49] Callam, A. Drone wars: Armed unmanned aerial vehicles. International Affairs Review. 18 (2010)

[50] Flury, R. & Wattenhofer, R. Randomized 3D geographic routing. IEEE INFOCOM 2008-The 27th Conference On Computer Communications. pp. 834-842 (2008)

[51] Li, Y., Xie, S. & Yu, Y. Analysis of greedy forwarding in vehicular ad hoc networks. 2011 International Conference On System Science, Engineering Design And Manufacturing Informatization. 2 pp. 344-347 (2011)

[52] Li, S., Gao, H. &Wu, D. An energy-balanced routing protocol with greedy forwarding for WSNs in cropland. 2016 IEEE International Conference On Electronic Information And Communication Technology (ICEICT). pp. 1-7 (2016)

[53] Zhou, J., Chen, Y., Leong, B. & Sundaramoorthy, P. Practical 3D geographic routing for wireless sensor networks. Proceedings Of The 8th ACM Conference On Embedded Networked Sensor Systems. pp. 337- 350 (2010)

[54] Ros´ario, D., Zhao, Z., Braun, T., Cerqueira, E., Santos, A. & Alyafawi, I. Opportunistic routing for multi-flow video dissemination over flying ad-hoc networks. Proceeding Of IEEE International Symposium On A World Of Wireless, Mobile And Multimedia Networks 2014. pp. 1-6 (2014)

[55] Qingwen, W., Gang, L., Zhi, L. & Qian, Q. An adaptive forwarding protocol for three-dimensional Flying Ad Hoc Networks. 2015 IEEE 5th International Conference On Electronics Information And Emergency Communication. pp. 142-145 (2015)

[56] Shirani, R., St-Hilaire, M., Kunz, T., Zhou, Y., Li, J. & Lamont, L. Combined reactive-geographic routing for unmanned aeronautical ad-hoc networks. 2012 8th International Wireless Communications And Mobile Computing Conference (IWCMC). pp. 820-826 (2012)

[57] Li, Y., St-Hilaire, M. & Kunz, T. Enhancements to reduce the overhead of the reactive-greedy-reactive routing protocol for unmanned aeronautical ad-hoc networks. 2012 8th International Conference on Wireless Communications, Networking, And Mobile Computing. pp. 1-4 (2012)

[58] Ros´ario, D., Zhao, Z., Santos, A., Braun, T. & Cerqueira, E. A beaconless opportunistic routing based on a cross-layer approach for efficient video dissemination in mobile multimedia IoT applications. Computer Communications. 45 pp. 21-31 (2014)

[59] Temel, S. & Bekmezci, I. LODMAC: Location oriented directionalMAC protocol for FANETs. Computer Networks. 83 pp. 76-84 (2015)

[60] Biswas, S. & Morris, R. Opportunistic routing in multi-hop wireless networks. ACM SIGCOMM Computer Communication Review. 34, 69-74 (2004)

[61] Ko, Y. & Vaidya, N. Location-Aided Routing (LAR) in mobile ad hoc networks. Wireless Networks. 6, 307-321 (2000)

[62] Devarajan, K. & Padmathilagam, V. An enhanced cluster gateway switch routing protocol (ECGSR) for congestion control using AODV algorithm in MANET. International Journal Of Computer Applications. 123 (2015)

[63] Obraczka, K., Viswanath, K. & Tsudik, G. Flooding for reliable multicast in multi-hop ad hoc networks. Wireless Networks. 7, 627-634 (2001)

[64] Sasson, Y., Cavin, D. & Schiper, A. Probabilistic broadcast for flooding in wireless mobile ad hoc networks. 2003 IEEE Wireless Communications And Networking, 2003. WCNC 2003.. 2 pp. 1124-1130 (2003)

[65] Arafat, M. & Moh, S. Routing protocols for unmanned aerial vehicle networks: A survey. IEEE Access. 7 pp. 99694-99720 (2019)

