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Role of Drone Technology in Alleviating the Pandemic and Disasters

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A B S T R A C T

the global response to the COVID pandemic, triggered by a novel coronavirus, has had far-reaching impacts on both economic and societal norms. Governments and healthcare regulatory bodies worldwide have expressed concerns and implemented stringent preventive measures to curb the spread and severity of the disease. Many experts and scholars are primarily focused on containing the relentless transmission of this unique virus. Key methods include social distancing, border closures, the avoidance of large gatherings, contactless transportation, and quarantine measures. Several countries have also turned to autonomous, digital, wireless, and other innovative technologies to combat this viral respiratory disease. This study explores a range of potential technologies, such as unmanned aerial vehicles (UAVs), artificial intelligence (AI), block chain, deep learning (DL), the Internet of Things (IoT), edge computing, and virtual reality (VR), in an effort to mitigate the risks associated with COVID.

UAVs have emerged as a ground-breaking tool in the battle against this pandemic, thanks to their capacity to transport essential supplies like food and medical resources to specific locations. This research aims to thoroughly examine the various roles UAVs can play within the context of the COVID crisis. UAVs present intriguing possibilities, including the delivery of medical supplies, the distribution of disinfectants, communication broadcasting, surveillance operations, patient screening for infection, and more [162]. This article delves into the deployment of drones in healthcare, discussing the advantages and disadvantages of their widespread adoption. Ultimately, it addresses the challenges, opportunities, and future prospects of integrating drone technology as a valuable asset in the fight against COVID and similar infectious diseases.

Keywords: — Robotic; AI; Drone; Pandemic; Covid

1. Introduction

The current global landscape is marred by the unprecedented spread of COVID, a disease that has had profound and far-reaching effects on human lives, research endeavors, economies, and industries worldwide. Given the severity of its impact and its highly contagious nature, the management of COVID and healthcare have become paramount concerns, even in the presence of innovative treatments, vaccines, and medical facilities [1].

Numerous research initiatives have been undertaken to address this crisis through the utilization of cutting-edge technologies, including the Internet of Medical Things (IoMT), robotics [2], artificial intelligence (AI) [3], and unmanned aerial vehicles (UAVs) [4]. Disruptive wireless, automated, and digital technologies like AI, machine learning (ML), deep learning (DL), and deep neural networks (DNNs) have exhibited remarkable potential in the battle against the coronavirus [5,6]. Automated technologies, such as UAVs and robots capable of carrying substantial payloads, have been instrumental in intelligently managing the virus's spread by minimizing human interactions across various settings. These technologies contribute to medical testing, treatment, vaccine distribution, and precise diagnosis.

Robotic technologies have been effectively deployed to aid medical personnel in symptom detection, assist infected individuals, and mitigate further virus transmission [7]. These promising innovations promote social and physical distancing while containing the virus. Their applicability extends to challenging environments where human involvement is perilous [8], transforming public spaces into potentially hostile environments. Key intersections between COVID management and robotic technologies are based on the following principles [8]:

- Minimizing Human-to-Human Contact: Robots serve to reduce human involvement, ensuring cost-effectiveness, reliability, and efficiency in various tasks, from social services to healthcare and logistics. They are valuable in curbing pandemics by reducing virus transmission, facilitating social distancing, regulating human contact, and operating autonomously.
- Managing, Monitoring, and Controlling Mobility: Quarantine measures, lockdowns, and control over human mobility are essential in preventing the disease's further spread. AI, ML, and robotic technologies play a vital role in monitoring human mobility and preventing gatherings through territorial control at different checkpoints.

Similarly, UAV technology has proven to be an effective tool in mitigating the risk of COVID [9]. Several countries, including China, the USA, Japan, and Australia, have harnessed this technology in the fight against the virus. For instance, China has deployed over 100 UAVs for surveillance in various cities [10], effectively curbing virus transmission and ensuring social distancing. Other nations are also exploring the use of UAVs for surveillance, governance, food and medical supply deliveries, thermal scanning, monitoring, and sanitization. In the United States, UAVs have been employed to deliver COVID medical kits to remote areas [10], while in Australia, UAVs have been instrumental in monitoring individuals with suspected virus symptoms [11]. UAVs equipped with sensors are used to monitor vital signs, such as respiratory rate, heartbeat, body temperature, and other health parameters. Furthermore, the synergy of UAVs with other technologies, such as thermal imaging, AI, ML, DL, and the Internet of Things (IoT), has the potential to yield significant results in the battle against this virus.

1.1. Scope and Contributions

This review article is dedicated to providing valuable insights for individuals interested in harnessing UAV (Unmanned Aerial Vehicle) technology to combat the COVID pandemic. With a focus on this pressing concern, the article offers a concise introduction to UAV technology and its potential in mitigating the risks associated with COVID. Additionally, it offers an extensive review of the cutting-edge applications of UAV technology, ranging from disinfectant spraying, message dissemination via QR codes or loudspeakers, medical supply delivery, surveillance, inspection, screening, and detection. Furthermore, this paper explores practical strategies for effectively combating COVID by integrating promising technologies, such as Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), the Internet of Things (IoT), and edge computing. Thorough assessments are carried out on various feasible solutions, utilizing technologies like robotics, sensors, wearable devices, and virtual reality (VR).

The study concludes by delving into the current challenges, security considerations, untapped potential, and offers recommendations for the future utilization of these technologies in the fight against COVID and similar infectious diseases.

1.2. Organization of the Paper

The structure of this paper is as follows: In Section 2, we delve into the research contributions related to Unmanned Aerial Vehicles (UAVs) in the context of combating COVID. Section 3 furnishes fundamental information about UAVs, while Section 4 explores the various applications of UAVs in addressing the challenges posed by COVID. Turning our attention to the integration of emerging technologies for mitigating the risk of COVID, Section 5 is dedicated to this subject. In Section 6, we provide concise explanations about the prevailing open challenges, security concerns, opportunities, and offer recommendations for the future. Finally, Section 7 offers the conclusion of this paper.

Related Work

The viral illness known as COVID has caused significant respiratory distress in humans. The World Health Organization (WHO) declared it a Public Health Emergency of International Concern (PHEIC) on January 30, 2020, due to its widespread impact on public health. Given its rapid spread across populations, COVID was classified as a global pandemic. The WHO emphasized the importance of early precautions to prevent transmission. Healthcare organizations have focused on extensive testing and effective treatment to combat the pandemic. Lockdowns in infection-prone areas are widely considered an effective strategy to curb the spread.

Implementing these measures while maintaining a functional healthcare system requires a specific societal reshaping framework. Smart technologies have played a pivotal role in healthcare, government, and business during this crisis. Telemedicine, artificial intelligence (AI), robots, and drones have been increasingly utilized to support the healthcare system. Robotics and drones have been employed for monitoring, early infection screening, transporting medical supplies, and disinfection. AI has been instrumental in forecasting infection trends, prescribing medications, and providing quick diagnosis results. Mobile phone networks have been vital in connecting and informing urban populations. Smartphone apps have played a crucial role in awareness, medical assistance, and contact tracing to prevent the virus's spread.

Efforts are focused on implementing protective measures and rapid testing as we strive to return to normalcy. The use of face masks has proven effective in curbing the virus's transmission, leading to advancements in mask manufacturing technology. Collaboration across industries, the application of technology, and effective governance have established a defense against COVID. Understanding how these advancements work together is essential in the fight against the pandemic. Below is a summary of UAV-based systems related to pandemics and disasters in Table 1.

Table 1. UAV-based system for pandemic or disaster analysis.

