Future Technology
Open Access Journal
ISSN 2832-0379

May 2022| Volume 01 | Issue 01 | Pages 07-13

Journal homepage: https://fupubco.com/futech

https://doi.org/10.55670/fpll.futech.1.1.2

Future Publishing LLC

Review

How do drones facilitate human life?

Gerardo Antonio Urdaneta*, **Christopher Meyers, Lauren Rogalski**

Department of Mechanical Engineering, Arkansas Tech University, 1811 N Boulder Ave, Russellville, AR, 72801, USA

ARTICLE INFO

Article history:
Received 01 March 2022
Received in revised form
28 March 2022
Accepted 31 March 2022

Keywords:
Drones, LIDAR, metaheuristics, heuristics, stochastic

*Corresponding author
Email address: gerar4406@gmail.com

DOI: 10.55670/fpll.futech.1.1.2

ABSTRACT

Drone technology can provide a more cost-effective solution for many problems in different industries. This paper focuses on discussing how drones facilitate human life in various fields. They include infrastructure inspection, agriculture, medium and high-valued good delivery, geographical monitoring, rescue, and law enforcement. These areas were chosen because they can have the greatest impact if drones are used. Aerial unmanned vehicles can be used to map both horizontal surfaces and vertical structures. This can allow for a reduction in maintenance costs for buildings, cranes, wind turbines, speedways, and other infrastructures. It was found that the inspection cost for wind turbines could be reduced from 0.7% to 0.21% using drones. In terms of agriculture benefits, drones can use 800% less pesticide to provide the same protection benefits against plagues when compared to more conventional electric air-pressure knapsack sprayer (EAP) systems. Furthermore, it was determined that drones could save countless police officers' and civilians' lives by providing critical information in highly dangerous situations such as robberies, hostage cases, and car chases. The main obstacle that refrained from the widespread use of copter drones in these industries has been their limited flight time. Flight times of over two hours must be constantly achieved for the system to become cost-effective when compared to the traditional methods that are already in place.

1. Introduction

During the past two decades, there has been an increase in the application of unmanned aerial vehicles (UAV) for communication, delivery of products, and transportation. Aerial entertainment for the movie industry, photography, precision agriculture, and law enforcement are some of the many industries drones are currently used in [1]. Drones are being used for military purposes in extensive missions [2]. Unmanned aerial vehicles can be used to survey roads, inspect infrastructure projects, and scan bridges for failure points in conditions where remote access is crucial. Furthermore, container crane health monitoring is a time-consuming and expensive process based on human visual inspection. Due to the high costs attributed to the different safety regulations for this dangerous job, automation with drones and image processing techniques is a viable way to reduce the procedure costs [3]. According to the Michigan Department of Transportation, an 8-hour manual inspection of the deck on a four-lane divided highway bridge located near a metropolitan with a two men crew and heavy equipment would take $4,600. On the other hand, conducting an inspection using drones with a crew of one pilot and one spotter would take $1,200, and it would be completed within an hour [4]. The agricultural industry can also employ the drone for precision farming by outfitting a spraying system for autonomous pesticide spraying [5], mounting a camera to track livestock [6], configuring LIDAR to map the terrain for crop fields [7], and structure planning. With an estimated increase of 70% in the global food demand projected for 2050, alongside a reduction in arable land the farming sector needs a cost-effective way to increase production by automating the agricultural process. UAVs can provide a solution to this problem for small-scale farmers whose resources are limited [8]. Drones can be used to provide a fast response in case a wildfire arises. The current techniques for wildfire early response are ground assessment teams, helicopter aerial visualization, and satellite imagery, but all of them have their practical limitations. Manual wildfire assessment has the constraint of limited visibility, while aerial evaluation through human-crewed vehicles is expensive, cannot be instantly deployed, and are especially dangerous for the pilots involved. Satellite photography also has its limitations due to limited resolution, which leads to data averaging for extensive areas making it difficult to have a clear picture of the spreading fire, and the prolonged times it takes to resurvey the same area [9]. An unmanned aircraft can increase awareness and extend law enforcement reach in different scenarios during perilous circumstances, for example, a hostage situation, without putting human lives in any danger [10]. They can also be used as a method to help police patrol to manage traffic accidents, traffic congestion, and car chases. Drones are also being used in the delivery/parcel service with different private companies. Research has shown that it is inevitable that drones will become more widely used and accepted. Medical supplies and other extremely important goods can be shipped in remote areas using drones. Even though they are a revolutionary idea, their use is still restricted in urban areas due to Federal Aviation Administration (FAA) restrictions. Finally, they can also be used to assess potential pollution zones during natural and human disasters. Sensors can be attached to provide the system with the capabilities to detect radiation or cancerous chemicals. Their use can also be extended to recovery missions, one set of drones can go into the affected area and determine where the critical pollutants are, while another group of drones can scan for survivors and provide essential information for rescue teams. By employing drones in these cases manned aircrafts do not have to be used, avoiding putting the pilots at any risk.