[66] Sakiz, F. & Sen, S. A survey of attacks and detection mechanisms on intelligent transportation systems: VANETs and IoV. Ad Hoc Networks. 61 pp. 33-50 (2017)

[67] Wang, J., Jiang, C., Han, Z., Ren, Y., Maunder, R. & Hanzo, L. Taking drones to the next level: Cooperative distributed unmanned-aerial-vehicular networks for small and mini drones. Ieee VehIcular Technology Magazine. 12, 73-82 (2017)

[68] Rohi, G., Ofualagba, G. & Others Autonomous monitoring, analysis, and countering of air pollution using environmental drones. Heliyon. 6, e03252

[69] Liu, C. & Wu, J. Efficient geometric routing in three-dimensional ad hoc networks. IEEE INFOCOM 2009. pp. 2751-2755 (2009)

[70] Lu, X., Mao, F., Pan, Z., Gong, W., Zhu, Y. & Yang, J. Enhancement of atmospheric stability by anomalous elevated aerosols during winter in China. Journal Of Geophysical Research: Atmospheres. 125, e2019JD031734 (2020)

[71] Witte, B., Singler, R. & Bailey, S. Development of an unmanned aerial vehicle for the measurement of turbulence in the atmospheric boundary layer. Atmosphere. 8, 195 (2017)

[72] Kral, S., Reuder, J., Vihma, T., Suomi, I., O'Connor, E., Kouznetsov, R., Wrenger, B., Rautenberg, A., Urbancic, G., Jonassen, M. & Others Innovative strategies for observations in the arctic atmospheric boundary layer (ISOBAR)—the Hailuoto 2017 campaign. Atmosphere. 9, 268 (2018)

[73] Kim, M. & Kwon, B. Estimation of sensible heat flux and atmospheric boundary layer height using an unmanned aerial vehicle. Atmosphere. 10, 363 (2019)

[74] Lampert, A., Altst¨adter, B., B¨arfuss, K., Bretschneider, L., Sandgaard, J., Michaelis, J., Lobitz, L., Asmussen, M., Damm, E., K¨athner, R. & Others Unmanned aerial systems for investigating the polar atmospheric boundary layer—Technical challenges and examples of applications. Atmosphere. 11, 416 (2020)

[75] Guimar˜aes, P., Ye, J., Batista, C., Barbosa, R., Ribeiro, I., Medeiros, A., Zhao, T., Hwang, W., Hung, H., Souza, R. & Others Vertical Profiles of Atmospheric Species Concentrations and Nighttime Boundary Layer Structure in the Dry Season over an Urban Environment in Central Amazon Collected by an Unmanned Aerial Vehicle. Atmosphere. 11, 1371 (2020)

[76] Novotn, J., Bystˇrick, R. & Dejmal, K. Meteorological application of UAV as a new way of the vertical profile of lower atmosphere measurement. Challenges To National Defence In Contemporary Geopolitical Situation. (2018)

[77] Ke, R., Li, Z., Kim, S., Ash, J., Cui, Z. & Wang, Y. Real-time bidirectional traffic flow parameter estimation from aerial videos. IEEE Transactions On Intelligent Transportation Systems. 18, 890-901 (2016)

[78] Alaoui-Sosse, S., Durand, P., Medina, P., Pastor, P., Lothon, M. & Cernov, I. OVLI-TA: An unmanned aerial system for measuring profiles and turbulence in the atmospheric boundary layer. Sensors. 19, 581 (2019)

[79] Chang, C., Monstein, C., Refregier, A., Amara, A., Glauser, A. & Casura, S. Beam calibration of radio telescopes with drones. Publications Of The Astronomical Society Of The Pacific. 127, 1131 (2015)

[80] Babaan, J., Ballori, J., Tamondong, A., Ramos, R. & Ostrea, P. Estimation of pm2. 5 vertical distribution using customized UAV and mobile sensors in Brgy. up campus Diliman Quezon city. International Archives Of The Photogrammetry, Remote Sensing And Spatial Information Sciences. 42 (2018)