Reference	Year	System Purpose
[15]	2018	UAV-aided system for medical applications
[16]	2018	UAV system for post-disaster operations
[17]	2019	UAV-based system for healthcare use cases

Reference	Year	System Purpose
[18]	2019	UAV system to deliver medical drugs
[19]	2020	UAV system for medical supply during disaster in Japan
[9]	2021	UAV-based system to combat COVID
[20]	2021	UAV-based system to monitor social distancing
[21]	2021	UAV-based system to supply medical resources during epidemics
[22]	2022	UAV-based smart visual sensing for overcrowding
[23]	2022	UAV-based isolation control proposal for COVID

2. The Crisis due to the COVID Pandemic

The marketing of numerous everyday products has been thrown into disarray, with the closure of stores selling non-essential items in various locations. Major corporations are now being called upon to supply critical items like masks, ventilators, and medical kits to combat the scarcity of healthcare supplies. However, they are grappling with a significant logistical challenge [24]. One of the industries hit hardest by these disruptions is the tourism and travel sector. Both domestic and international travel have come to a standstill, with travelers deferring important global events. Many businesses are shuttering, and some countries are even pausing the production of television shows. International sports events have been postponed on multiple occasions [25]. This situation has led to intense scrutiny of governance frameworks, fueling people's frustration and anger, particularly towards those in positions of authority. Critics argue that substantial funding allocated to the arms industry and research support for armaments could have been better invested in public health, potentially averting a pandemic of this magnitude. This frustration sometimes extends to those responsible for transmitting the disease. Additionally, disaster management authorities have become targets of public anger. People are unwilling to take risks and are focused on avoiding infection. Public gatherings and the use of public transportation have been discouraged. Unfortunately, social media platforms are spreading misinformation, further discouraging individuals. Moreover, social events like weddings, vacations, and leisure activities have been postponed or canceled [26,27]. Transportation and logistics pose significant challenges during this epidemic.

3. Unmanned Aerial Vehicles (UAVs)

Unmanned aerial vehicles (UAVs), commonly known as drones, have garnered significant attention across both civil and military sectors due to their exceptional mobility, stability, cost-effectiveness, and extended operational endurance. This increased interest is primarily attributed to their seamless integration with emerging technologies such as 5G/B5G, artificial intelligence, Internet of Things (IoT), and mobile edge computing. As a result, UAVs are finding an expanding array of applications in fields ranging from logistics, forest monitoring, construction, freight transportation, communication, healthcare, post-disaster operations, search and rescue missions, remote sensing, precision agriculture, power-line inspections, traffic surveillance, to object detection and tracking [28, 29, 30].

In essence, UAVs are autonomous aerial platforms that operate without human pilots onboard. Their control is facilitated through a combination of microprocessors, sensors, and other essential equipment [31]. UAVs rely on communication links to establish connections with satellites or ground control stations (GCSs), which can include smartphones or laptops. For remote operations, a human operator is responsible for guiding the UAV using a remote control. UAVs are particularly advantageous in scenarios where human intervention is either severely restricted or poses significant risks.

With the overwhelming interest in drones [32, 33, 34], a multitude of UAVs with varying sizes and configurations (as illustrated in Figure 1) have been developed to fulfill an array of tasks. These UAVs fall into several categories, including single-rotor, multi-rotor, fixed-wing, and hybrid UAVs, each with its own set of advantages and disadvantages, aiding in the selection of the most suitable model for specific applications, as detailed in Table 2. Additionally, Table 3 provides a summary of the distinguishing characteristics of these UAV categories.

Figure 1. Different types of UAV: (a) rotary wing, (b) fixed wing, (c) fixed-wing hybrid [35].

Table 2. Applications, advantages, and disadvantages of different types of UAVs.

UAV Type	USD Price	Applications	Advantages	Drawbacks
Fixed wing	USD 20,000–150,000	Structural inspection, area survey	Large area coverage, long endurance, high speed	Launching, landing, high price
Rotary wing (helicopter)	USD 20,000–150,000	Supply drops, inspection	Hovering, large payload	High price
Rotary wing (multicopter)	USD 3,000–50,000	Photography, filmography, inspection	Hovering, availability, low price	Short flight time, small payload

Table 3. Characteristics of different UAVs.

Characteristics	Fixed Wing	Rotary Wing	Hybrid
Energy efficiency	High	Low	High
Flight system	Complicated	Simple	Complicated
Landing	Conventional	Vertical	Vertical
Autonomy	No	Yes	Yes
Hovering	No	Yes	Yes
Power supply	Battery, fuel	Battery	Battery, fuel
Endurance	60–3000 m	6–180 m	180–480 m
Payload	1000 kg	50 kg	10 kg
Weight	0.1–400,000 kg	0.01–100 kg	1.5–65 kg

4. Applications of UAVs during COVID

Unmanned Aerial Vehicles (UAVs) have demonstrated significant potential in the context of smart cities across the globe. These smart cities boast advanced healthcare systems that utilize telemetry, implantable medical devices, and medical drones for the rapid delivery of essential first-aid resources. UAVs have notably showcased their effectiveness in addressing the challenges posed by the COVID pandemic in various countries. It is important to emphasize, however, that the primary force at the forefront of the battle against COVID is the national Emergency Medical Services (EMS) institution, working in coordination with various stakeholders, including EMS personnel, nurses, and medical doctors.

Furthermore, multiple policymakers are deliberating on diverse preventative measures to combat COVID. These measures encompass the adoption of surgical masks, the avoidance of face touching, frequent handwashing, the implementation of city lockdowns, steering clear of high-risk areas, refraining from social gatherings, and the enforcement of health codes. Policymakers must carefully weigh the economic implications against public safety when introducing new measures.

Presently, UAVs are being actively deployed for a range of tasks to combat COVID, as illustrated in Figure 2. These tasks include:

- Transporting vaccines and essential medical supplies.
- Disseminating public announcements.
- Conducting crowd surveillance.
- Applying disinfectants through aerial spraying.
- Carrying out mass screenings.
- Monitoring crowded areas from the sky.
- Facilitating the delivery of vaccines and other crucial medical resources.

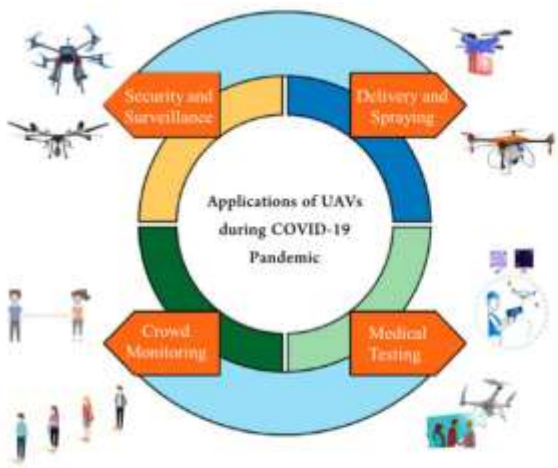

Figure 2. Role of UAVs in COVID pandemic.

4.1. Surveillance and Inspection

Drones serve various purposes, with area monitoring and aerial surveillance being the most prevalent applications. This is true not only in regular operations but also during special efforts to combat COVID. Across the globe, countries have employed these methods extensively. When overseeing a specific region visually, several critical factors come into play, including the area's size, topography, density, built-up areas, key locations within the region, access points, and the duration of the observation. For smaller or open spaces, point monitoring can suffice. However, larger areas necessitate the deployment of a network of multiple drones, while intermittent monitoring calls for a single drone to patrol [4]. Drones can even oversee remote or challenging-to-reach areas where human presence is limited. Nonetheless, concerns about privacy infringement remain a significant hurdle for monitoring individuals using drones. Governments are addressing this issue by issuing guidelines that prioritize public interests.

Since 2019, the enigmatic COVID pandemic has profoundly impacted various healthcare professionals, including doctors, nurses, cleaning staff, and security personnel. Drones have proven invaluable in monitoring high-risk areas without physical presence. They can capture images of potential violators of government-mandated preventive measures, thus offering several advantages. These include safeguarding security personnel from COVID exposure, reducing fuel consumption and resource usage typically associated with physical surveillance, and providing the flexibility of surveillance at any time and place. In the absence of drones, police officers are often hesitant to enter high-risk areas, but this is an essential part of their duty. Recognizing their obligation to protect security personnel from COVID exposure, many governments have granted their monitoring departments access to drones. To integrate multiple Flying Ad Hoc Network (FANET) devices into COVID response teams, government authorities are adjusting their regulations. Security personnel, in addition to monitoring human mobility [36], can offer guidance to the public on practices such as social distancing and minimizing one-on-one interactions. In a specific region, a drone swarm, equipped with cameras and sensors, is used to provide real-time video footage.