The purpose of this review paper is to deliver a comprehensive study about how drones facilitate human life. The use of drones in agriculture, infrastructure inspection, wildfire management, medium and high-valued goods delivery, geographical monitoring, rescue, and traffic enforcement drones will be explored since these are the industries that look the most promising for unmanned aircraft.

2. Infrastructure inspection

There are still significantly many homes from 1970s that are not efficiently built as those of today. Almost 40% of energy lost is due to heat transfer and air leaks in these residences [11]. Although there are already ways to detect the infiltration and exfiltration regions of houses, the idea of using Unmanned Aerial Systems (UAS) paired with infrared cameras and 3D CAD modeling has become a new topic of discussion based on safety, low costs, non-destructive nature, and efficiency [12]. The use of infrared technology has shown to be of effective use because almost all materials emit infrared energy, which can be absorbed. This helps with the detection of changes in temperature and as a cost-reducing monitoring system. The most significant benefit of using infrared technology, besides its non-destructive and no-contact properties, is the stark contrast and immediate notification of irregular conditions [13]. There are two methods to audit a building: active thermography, where an energy source must create a thermal boundary between the background and the element of interest, and passive thermography, where the element of interest is already at a higher temperature than its surroundings. If using the former, pre-existing knowledge about the building defects must be known, thus why passive thermography is used on buildings showing suspicion of thermal defects [14]. It has been widely accepted to split the building audit process into three steps: pre-flight drone path planning, in-flight infrared thermography, and post-flight image processing. For the first step, there are many factors for flight planning, but the drone heavily relies on the Global Positioning System (GPS) for accuracy [15]. Some obstacles to drone flight are battery life, power output, and legal regulations of air space [16]. It is recommended that there is an established flight plan that targets all wanted areas of the building and that there are no outside obstacles that would prevent the drone from following its path. An acquired method is having "waypoints" that the drone uses as a reference on the GPS system. In order to facilitate the building mapping operation, developed three modes that the unmanned system (US) can operate with. The first mode is fully controlled by a human operator, although it increases the vibrations in the system due to the operator's inability to completely dampen the motion, it can be used as a fast way to reach a point of interest. The second mode is an assisted autonomous hovering technique alongside human-controlled operation. Lastly, the third mode is a fully autonomous flying method guided by a GPS through markers. To attain a highly efficient flying plan, it is preferred to use a hybrid combination of human operator control and autonomous hovering. The operator will quickly reach the point of interest; then the independent hovering system will take over to achieve stable flight so the images can be taken with the highest possible precision. Another approach to drone mapping is the use of mathematical planning. This planning has discovered that it is best for the drone to fly in strips in a "zig-zag" motion with an altitude twice the height of the building for best results [17]. It was proven from the case study that a strip pattern with at least a 70% overlap is suitable for gathering data to audit or visualize energy use in buildings. The time of the day when the drone flies is also considered to avoid direct radiation from the sun that would cause false positives; for maximum accuracy, it is preferred to scan the desired infrastructure before sunrise or after sunset. It is best to have the drone take pictures before sunrise and after sunset [18]. Having four combined wide-angle cameras helps to increase the base-height ratio and expand the angle of view, which also requires fewer ground control points. Since the determination of the shortest route between several points is a non-deterministic polynomial (NP) problem, the most efficient path will usually be determined by the shape of the area that wants to be mapped. Metaheuristic methods can be used to find near-optimized routes in a given area. The benefit of using Metaheuristic methods over "zig-zag" paths is the reduction of flying time. It is also possible to include other external factors in the heuristic solution that otherwise would not be included in the zigzagging route, such as distance from the take-off platform and interference with drone paths. Figure 1 shows the difference between "zig-zag" and metaheuristic paths (scan-based area division) while using three drones to scan a given area [19]. As far as post-flight image processing goes, it depends on altitude, quality, timing, spectrum, and overlap [20]. Geo-referencing is greatly used with time-stamped data from the GPS during the flight [21]. However, it was found that eliminating the measurements of the ground control points and just using the geotags results in lower accuracy, but for difficult terrains, this is needed. The 3D modeling methods can be separated into geo clusters and singular buildings. As for the specific 3D modeling process, it was found that 3D model generation software tends to be more successful with RGB photos. No truly autonomous system for 3D model generation of building geometry using thermal imaging has been recorded in a scholarly article [22]. For enough data, it is recommended to take approximately 1000-1300 photos for one simulation. Similar to the building inspection, the crane inspection can be segmented into three steps: pre-flight drone path planning, in-flight photography, and post-flight image processing. Contrary to the previously mentioned case, the crane is both an obstruction and a target of interest. Additionally, the unmanned vehicle must move in all three directions to obtain a clear picture of the system. Figure 2 shows a linear pre-processed trajectory for a quay crane.