[81] Demule, H. & Theissen, K. Using UAV multicopters as an extension of ILS ground measurements: This innovative idea has already become reality in Switzerland. Proceedings Of The 2018 International Flight Inspection Symposium, Monterey, CA, USA. pp. 16-20 (2018)

[82] MORAND´ E, J., TREZZA, R., ANDERSON, A., THA, K., Paw, Y., CHEN, Y., VIERS, J. & MEDELL´INAZUARA, J. Appendix K. Evapotranspiration Estimation from Unmanned Aerial Vehicles. UC Water Secur. Sustain. Res. Initiat. Interim Report.

[83] Karp, B. & Kung, H. GPSR: Greedy perimeter stateless routing for wireless networks. Proceedings Of The 6th Annual International Conference On Mobile Computing And Networking. pp. 243-254 (2000)

[84] Brewer, M. & Clements, C. Meteorological profiling in the fire environment using UAS. Fire. 3, 36 (2020)

[85] Rutkauskas, M., Asenov, M., Ramamoorthy, S. & Reid, D. Autonomous multi-species environmental gas sensing using drone-based Fourier-transform infrared spectroscopy. Optics Express. 27, 9578-9587 (2019)

[86] Sekula, P., Zimnoch, M., Bartyzel, J., Bokwa, A., Kud, M. & Necki, J. Ultra-Light Airborne Measurement System for Investigation of Urban Boundary Layer Dynamics. Sensors. 21, 2920 (2021)

[87] Prior, E., Brumbelow, J., Miller, G. & Moore, G. Using UAV Technology to Collect Vertical Temperature and Relative Humidity Profiles over a Tropical Montane Rainforest. (2018)

[88] Prior, E., Brumbelo, K. & Miller, G. Measurement of above-canopy meteorological profiles using unmanned aerial systems. Hydrological Processes. 34 (2019)

[89] Lu, S., Wang, D., Wang, Z., Li, B., Peng, Z., Li, X., et al. Investigating the role of meteorological factors in the vertical variation in PM2. 5 by unmanned aerial vehicle measurement. Aerosol And Air Quality Research. 19, 1493-1507 (2019)

[90] Martin, S., Bange, J. & Beyrich, F. Meteorological profiling of the lower troposphere using the research UAV" M 2 AV Carolo". Atmospheric Measurement Techniques. 4, 705-716 (2011)

[91] Singhal, G., Bansod, B. & Mathew, L. Unmanned aerial vehicle classification, applications, and challenges: A review. (Preprints,2018)

[92] Rovira-Sugranes, A., Afghah, F., Chakareski, J. & Razi, A. A Review of AI-enabled Routing Protocols for UAV Networks: Trends, Challenges, and Future Outlook. ArXiv Preprint ArXiv:2104.01283. (2021)

[93] Rautenberg, A., Sch¨on, M., Zum Berge, K., Mauz, M., Manz, P., Platis, A., et al. The multi-purpose airborne sensor carrier MASC-3 for wind and turbulence measurements in the atmospheric boundary layer. Sensors. 19, 2292 (2019)

[94] Yang, J., Khedar, Y., Ben-Larbi, M., Backhaus, J., Lampert, A., Bestmann, U. et al. Concept and Feasibility Evaluation of Distributed Sensor-Based Measurement Systems Using Formation Flying Multicopters. Atmosphere. 12, 874 (2021)

[95] Adkins, K., Wambolt, P., Sescu, A., Swinford, C. & Macchiarella, N. Observational Practices for Urban Microclimates Using Meteorologically Instrumented Unmanned Aircraft Systems. Atmosphere. 11, 1008 (2020)

[96] Cao, R., Li, B., Wang, H., Tao, S., Peng, Z., He, H.et al. Vertical and horizontal profiles of particulate matter and black carbon near elevated highways based on unmanned aerial vehicle monitoring. Sustainability. 12, 1204 (2020)

[97] Barnhart, R., Marshall, D. & Shappee, E. Introduction to unmanned aircraft systems. (Crc Press,2021)