Medical personnel operating through Ground Control Stations (GCS) can identify infected individuals using thermal cameras. Cameras can also monitor adherence to social distancing measures, as depicted in Figure 3. Drones collect data through GCS and communicate it to the public via voice announcements or display screens. Table 4 summarizes the use of drone technology in surveillance efforts across different countries.

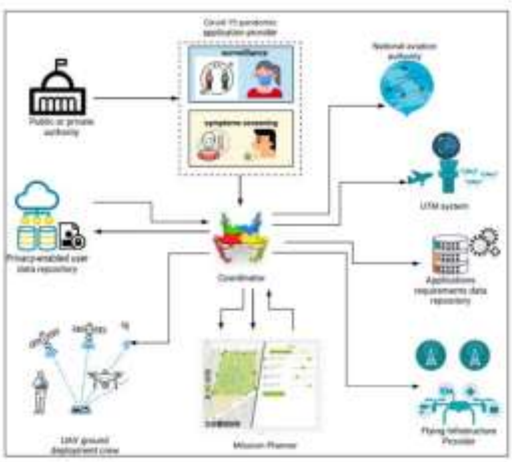

Figure 3. UAV swarm in COVID pandemic [37].

Table 4. Drone technology used for surveillance during the COVID pandemic.

Reference	Country	Operation
[38]	Kazakhstan	To patrol and monitor illegal border activities to stop the spread of COVID
[39]	France	To patrol over a closed beach to monitor public
[40]	Australia	To monitor social distancing at the beach
[41]	India	To ensure lockdown implementation by monitoring public
[42]	Spain	To monitor streets for anyone ignoring COVID lockdown

4.2. Broadcasting Messages Using Loudspeaker on Board

To disseminate information, drones equipped with various tools, such as speakers, flags, QR codes, and more, play a vital role, particularly in times of epidemics. They serve as invaluable assets for authorities, helping bridge communication gaps in areas with disrupted networks. These versatile drones prove highly effective as communication tools during lockdowns. Municipalities can employ sky-speaker-equipped drones to convey essential messages to their residents, including updates on lockdown extensions, permitted businesses, health advisories, social distancing guidelines, and other precautions.

Given that many individuals, especially in rural areas, rely heavily on television for communication, these drones break down barriers between local governments and the general population. Figure 4 illustrates how speaker-equipped drones operate to provide alerts and ensure public safety. These drones have been adopted by several countries, including the US, Spain, Britain, and China, to communicate with those impacted by the COVID pandemic.

However, the use of loudspeakers on drones necessitates careful consideration of factors like speaker efficiency, interference, voice quality, pitch, speech clarity, and the distance between the drone and the individuals or groups being addressed. It's crucial to maintain a minimum safe distance of 5 meters to ensure flight safety when entering public spaces. At longer distances, the information provided can be considered instructive, while at relatively short distances, it serves as a warning, and in close proximity to the open area, it may be perceived as a threat.

Drones that make sudden or dramatic maneuvers in close proximity and communicate at an excessive volume may be intended as warnings but could be misconstrued as menacing. These speaker-equipped drones have multiple applications beyond simple communication, including aiding in critical communications, issuing alerts during hazardous tasks, and supporting rescue missions. They prove to be highly effective in vast, crowded, and challenging environments during disasters such as floods, earthquakes, and fires.

Despite their numerous advantages, these drones also serve a vital role during emergencies and epidemics by allowing authorities to maintain a safe distance from potentially infected individuals, ensuring the continuity of essential services. Table 5 summarizes the use of drone technology for broadcasting messages in various countries to implement COVID precautionary measures.

Table 5. Drone technology used to broadcast messages for COVID.

Reference	**Country**	**Purpose**
[43]	USA	To broadcast a warning to suspected people to follow social distancing rules
[44]	Spain	Police used drones to yell at the public for being outside and ignoring the lockdown
[45]	China	Drone mounted with a speaker to inform the public to wear a mask
[46]	Malaysia	To give announcements and alerts to the public to curb COVID spread
[47]	Hungary	To inform the public to stay at home due to COVID
[48]	USA	Anti-COVID volunteer drone to ensure social distancing of 6 feet
[49]	Rwanda	To broadcast a crucial message about COVID

Figure 4. Broadcasting a message by using a loudspeaker [50].

4.3. Broadcasting Messages by Towing QR Code Flag and Illumination

Numerous instances highlight the utilization of drones to display QR code banners instead of employing loudspeakers for communication facilitation. The option to employ a QR code flag either alongside or in lieu of a traditional loudspeaker exists. QR codes are generally perceived as a "static" mode of communication, whereas loudspeakers are viewed as "dynamic" due to their ability to broadcast real-time messages to a wide audience. In the first scenario, drone operators or mission commanders directly address the target population, swiftly responding with concise messages in a dynamic environment. In contrast, the second scenario involves a more static environment, requiring operators or commanders to convey more elaborate yet standard messages. In the latter case, it is assumed that the target demographic will access the necessary information online through their mobile phones. QR codes prove particularly valuable in various locations such as intersections, shopping mall parking lots, congested roads, and large-scale sporting events where daily changes in border or gate crossing procedures and living situations necessitate quick access to information. On a different note, Chinese authorities have harnessed unmanned aerial vehicles (UAVs) to scan incoming drivers entering Shenzhen city by positioning QR codes overhead. Figure 5 illustrates a motorist registering their entry into Shenzhen by scanning the QR code.

These UAVs are deployed near highway exits and toll booths to encourage approaching vehicles to register, enabling authorities to monitor their movements within the city. However, this application poses challenges related to proximity, potentially causing delays and traffic congestion. It demands precise control and proximity management to prevent physical or economic hazards.

Figure 5. Broadcasting a message through a QR code [51].

In 2020, the Netherlands used 300 drones to create a stunning sky tribute to honor frontline heroes, medical professionals, and patients. Additionally, in Seoul, South Korea, a remarkable display featuring hundreds of drones conveyed messages of solidarity and support in the battle against COVID. The spectacle began with demonstrations of precautionary measures and concluded by expressing gratitude to healthcare workers and the general public for their collective dedication in the fight against the virus, as depicted in Figure 6.

Figure 6. Broadcasting messages through the illumination of drone swarms in South Korea [53].

4.4. Disinfecting Surfaces and Common Areas

As the rapid surge in COVID cases continues, it becomes evident that a significant portion of these cases stems from contact with contaminated surfaces in public areas, including items such as chairs, tables, handrails, doorknobs, elevator buttons, public transportation, and shopping centers. Depending on environmental conditions, the COVID virus can persist on various surfaces for varying durations, ranging from hours to several days. The initial step in curbing secondary transmissions is the thorough sanitization of these surfaces and locations. In the realm of disinfection, two primary approaches have gained popularity: air disinfection and surface disinfection.

When it comes to combatting the COVID pandemic, surface disinfection has proven to be more effective than air decontamination. On the other hand, air disinfection serves a dual purpose: it provides psychological comfort and a sense of assurance that authorities are actively addressing the crisis, while also helping control pest populations. Among the myriad methods for air sanitization, drone-based spraying has shown promise. These drones come in various configurations, with differences in power and tank capacity. Figure 7 illustrates a generalized concept of a UAV (Unmanned Aerial Vehicle) equipped for spraying with a small tank. Unlike sanitation workers who risk exposure to viral diseases while performing their essential duties, these UAVs are straightforward to operate and mobilize, eliminating the risk to operators.