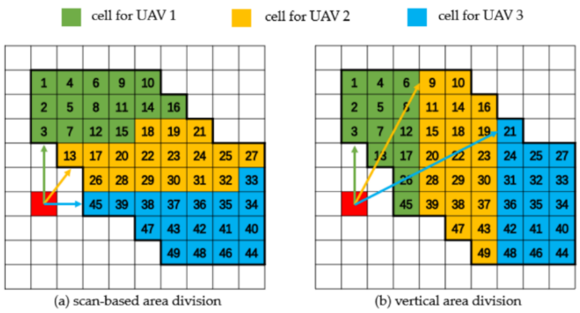
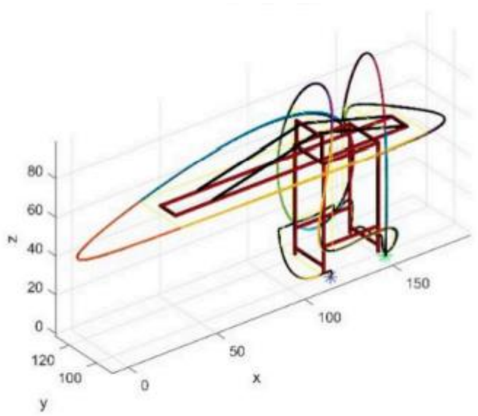
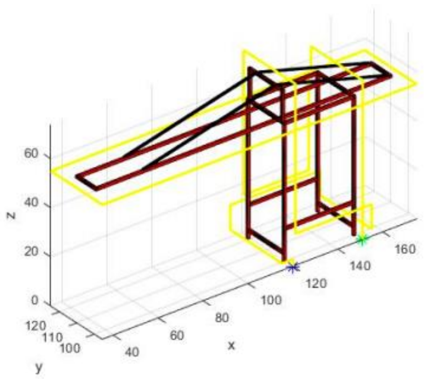


Figure 1. Difference between scan-based (a) area division and (b) vertical "zig-zag" division [19]



(a)



(b)

Figure 2. Model of a crane unmanned system detection path. (a) Optimized and (b) non-optimized

The set path from Figure (b) does not consider the drone dynamics, and therefore it would be difficult and inefficient for the system to follow that trajectory. Through the use of a piecewise polynomial function by taking into consideration the system's equations of motion, it is possible to observe a deviation from the initial trajectory that would be more fitted for the drone's hovering motion. For a large enough dataset, it is required to have around 500 pictures of a single crane to create an accurate model to estimate its fatigue life [3]. These techniques for infrastructure inspection are not subjected to buildings or cranes. The same strategy can be applied to a variety of infrastructures such as railways, transmission lines [23], bridges, highways, wind farms, dams, manufacturing plants, and other highly dangerous areas. It was determined that the manual inspection for wind farms accounted for 0.7% of the total turbine operational cost, and if drones were to fully automate the process, that cost would be reduced by 70%. Moreover, a reduction of 90% in the lost revenue during the inspection could be attained [24].