[98] Chen, A., Huang, Y., Han, J. & Kang, S. A review of rotorcraft unmanned aerial vehicle (UAV) developments

and applications in civil engineering. Smart Struct. Syst. 13, 1065-1094 (2014)

[99] Kim, J., Jeong, Y. & Lee, I. Automatic sensor arrangement system for building energy and environmental management. Energy Procedia. 14 pp. 265-270 (2012)

[100] Lambey, V. & Prasad, A. A review on air quality measurement using an unmanned aerial vehicle. Water, Air, and Soil Pollution. 232, 1-32 (2021)

[101] Arafat, M., Habib, M. & Moh, S. Routing protocols for UAV-aided wireless sensor networks. Applied Sciences. 10, 4077 (2020)

[102] Baek, J., Han, S. & Han, Y. Energy-efficient UAV routing for wireless sensor networks. IEEE Transactions On Vehicular Technology. 69, 1741-1750 (2019)

[103] Huang, H., Luo, P., Li, M., Li, D., Li, X., Shu, W. et al. Performance evaluation of SUVnet with real-time traffic data. IEEE Transactions On Vehicular Technology. 56, 3381-3396 (2007)

[104] Brady, J., Stokes, M., Bonnardel, J. & Bertram, T. Characterization of a quadrotor unmanned aircraft system for aerosol-particle-concentration measurements. Environmental Science Technology. 50, 1376- 1383 (2016)

[105] Malaver, A., Motta, N., Corke, P. & Gonzalez, F. Development and integration of a solar-powered unmanned aerial vehicle and a wireless sensor network to monitor greenhouse gases. Sensors. 15, 4072- 4096 (2015)

[106] Harrison, W., Lary, D., Nathan, B. & Moore, A. Using remote control aerial vehicles to study the variability of airborne particulates. Air, Soil and Water Research. 8 pp. ASWR-S30774 (2015)

[107] Xin, K., Zhao, J., Ma, X., Han, L., Liu, Y., Zhang, J. et al. Effect of urban underlying surface on PM2. 5 vertical distribution based on UAV in Xi'an, China. Environmental Monitoring And Assessment. 193, 1-20 (2021)

[108] Tseng, H., Huang, C., Yen, L., Lin, T., Lee, Y. & Chen, Y. A method of measuring sleep quality by using PPG. 2016 IEEE International Conference On Consumer Electronics-Taiwan (ICCE-TW). pp. 1-2 (2016)

[109] Chamoso, P., Gonz´alez-Briones, A., Rivas, A., Bueno De Mata, F. & Corchado, J. The use of drones in Spain: Towards a platform for controlling UAVs in urban environments. Sensors. 18, 1416 (2018)

[110] https://www.adorama.com/alc/different-drone-types-and-their-differences/

[111] https://www.auav.com.au/articles/drone-types/

[112] Cao, H-R.; Yang, Z.; Yue, X.; Liu, Y.-X. An optimization method to improve the performance of unmanned aerial vehicle wireless sensor networks. Int. J. Distrib. Sens. Netw. **2017**

[113] Global UAV Technologies, Ltd. Available online: https://globaluavtech.com/http40

[114] Valavanis, K.P.; Vachtsevanos, G.J. Handbook of Unmanned Aerial Vehicles; Springer: Berlin/Heidelberg, Germany, 2015; Volume 1.

[115] Position-Based Routing in Mobile Ad-Hoc Networks: An Overview 1Simardeep Kaur, 2Anuj K. Gupta, Research gate 2012

[116] Sharma et al (2020) Journal of Network and Computer Application. Research gate

[117] https://kstatelibraries.pressbooks.pub/unmannedaircraftsystems/ `chapter/ chapter-13-data-links-functions-attributes-and-latency

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Not Applicable

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AC, OE, and CO managed the literature searches and wrote the first draft of the manuscript. Authors PA and OS managed the final compilation of the approaches, open issues, and challenges of the manuscript.