Nevertheless, despite its benefits, air disinfection has not proven to be a reliable means of halting virus transmission. Excessive use of alcohol-based and other chemical sprays on people, vehicles, or the environment is strongly discouraged due to their potential hazards. Drones, however, can be effectively employed for disinfecting public spaces during times when they are unoccupied, such as at the end of the day or during holidays, without posing the same risks associated with chemical sprays meant for agricultural use. Recent studies have explored the use of drones for spraying disinfectants to combat novel coronaviruses. Notably, Kumar et al.'s research [9] focused on interconnected drone-based systems and their potential for disinfectant spraying. Although the study reported a 2 km radius being disinfected within 10 minutes, details about the specific conditions were lacking. Similarly, Alsamhi et al. [55] introduced a framework for employing multiple drones in decentralized ways but did not provide specific operational details. In another study [56], UAVs were used for disinfection tasks in specific areas, with a focus on evaluating static and dynamic behaviors, spray flow impact, mission speed, and flying height. The study recommended a feasible flying height of 3 meters for optimal performance. Table 6 summarizes the utilization of drone technology for disinfectant spraying in various countries in response to COVID.

Table 6. Drone technology used to spray disinfectants for COVID.

Reference	Country	Purpose
[57]	China	To spray disinfectants to stop the spread of COVID
[58]	India	To improve the efficiency and speed of the sterilization operations in public places
[59]	Spain	Spain's military used agriculture drones to spray disinfectants to stop the spread of COVID
[60]	USA	Drone to spray disinfectants in large places
[61]	UAE	Dubai Municipality conducts a massive sterilization drive against COVID through drones

Figure 7. Drone used for spraying disinfectants [62].

4.5. Supporting Medical Services

The utilization of drones has the potential to revolutionize delivery services, making them faster, more sustainable, and cost-effective when compared to traditional methods involving vans and vehicles. This transformation in delivery methods can lead to automated, unmanned, and information-driven distribution, effectively bridging the gap between customer orders and delivery capabilities. Among the key stakeholders facilitating and managing these services, healthcare professionals stand out as champions of technological adoption. A study conducted in Oslo, Norway, revealed their positive disposition towards drone utilization. In an era heavily marked by the urgency of transporting vaccines, especially in the midst of the COVID pandemic, drones emerge as a valuable tool for reaching remote and inaccessible areas with critical healthcare supplies. Numerous research studies have explored the feasibility of using drones for delivering COVID vaccines to such regions, underscoring their potential significance. While a few studies have examined public attitudes towards drones in the context of general goods or food delivery during the pandemic, the specific viewpoint of healthcare professionals regarding the use of drones to deliver medications and vaccines remains a subject of interest. Malaysia, for instance, is actively exploring the use of drones for this purpose. Yet, the adoption of drone technology in healthcare, particularly for reaching rural areas, remains relatively understudied. Recent research efforts have assessed the viability of drone-based medical supply delivery, considering factors like payload capacity, fleet development, and delivery simulations. Optimization of drone delivery trajectories has also been investigated, with algorithms such as K-means clustering and ant colony optimization being evaluated. Notably, the ant colony algorithm has shown promising results. To illustrate the real-world application of drones for healthcare and food supply during the COVID pandemic, Figure 8 provides visual evidence. Additionally, Table 7 summarizes the state of drone technology in delivery services across different countries.

Innovative collaborations, such as that between the Massachusetts Institute of Technology (MIT) and UNICEF have been crucial in exploring the impact of drone delivery for vaccines in remote communities. Such initiatives have identified key parameters for optimizing drone systems, including delivery hubs, payload, and range. Their analysis has revealed potential cost savings compared to traditional methods, provided that capital costs are subsidized.

However, several challenges must be addressed to ensure seamless drone delivery of healthcare supplies. Regulatory clarity is a primary concern, as is the potential social impact on labor markets due to automation. Technical considerations, including payload capacity, vendor availability, and weather conditions, also influence the drone delivery industry.

Figure 8. Drones used to deliver (a) medical supplies [63] and (b) food supplies [74].

Table 7. Drone technology used for delivery services during the COVID pandemic.

Reference	Country	Purpose
[75]	UK	To deliver COVID tests, medicines, and personal protective equipment (PPE) to remote communities in the UK
[76]	Ghana	Zipline and UPS are working together to deliver COVID vaccines to health centers in remote areas
[77]	USA	A North Carolina health system used UPS Flight Forward drones to deliver COVID vaccines
[78]	UK	An NHS drone-based delivery service is used to carry personal protective equipment, blood tests, and COVID samples
[79]	Indonesia	A group of drones has been used for contactless delivery of food and medicine
[80]	Scotland	UK-based drone specialist Skyports is providing drone service to deliver medical supplies and COVID samples
[81]	China	Shanghai firefighters have been using drones to deliver medicines during lockdown
[82]	USA	Walmart has started a drone delivery service to collect kits in North Las Vegas and New York

4.6. COVID Screening and Detection

Person-to-person encounters represent one of the most common ways for coronavirus transmission. Therefore, it's imperative to swiftly identify both those who are infected and individuals who may have been exposed during such interactions. The overarching strategy is to conduct extensive and rapid screening in the vicinity while minimizing direct human contact. In this context, the introduction of drone technology has revolutionized the approach and greatly facilitated the mass screening of individuals based on their symptoms [83]. These drones are equipped with a temperature sensor to monitor individuals while keeping a safe distance from their residences. Furthermore, they feature a camera for capturing images of the subject and a GPS system [84] for precise location tracking.

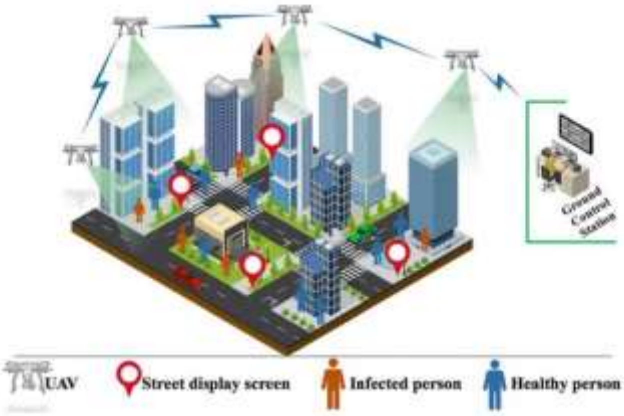

Figure 9. Drone technology used for the detection of infected people [37].

In their study [1], the authors introduced the concept of "Covidrone," a groundbreaking technology employing biomedical sensors to gather vital medical data from individuals connected to COVID. The payload of Covidrone encompasses a sensor module, a disinfection component, testing kits, wireless communication infrastructure, and a Deep Neural Network (DNN) model, as depicted in Figure 10. These drones can be strategically stationed, ready to serve individuals in need. Upon arrival, smart medical sensors on the drone authenticate the user and sanitize the sensing equipment before collecting essential medical information. Subsequently, a DNN-based model processes this medical data for the identification and analysis of COVID. Based on the test results, users receive recommendations for medical treatment or preventative measures. These test results are made available to remote healthcare professionals through cloud services for further analysis. The automation of this process minimizes human interaction, contributing to the battle against COVID.

This innovative approach expands access to critical medical care and testing services, particularly benefiting older and physically challenged individuals. Covidrone is anticipated to play a significant role in flattening the COVID curve, especially in remote areas lacking accessible medical facilities. Table 8 offers a summary of drone technologies used for COVID detection across various countries.

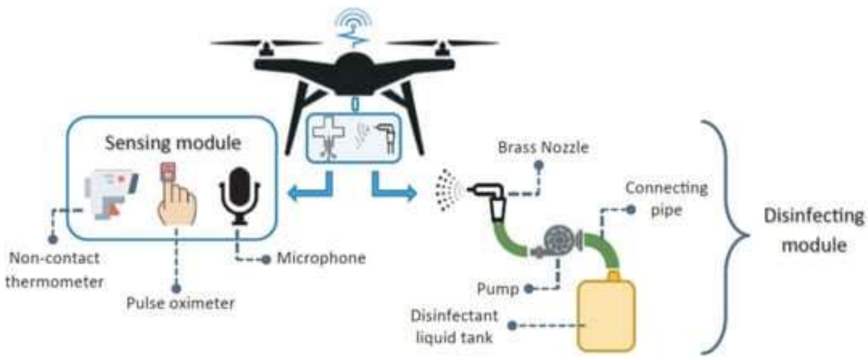

Figure 10. Covidrone schematic for sensing and disinfection [1].