3. Agricultural industry

As a response to the global food crisis the world is heading towards in the next decades, unmanned aircraft technologies can soothe the disaster by providing small farmers in developing countries with an accessible way of increasing their yield production. Unmanned aircraft can be used as a spraying mechanism due to their ability to achieve long distances in single flights. Even though the amount of pesticide is limited by the drone's payload capabilities, by increasing the propeller size and reducing the number of motors, it is possible to decrease the power consumed and thus amount superior flight times. This relies on the fact that by having a larger rotor, the effective area that pushes air down increases, and it is translated into a more efficient hovering. Yallappa et al. [25] was able to cover an area of 1.15 ha/hr with an application rate of 55.15 L/ha. The work compared the coarse nozzle control efficacy between a volumetric spraying rate of 16.8 L/ha and 28.1 L/ha and determined that it did not differ significantly, but it was meaningfully higher than finer nozzles with spraying rates of 9 L/ha. Therefore, it was found that a spraying rate of 16.9 L/ha was optimal. It is important to note that these values reflected the efficacy characteristics of the systemic pesticide imidacloprid. The contact pesticide lambda-cyhalothrin showed an optimal efficiency rate of 28.1 L/ha. On the other hand, conventional electric air-pressure knapsack sprayer (EAP) had a drastically higher spraying rate of 225 L/ha and 450 L/ha and achieved similar deposition losses compared to the UAV spraying methods. Furthermore, control efficacy on wheat aphids showed to be similar in both situations [26]. From the previous results, it is possible to show how including spraying systems on drones seems like a promising idea to modernize agriculture with low initial costs; these systems are less wasteful and more time-efficient than the more traditional manual EAPs.

Huang et al. [5] used a low volumetric rate of 0.3 L/ha and was able to cover an area of 14 hectares. Even though it may not be optimized for certain applications, the lower flow rate allows for a faster insecticide distribution that will allow covering more surface area with the same amount of fuel, maximizing the fuel to pesticide ratio. It is estimated that the system will be capable of covering 0.4 hectares per minute. The widespread objective in the mentioned systems focuses on increasing the chemical payload and flight duration capabilities for these systems. Hydrogen can provide a solution to this problem; hydrogen has the highest power density among any elements with 120 KJ/g compared to the batteries 1 KJ/g. The use of a hydrogen fuel cell would allow the drone to achieve longer flights of up to 4 hours for copter configurations. Another application for drones in agriculture focuses on mapping extensive areas for crop cultivation. Fixed wings drones such as the Honeycomb AgDrone Sytem or EBEE SQ-SenseFly can cover over 600 acres every hour, making them capable of imagining crops, obtaining sunlight absorption rates, and soil compositions [27]. In soil sampling, the traditional practice consists in obtaining specimens from different soil sections and sending them to a laboratory for analysis. Additionally, countries' regulations make the constant use of this practice unviable. In some cases, farmers are limited in using it once every five years and only for every ten hectares. Aerial images can provide a useful insight into where the specimens should be taken from, which would be translated in time and money savings. For soil pictures, an RGB camera is sufficient [28]. Comparable to the previous infrastructure section, the process can be divided into two sections: pre-flight path planning and post-flight image processing. Depending on the surface shape, the system path can either have a "zig-zag" shape or heuristics can be used if other factors besides path length must also be considered [19]. As far as image processing goes, the image segmentation is performed in two phases: the picture division into clusters through the simple linear iterative cluster, and their classification into a smaller number of color categories through K-mean clustering. Finally, after inputting the total amount of samples desired, an algorithm would map the location where the specimens should be taken from on the image. This method of localizing the place where the specimens should be extracted is more precise than estimating it through visual methods. Despite the numerous benefits, visual soil techniques still have their own drawbacks. The moisture in the soil must be the same such that the light reflected by the soil parallels the expected color. One of the most recurring problems in the farming industry, especially in developing countries, has been the incapability to track large amounts of livestock through extensive areas. Ranchers usually own extensive territories where their assets tend to be scattered around. It requires experience personnel to locate and count the number of cattle in a certain area. It is common to obtain incorrect evaluations regarding the actual condition of the farm. Apart from the fact that miscounting is a common issue, this is a costly and labor-intensive process that leads to missing assets.

A potential detection system for large-scale farms can consist of a system containing transceivers emitting a signal to a receiver attached to the cattle (through a collar), several sensing nodes located in areas of interest, and a path optimization plan. The location of the cattle will be sent through a signal to the closest receiver, and the drone will be capable of picking it up after passing through a determined path [29]. Alternatively, it is possible to have a certain amount of unmanned copter systems spanning over the cattle's location. The livestock will send a signal to one of the drones in the sky through a collar transmitter, and that drone will send a signal to the server cloud. The former method may be more useful for smaller farmers because fewer drones are used, in fact, only one drone is used but at the expense of lower accuracy and added expense for the implementation of local antennas. On the other hand, having multiple copters covering a certain area translates into more accurate readings, but with more drones, that also incorporates higher initial, operating, and maintenance costs. Therefore, the latter method should be used for big-scale farms with large disposable capital. An additional use for drones in agriculture could be reducing the response time necessary to combat a wildfire. According to Spinoni et al. [30], a 4°C increase in the average global temperature will result in 4.5% of the global land becoming arid; this is for a scenario where fossil fuels persist as the main source of energy in the future. This shift will likely result in more wildfires in regions like Africa and South America, causing a subsequent drop in their main commodities exports. Drones can be employed to alert people in nearby areas about any possible wildfires and get into action to reduce the impact.

4. Law enforcement

An essential part of regulating traffic crashes is traffic enforcement. An advantage for drones in traffic enforcement is that they provide an aerial view of drivers and are not confined to the obstacles of normal enforcement congestion or road network structure. The most recent areas where drones are being used in law enforcement are in hostage situations, manhunts, crime scene investigations, and traffic administration [31]. Other results from the survey concluded that traffic enforcement drones are more effective compared to other aerial resources like police helicopters [32]. This led to an experiment on the enforcement of drones on driving speed versus police cruisers. The results showed that drivers tend to slow down more for police cruisers which shows that drones should not be replacements for human-based traffic enforcement but serve more as an aid. UAVs still have many challenges that they must undergo related to economics, technology, legislature, and public acceptance. The main one, in this case, is that of public acceptance. A survey was conducted between two groups, those from the US and those from Israel, to better grasp the public opinion of drones in traffic enforcement. The survey showed that 60-70% of Americans support drone technology for fighting crime. The second most troubling concern for the public is their privacy. It was found from the survey that there was not much of a difference in the public opinion regarding drone use for civil or police purposes, in both cases the public showed concern about drones and their privacy. The study also showed that it would be better to start drone enforcement integration in interurban spaces that are more open and seen as less troubling. It was also acknowledged that there should be some official privacy-preserving policy to further help with public opinion [32]. Even though many problems must be solved to incorporate drones into daily life, their future in the industry is promising because they could replace people in dangerous jobs, such as a hostage situation, or provide surveillance if somebody tries to escape the police.