In response to the COVID pandemic, innovative healthcare solutions are being developed, incorporating advanced detection technologies. These technologies include drones, the Internet of Things (IoT), fifth-generation cellular networks (5G), and deep neural network (DNN) models. While drones have traditionally been associated with military applications, such as remote missile deployment, their utility has expanded in recent years to address a wide range of tasks, including climate monitoring, photography, video capture, and even medical supply delivery.

Researchers, as described in reference [85], propose leveraging fleets of unmanned aerial vehicles (UAVs) to tackle various challenges posed by COVID. These challenges encompass issues like social isolation, symptom monitoring, and sanitation. To ensure optimal performance and security, they recommend the incorporation of emerging technologies like 6G, block chain, and software-defined networking (SDN). In another study [9], the authors employed both robots and drones to monitor COVID hotspots and provide medical support as needed. Their platform offers support for various pandemic-related activities, including sanitation, thermal imaging, crowd monitoring, and control. Nevertheless, the feasibility of deploying such systems on a larger scale, such as in rural areas, remains a subject of concern due to the potential demands on network resources and coordination. A recent investigation, detailed in reference [86], explored the use of drone swarms to curtail the spread of COVID. They put forward a system architecture designed to identify infected cases by assessing their biomedical indicators. This approach incorporates various techniques like remote photo plethysmography, thermal measurements, and stereoscopic vision for risk assessment. The system is capable of measuring crucial parameters, including image photo plethysmography signals, skin temperature, and social distancing adherence, all of which are vital for tracking and identifying infected individuals.

Table 8. Drone technology used for detection during the COVID pandemic.

Reference	Country	Purpose
[87]	Australia	The Australian Department of Defense and the University of South Australia are working on drone technology to detect breathing, heartbeat, temperature, and infectious respiratory conditions through sensors and integrated cameras
[88]	India	Researchers from the Indian Institute of Technology (IIT) designed an IR-based drone for thermal screening and identifying COVID suspected cases
[89]	China	Jiangxi province, China, used drones to check the temperature of people standing on balconies during lockdown
[90]	USA	In New York, Dragonfly's pandemic drone is used to detect COVID infectious conditions including coughing, sneezing, and temperature through integrated sensor and computer vision technologies

5. Emerging Technologies to Fight against COVID

This section explores a range of emerging technologies that play a pivotal role in the battle against COVID. Currently, a diverse array of technologies is actively employed in the fight against the pandemic. These encompass block chain [55,91], smartphone applications [92,93,94,95,96,97,98,99,100], wearable sensors [101,102,103,104,105,106,107,108], artificial intelligence (AI) [109], robotic systems [110], deep learning (DL) [111,112,113,114], virtual reality (VR) [115,116], and edge computing [117,118]. Figure 11 offers a comprehensive overview of these technological innovations.

Figure 11. Some ingenious technologies to fight against COVID.

5.1. Blockchain

Blockchain technology has gained significant momentum thanks to its successful proof of concept and its diverse applications across various industries. This technology is characterized by its fundamental attributes of trust and resilience, offering decentralized data storage. In the healthcare sector, it empowers both patients and medical service providers by facilitating secure data transactions, effectively reducing the physical workload for medical staff and minimizing infection risks. The integration of blockchain technology holds the promise of substantially enhancing epidemic prevention and control, ensuring the reliability of collected data [91]. This is particularly crucial because most COVID data originates from sources like the media, the general public, and hospitals, which often lack robust privacy measures. With blockchain, the integrity and security of COVID data are significantly improved, as it becomes nearly impossible to tamper with transaction data once it's stored in the blockchain. Blockchain technology also provides a robust defense against cheating and hacking, ensuring authentication and accountability to maintain data availability, integrity, and confidentiality.

Even in the event of partial system failures, blockchain remains operational, offering advantages such as transparency, immutability, and security that set it apart from other existing technologies. These decentralized and traceable features of blockchain technology are invaluable for improving the collection and analysis of COVID data.

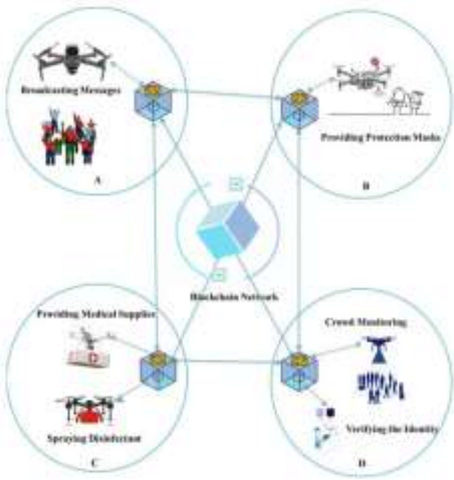

Figure 12 illustrates how blockchain technology is employed to address pandemic challenges through collaborative efforts of multiple drones [55].

The proposed architecture is built on four core components. Various drones are strategically positioned to carry out diverse tasks, and blockchain technology plays a crucial role in ensuring the security and coordination of each drone's operations. This includes granting each drone access to the locations of other drones, thus preventing potential collisions. While the utilization of blockchain technology for multi-drone collaboration offers numerous benefits in addressing COVID pandemic concerns, it also comes with certain limitations.

The first challenge pertains to legal matters, which necessitate resolution by various stakeholders, including international health organizations, government leaders, and policymakers. Addressing issues related to health policy, data sharing, digital health service regulations, and disparities in digital connectivity and access, especially in developing nations, is crucial. The second and most significant concern is scalability. Drones typically have limited computational and memory capabilities [119]. As the volume of transactions on the blockchain grows, network traffic becomes increasingly burdensome. Each node in the blockchain network is required to retain all validated transactions, posing a challenge due to block size constraints and the time required to generate new blocks [120].

Figure 12. Utilizing Blockchain for Multi-Drone Collaboration:

(A) Broadcasting Information,

(B) Distributing Protective Masks,

(C) Supplying Medical Resources and Conducting Disinfection Operations,

(D) Overseeing Crowd Surveillance and Identity Verification (Adapted from Reference [55]).

5.2. Wearable Sensing

Wearable technologies are the result of seamlessly integrating sensors into the human body. These devices take various forms, including glasses, helmets, wristbands, and watches. Their versatility allows them to tackle a wide range of tasks related to lifestyle, fitness, and healthcare [101]. Within the healthcare realm, they serve the purpose of monitoring patients' medical records.

Incorporating the Internet of Things (IoT), wearable devices encompass products like the IoT-Q-Band [102], smart glasses [103], and smart helmets [104]. Figure 13 illustrates an array of wearable devices employed in the context of COVID. More recently, research has explored innovative interfaces that enable the integration of humans with drones to execute tasks like search and rescue missions [121], personal identification efforts [122], and combating pandemics [9].

The work detailed in reference [122] lays the foundation for tracking individuals, which has applications in monitoring, surveillance, and security, through the use of drone technology. For instance, individuals, patients, or individuals under suspicion can be equipped with wearable sensors like smart bracelets, which are connected to the internet. The IoT data collected from these wearables can then be accessed via a drone for the purpose of personal identification.

Figure 13. Various wearable sensing devices for COVID.

In their ninth reference, the authors introduced a UAV-enabled intelligent healthcare framework designed to address various aspects of the COVID pandemic, including social distancing, sanitization, monitoring, and data analysis. This innovative system employs multiple data collection methods, including thermal image processing, mobility sensors, and wearable sensors. The collected data undergo a comprehensive, multi-layered analysis framework to inform decision-making. The authors substantiated their approach through simulation and practical implementation, highlighting the impressive coverage capabilities of this drone-assisted smart healthcare architecture for combating COVID. Figure 14 provides an overview of the proposed drone-assisted person monitoring system utilizing wearable sensor technology. Wearable sensors are employed for continuous patient monitoring, with drones acting as data collectors from these wearables, storing the information in their memory. To handle the vast amount of data generated, multiple servers are utilized to relay the data to a big data infrastructure. These servers leverage cloud, fog, and edge computing for data processing, modeling, profiling, and analysis. Refined data results from this analysis are securely shared with hospitals in accordance with governmental and medical board policies and regulations. Medical staff can access the data whenever necessary, thus making this framework a valuable resource for addressing the challenges posed by the COVID pandemic.

Our discussion underscores the potential of wearable devices in the context of the COVID pandemic. However, it is important to recognize and address several existing limitations. The majority of wearable devices remain in the prototype development stage, making their integration into drone-based COVID response systems a complex challenge.

Factors such as consumer acceptability, security, ethical considerations, and the handling of big data associated with wearable technology must be carefully addressed to enhance the practical utility and effectiveness of these devices.

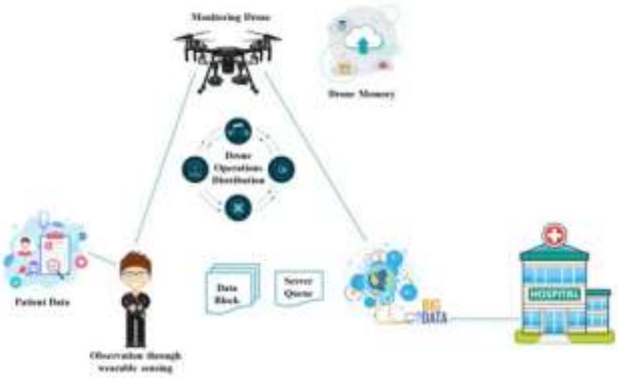

Figure 14. Drone-assisted person monitoring system using wearable-sensor data (modified from [9]).

5.3. Artificial Intelligence

Artificial Intelligence (AI) stands as a potent technology, enabling computers to think, learn, and predict patterns. Its influence has grown considerably, with the research community increasingly integrating AI algorithms into the realms of drones, robotics, medical imaging, and various healthcare applications. AI plays a pivotal role in predicting the outbreak and spread of diseases like COVID, alleviating the healthcare workforce's burden by providing statistical data verification, thus sparing them from certain tasks like patient examinations. Moreover, AI empowers drones to elevate their performance and productivity in the battle against COVID in various scenarios. The pandemic has significantly accelerated the adoption of AI across multiple domains. The promise of this technology is substantiated by the extensive body of research, as evident in the Scopus database, where more than 1000 articles, published as of March 1, 2021, encompass the keywords "Artificial Intelligence and COVID." Much like edge computing, AI excels at handling vast datasets, utilizing big data analytics for efficient data management. When integrated with Unmanned Aerial Vehicles (UAVs), AI proves invaluable for data collection, particularly in tracing hotspot locations. These AI-empowered drones and their integrated sensors eliminate the need for human intervention in gathering crucial data and executing necessary actions. AI-driven technology has displayed remarkable efficacy in diagnosing and treating infected patients, offering substantial support to medical staff by performing multiple tasks. AI-enhanced drones serve diverse functions, including transportation, physical inspections, and surveillance. For instance, a proposed IoT/AI-based framework in [128] incorporates thermal cameras integrated into helmets and an AI algorithm for processing thermal or detected images. These drones swiftly respond when an infected case is detected. In a recent study outlined in [129], a conceptual model, comprising a drone, an AI framework, RF links, and a GCU, addresses a multitude of tasks such as face mask detection, monitoring social distancing compliance, and supervising home quarantine protocols. Additionally, it tracks the activities of infected individuals and conducts thermal imaging to monitor body temperatures, all in a concerted effort to curb the virus's spread. The potential of AI as an effective tool against future diseases and pandemics hinges greatly on the availability of data. However, concerns regarding data privacy erosion loom large. There's a genuine worry that public health imperatives could lead to excessive surveillance by governments, even after the pandemic has subsided. Hence, apprehensions regarding data privacy are indeed well-founded.

Figure 15. Conceptual architecture of the proposed model AI framework [129].

5.4. Deep Learning Algorithm for UAVs

In reference [111], a team of researchers introduced a cutting-edge drone technology driven by deep learning (DL) algorithms. This innovative system is designed to oversee public spaces, detecting instances where individuals may not be wearing masks or adhering to social distancing guidelines. Whenever a breach of these preventative measures is identified, the system promptly sends alerts to the nearest police station. The solution hinges on a combination of a drone, integrated cameras, sensors, and the Yolov3 algorithm for comprehensive public monitoring. Additionally, the proposed system offers guidance on mask usage, ultimately serving as a potential lifesaving tool in the fight against the COVID pandemic. Nonetheless, it's important to acknowledge that deploying such a system in crowded areas raises concerns regarding individual privacy as it captures images of everyone. Figure 16 provides a visual representation of this DL-powered Unmanned Aerial Vehicle (UAV) technology in action. In a recent study mentioned in [112], authors provided a concise overview of DL methodologies employed in processing medical images related to COVID. They also discussed the utilization of DL techniques to manage and mitigate disease outbreaks and crises, with a focus on fostering intelligent and health-conscious urban environments.

Moreover, reference [113] presents another noteworthy contribution by authors who proposed a cost-effective security mechanism for using UAVs to detect mask compliance through DL and the Internet of Things (IoT). This solution aims to reduce the spread of COVID by encouraging mask usage.

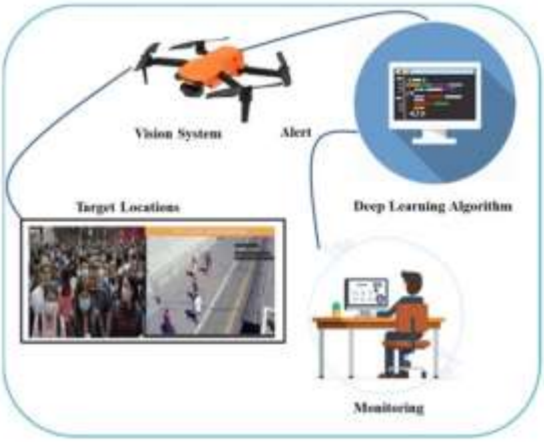

Figure 16. DL-based UAVs to monitor public places (modified from [114]).

In a recent investigation (Reference 22), researchers introduced an innovative real-time framework based on deep transfer learning (DTL) to pinpoint instances of overcrowding resulting from activities such as abnormal behavior and congestion.

This groundbreaking study marked the inception of a novel monitoring approach designed for the recognition of overcrowding using a Social Monitoring System (SMS) and an Unmanned Aerial Vehicle (UAV). The authors harnessed DTL for decision-making and leveraged the Water Cycle Algorithm (WCA) to substantially enhance the identification process by selecting optimal features. This newly proposed framework is adept at functioning in demanding environments, proficiently detecting overcrowding through SMS communication and analyzing video frames from UAVs. For a comprehensive understanding of this system's operation, refer to Figure 17, which illustrates how UAVs and computing components play a pivotal role in effectively managing and mitigating overcrowding.

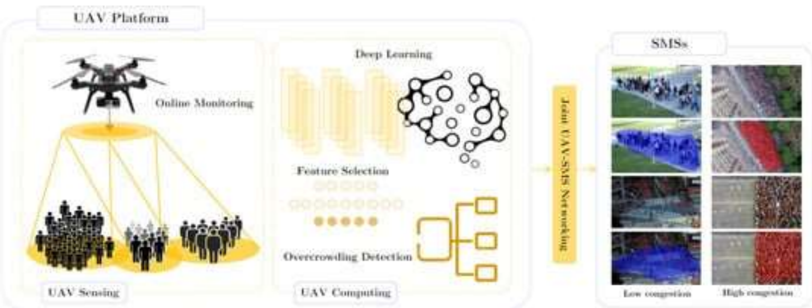

Figure 17. UAV and SMS to control COVID spread [22].

5.5. VR Technology

Virtual reality (VR), as denoted by reference [130], encompasses a wide array of technological interventions, ranging from expansive simulators to flat-screen projectors and head-mounted displays (HMDs) mentioned in reference [115]. These technologies immerse users in computer-generated graphics to create a multisensory, immersive experience. Current VR headsets provide an affordable and secure means of rehabilitation in the comfort of one's home. VR is harnessed within computer-based programs to craft highly realistic simulated environments, enabling individuals to engage in real-time activities via a shared virtual whiteboard. This technology has assumed a pivotal role in the realm of telemedicine [131], profoundly enriching medical knowledge, diagnostic proficiency, and surgical expertise. Moreover, VR's potential extends to addressing challenges posed by COVID by facilitating image acquisition for public awareness and impact mitigation.VR furnishes an ideal platform for facilitating video consultations between healthcare professionals and patients in quarantine or medical facilities. It serves to bolster the psychological well-being of patients, particularly those in isolation, instilling confidence that medical personnel are diligently monitoring vital signs and potential COVID complications [132]. Virtual visits reduce the need for physical assistance or family visits to hospitals, thereby cutting travel costs.

The manifold advantages of leveraging this technology in the context of COVID are expounded in Figure 18. This transformative tool can be seamlessly integrated with Unmanned Aerial Vehicles (UAVs) to afford a comprehensive, real-time view of various activities. Illustrated in Figure 19, the VR headset, equipped with integrated sensors, allows an operator to control the UAV's camera simply by moving their head. The camera can scan individuals, with the video feed transmitted directly to the VR headset. Notably, a Canadian firm named Dragonfly is pioneering drone technology for temperature and infectious respiratory condition detection [133,134]. Healthcare professionals can deploy this technology to remotely connect with, communicate, and treat patients, thus revolutionizing healthcare delivery.

Figure 18. Key benefits of using VR technology for COVID (modified from [135]).

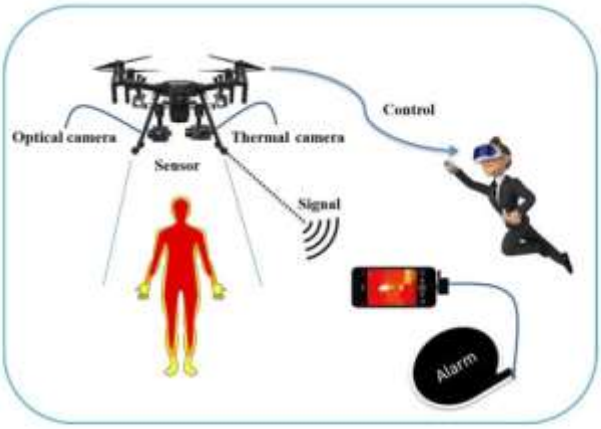

Figure 19. VR-based monitoring through UAV (modified from [116]).

5.6. Edge-Computing-Based Drone Technology

Internet of Things (IoT) devices provide a range of services, including autonomous driving, traffic management, location tracking, and augmented reality, all of which typically demand significant data processing, leading to substantial computational resource requirements. To effectively address this challenge, mobile edge computing (MEC) has been introduced. MEC servers are designed to alleviate the computational burden on IoT devices by integrating edge devices equipped with sensors, microcontrollers, or microprocessors for real-time data processing. Nevertheless, issues such as delays and communication overhead persist as critical concerns.

In addressing these challenges, Unmanned Aerial Vehicles (UAVs) offer a promising solution due to their potential for cost-effectiveness and high mobility when operating as MEC servers. These UAV-based MEC systems must make critical decisions related to execution delays, power consumption, and service latency. Recent research has focused on incorporating UAVs and edge computing to mitigate challenges related to on-site computation, data processing, connectivity, and latency. This innovative approach finds applications in various scenarios, such as containment zone detection and thermal sensing. It opens up the possibility of employing drones for addressing the complexities of the COVID pandemic in various social roles. In this system, edge computing plays a pivotal role in enhancing data processing capabilities without straining internet bandwidth. It also accommodates the flexible deployment of edge nodes and multiple drones, utilizing the capabilities of 5G spectra. The proposed system architecture, illustrated in Figure 20, allows multiple drones to be connected for data storage and communication with a central cloud server. This server is linked with users in the specific area where detection is conducted, such as deploying numerous drones on streets for COVID victim detection.

Table 9 provides a summary of the diverse applications of drones in pandemic response, showcasing their integration with various emerging technologies.

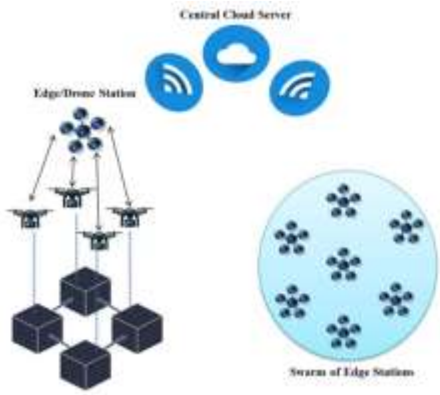

Figure 20. Edge–drone application scenario (modified from [118]).

Table 9. Use of drones with different integrated technologies.

Reference	Integrated Technology	Use Case
[1]	Internet of Mobile Things, Deep Neural Network	Rapid testing, quick delivery of medical kits
[9]	Wireless Sensor Networks	Sanitization, thermal image collection
[20]	YOLO-v3	Social distancing
[21]	Machine Learning	Medical source distribution
[22]	Visual Sensing, DTL	To monitor overcrowding in order to control COVID spreads
[118]	Edge Computing	Containment zone detection with offline data processing and computation
[131]	Could Virtual Reality	Role in the rehabilitation after COVID infection
[136]	IoT	Spread reduction
[137]	Blockchain, 5G networks	Vaccine distribution
[138]	Blockchain, 6G networks	Mass surveillance
[139]	Internet of Things	Sanitization
[140]	Blockchain, AI	Pandemic supervision
[141]	Convolution Neural Network (CNN)	Crowd density
[142]	Deep Learning	Fast detection of medical face masks
[143]	YOLO-v3	Localization, navigation, people detection, crowd identification, and social distancing warning

Reference	Integrated Technology	Use Case
[144]	Hybrid Reinforcement Learning	Optimized path planning for UAV COVID test kit delivery system
[145]	IoT	Identifying COVID patients for providing medical services using drones
[146]	6G and Blockchain	Proposes a generic scheme to integrate UAV, 6G, and BC for secured vaccine distribution
[147]	Machine Learning	Crowd surveillance
[148]	AI, IoMT	For monitoring and supplying COVID patients
[149]	Radar Sensing	Detection of respiratory disorders in COVID patients
[150]	Blockchain	Secure and QoS-aware drone delivery framework
[151]	Reinforcement Learning, Wireless Network	COVID tracing

6. Open Challenges, Opportunities, and Future Work

In the realm of UAV-based COVID applications, various challenges and security concerns necessitate attention in future endeavors:

1. Patient Health History: Presently, UAVs are predominantly used for authentication tasks, relying on camera-based scanning. In the future, researchers can harness advanced processing tools and cameras to maintain a patient's medical history and reports. This invaluable data can greatly aid medical staff in understanding a patient's past conditions and offering tailored medical advice.

2. Reconfigurable Platforms: The integration of reconfigurable platforms like FPGAs is essential. These platforms allow for virtual addition, modification, or removal of functions, ensuring flexibility, enhanced performance, optimal resource allocation, and reduced hardware payload.

3. Integration with Healthcare Databases: Upcoming studies should focus on integrating UAV-assisted COVID screening and detection systems with national or international health monitoring databases. This integration can provide real-time and precise updates on cases, high-risk areas, and assist regulatory bodies in implementing timely interventions.

4. Drone Navigation in Challenging Environments: UAVs may need to operate in densely populated or forest-covered areas, facing adverse atmospheric conditions like haze, fog, and rain. To address these issues, future work should incorporate computer-vision-based strategies to ensure safe UAV operations and establish proper insurance liability to cover damages and accidents.

5. Health and Safety Risks: UAVs in medical facilities operating near patients raise safety and health concerns. Proper safety measures should be established, such as safe and sealed drone batteries and guarded rotors, to prevent accidents and injuries.

6. Security, Privacy, and Safety Concerns Associated with Drone Use: UAV deployment in densely populated areas, particularly during pandemics, can give rise to security, privacy, and safety worries. Measures to counteract these issues include securing communication and navigation systems, protecting against cyberattacks, and ensuring data privacy.

7. Standardization: The absence of standardized regulations for UAV operations across different countries hampers widespread UAV adoption. Coordinated efforts between nations and regulatory bodies are crucial to establish consistent rules for UAV operations and safety.

8. Resource Allocation: Optimizing resource allocation is critical, especially considering UAV path constraints and limited battery life. Intelligent deployment and efficient resource allocation can enhance cost-effectiveness, coverage, task completion time, and overall computational efficiency.

9. Limited Energy: UAVs face energy constraints due to their battery-powered nature. Swarming drones, energy-efficient algorithms, and innovative recharging stations can help mitigate energy limitations and extend operational capabilities.

10. Connectivity: Ensuring continuous network connectivity for UAVs is essential, and addressing low battery issues is crucial to prevent interruptions in missions.

11. Atmospheric Conditions: Developing UAV capabilities to operate efficiently in adverse weather conditions is vital, particularly during natural disasters. Wind speed should be factored into mission planning to ensure safe UAV operations.

12. Privacy: UAVs equipped with cameras and tracking tools raise privacy concerns. Regulations, guidelines, and privacy-by-design principles must be implemented to safeguard individuals' privacy.

13. Cyber Security: With the increasing reliance on remote work and online interactions during pandemics, cybersecurity threats become more prominent. Developing innovative cybersecurity tools is essential to ensure secure operations.

14. Telehealth: The COVID pandemic has accelerated the adoption of telehealth technologies. Ensuring reliable and efficient wireless connectivity is critical to support remote healthcare services.

15. A More Connected World: The pandemic has reshaped the landscape of interconnected technologies. Technologies like 5G/6G, IoT, and AI are set to transform virtual conferencing, e-learning, and various industries.

16. The IoT Revolution: The growth of IoT networks, coupled with 5G and 6G technologies, is expected to drive automation in various sectors. Research activities in this domain will aid in handling future pandemics or disasters.

17. User Perspective and Emotional Impact : When developing counter-drone technologies, it's vital to consider not only cost and efficiency but also the societal and emotional impacts. This includes understanding public perceptions and addressing concerns through sentiment analysis and opinion mining.

18. Reliability: Maintaining reliability in UAV networks, despite mobility and short battery life, requires innovative solutions, possibly involving alternative channels or UAV relays.

19. Artificial Intelligence and Human-Machine Interaction: Artificial intelligence encounters a significant challenge when it comes to human-machine interaction, as it stands at the intersection of various AI disciplines. To address this challenge comprehensively, it must encompass several key aspects: understanding human behavior and cognition, acquiring, representing, and utilizing abstract personal knowledge in a user-friendly manner, explaining the information necessary for decision-making, and translating these decisions into physical actions that can be easily understood and coordinated with humans. Experts in human-computer interaction (HCI) are working diligently to make cutting-edge technologies like quantum computing and AI more accessible through interfaces that are relevant to our daily lives [161].

Natural language processing (NLP) plays a pivotal role in enhancing our understanding of human-machine interactions. Ensuring the credibility and acceptance of designed AI systems by human users is a primary concern for AI professionals. These professionals also observe certain patterns that illustrate how this structure supports the management and execution of associated learning pathways and model training while adhering to established AI principles. Trust-based strategies encompass five fundamental components: the surveillance and information gathering unit, the trust computation and evaluation unit, the trust recommendation unit, the decision-making unit, and the dissemination of the detection unit. Presently, trust-based approaches create a reputation system comprised of multiple elements to safeguard against potential attacks on networks or routes. Throughout the trust monitoring and development process, it becomes possible to detect anomalies and misbehavior within the system, particularly in the context of drone operations. When tasks are assigned to a drone swarm, offline and online collision assessment and stochastic models for collision evaluation can be employed. However, the analytical capabilities at the network's edge are limited by stringent end-to-end latency requirements and the inherent constraints of swarm drone systems. To address these challenges, a verified, scalable, and holistic approach can help reduce latency bottlenecks by automating the life cycle of AI interactions.

7. Conclusions

Amidst the crisis brought about by the COVID pandemic, healthcare professionals and researchers have been diligently exploring technological solutions to combat the spread of the virus. A diverse array of experts from various fields has introduced an assortment of strategies and possibilities in the ongoing battle against this epidemic. Notably, drones have emerged as valuable assets in the fight against COVID, exhibiting significant potential through their swift and efficient service delivery. Drone technology is poised to play a pivotal role in future endeavors aimed at countering diseases akin to COVID in a world characterized by enforced social isolation. This research delves into the practical applications of drone technology, drawing upon real-world examples to demonstrate its utility. Drones can be seamlessly integrated with various contemporary technologies, enabling distributed processing capabilities.

Furthermore, this paper provides a concise overview of the challenges and opportunities that arise in this context. The study explores a range of use cases for drones to mitigate the risks associated with COVID, encompassing surveillance, inspections, dissemination of information through QR codes and loudspeakers, transportation of medical supplies, disinfectant spraying, patient screening, and identification.

Additionally, the authors discuss the potential of emerging technologies such as artificial intelligence, machine learning, deep learning, blockchain, the Internet of Things, edge computing, and virtual reality, all of which offer innovative solutions to manage diseases with minimal human intervention. Concluding this research, the authors express their optimism that the insights provided will assist scholars and professionals in surmounting the numerous challenges hindering the utilization of unmanned aerial vehicles in situations of this nature.

Abbreviation

Label	Explanation
5G	Fifth Generation
B5G	Beyond Fifth Generation
6G	Sixth Generation
AI	Artificial Intelligence
ANN	Artificial Neural Network
AP	Access Point
AI	Artificial Intelligence
AR	Augmented Reality
BC	Blockchain
BS	Base Station
CNN	Convolutional Neural Network
DoS	Denial of Service
DTL	Deep Transfer Learning
DL	Deep Learning
DNN	Deep Neural Network
FAA	Federal Aviation Administration
FANET	Flying Ad Hoc Network
GCS	Ground Control Station
GPS	Global Positioning System
HCI	Human–Computer Interaction
HMDs	Head-Mounted Displays
IDS	Intrusion Detection System
IoT	Internet of Things
IoMT	Internet of Medical Things
LoS	Line of Sight
LPT	Laser Power Transfer

LTE	Long-Term Evolution
MBS	Macro Base Station
MEC	Mobile Edge Computing
MIMO	Multiple-Input Multiple-Output
ML	Machine Learning
NFV	Network Function Virtualization
NLP	Natural Language Processing
QoS	Quality of Service
QML	Quantum Machine Learning
PbD	Privacy by Design
PoW	Proof of Work
PPE	Personal protective equipment
RAN	Radio Access Network
RF	Radio Frequency
RIS	Reconfigurable Intelligent Surface
SBS	Small Base Station
SDN	Software-defined Networking
SMS	Social Monitoring System
THz	Terahertz
UAV	Unmanned Aerial Vehicle
uHDD	Ultra-High Data Density
uHSLLC	Ultra-High Speed Low Latency Communications
uMUB	Ubiquitous Mobile Ultrabroadband
URLLC	Ultra-Reliable Low-Latency Communications
VR	Virtual Reality
VLC	Visible-Light Communications
XR	Extended Reality

WCA	Water Cycle Algorithm
WPT	Wireless Power Transfer
WHO	World Health Organization

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