5. Goods and medical supplies delivery

Along with the increasing implementation of drones in society, unmanned aircraft systems can be used to deliver essential medical supplies in remote areas. In 2007, the National Health Laboratory Service (NHLS) and Denel Dynamics used a drone to transport biological samples from suburban areas to NHLS centers for testing. They are also being used in the delivery/parcel service with companies such as Amazon, Alibaba, and the DPD group in France. When it comes to the distribution industry, people have a choice model nowadays to which type of service they prefer to use; some customers prefer traditional methods such as trucks and motorcycles. Therefore, drones already have started with a vital disadvantage relative to the more conventional supply options. Drones are restricted by FAA regulations in urban zones, and privacy concerns among the public are a problem delivery companies should consider [32]. On the other hand, medical supplies delivery in isolated areas shows a promising future for remote-controlled systems because they are not subjected to the more strict urban airspace regulations. Zipline and United States Postal Service (USPS) evaluated the possibility of medication delivery in Rwanda. Pulver et al. [33] developed a simulation indicating that drones can reach 96% of the population in a minute, compared to the traditional 4.3% ambulances could provide. Even though important achievements have been made, it is essential to note that collisions still occur, and samples do not always reach their destination intact. Remote systems delivery of low and medium-valued goods is likewise plagued by difficulties. Due to the stochastic behavior of delivery requests and the NP nature of the traveling salesman problem, creating a drone path for different parcels is a highly complex problem. Several solutions have been developed, such as utilizing drones along with trucks or employing drones along with recharging stations. Murray et al. [34] developed a method by which the truck would be able to operate in a certain location, and then the drone would be used to reach the farthest points. Another proposed method consists of using several drones along with different trucks where they can be deployed in order to minimize completion time. In this case, the main objective is to distribute as many packages as possible in the shortest period of time [35]. The second most important problem for drone delivery is its rechargeability. There are proposed solutions where the algorithm develops a path maximizing the number of packages that could be delivered while reducing the flight distance between recharging stations [36]. The drone can also be recharged by landing on mobile recharging stations. The algorithm proposed by Yu et al. [37] finds the optimal path for the drone to go to different locations and determines the landing times on the charging stations. Unmanned aircrafts not only have to overcome the mentioned technical problems, but they also have to be well perceived by the public and show their convenience over traditional methods. A study was produced with a choice model to compare drones to trucks and motorcycles in delivery services; different products for delivery and the effects of gender, age, and income were considered as variables [38]. The products chosen for the study were clothing, beauty products, and urgent documents. A hypothesis was then made that customers would be willing to use faster, more expensive delivery as the price of the product increased. The study concluded that the preference for drone delivery depended on the price and type of commodity. Customers were worried about the reliability of the drone for expensive items. The results also showed that socio-demographic characteristics did affect the opinion on drone delivery; younger people supported the use of drones more than older people. Finally, it is also important to note that this survey took data from subjects who have not used the drone service before and thus are only predicting how they feel about it [38].

6. Geographical monitoring, discovery, and rescue missions

Geographical monitoring in remotes areas can be performed using unoccupied aerial vehicles. For example, seagrass environmental monitoring can be achieved through the employment of UAVs with high-resolution cameras [39]. The advantage of using drones over satellite imagery lies in their finer resolution (the best satellite resolution can only achieve 1 m compared to drones' 0.1 m) [40] and more accessible time windows; satellites usually have inflexible and long revisit cycles. Unmanned vehicles can be employed as early survey elements to assess the initial damage in disaster zones. During the Haiyon Hurricane in 2013, unmanned vehicles were used to determine initial damage and locate the most affected neighborhoods [41]. Remote-controlled aircrafts can also be applied to detect harmful chemicals in different environments. Researchers from the Rochester Institute of Technology (RIT) are thinking about ways to measure nitrogen oxide contamination using a series of drones that would fly into the polluted volume with synchronized cameras [42]. Capolupo et al. [43] used high-definition cameras to determine the copper content in agricultural areas to predict cancer risks. The recognition of the affected areas by chemical, biological, or nuclear contamination will provide valuable information if a rescue mission has to be planned. The service of drones in the field is crucial since it will avoid the use of manned aircrafts. Several sensory techniques can be employed to perceive different electromagnetic frequencies. Some methods are scattering, differential absorption, fluorescent, and doppler. Sensors are used depending upon the electromagnetic spectrum desired to analyze. Some examples of commercial sensors are Zenmuse XT2 which is used for infrared detection, and DroneRad for radiation [44]. Depending on the nature of the disaster (chemical, nuclear…) a swarm of drones could be easily equipped with the precise sensor to detect the pollution coverage. Furthermore, an individual using virtual reality goggles would be able to control a drone in a first-person view, making him/her capable of maneuvering the system to detect the critical areas in the accident without putting them in danger. Once more, the system's endurance is critical for the mission. The area spanned by the disaster will directly affect the UAVs effectiveness. The greater the disaster area, the more drones will be needed in order to cover it. This could mean delays in subsequent rescue missions. Additionally, the effects of long-term exposure to different substances and radiation on drone performance should be studied further. More research in this area will allow rescue and monitoring teams to have a better picture of the drone's performance during the mission.

7. Conclusions

The importance of drones in the infrastructure, agriculture, medium and high-valued good delivery, geographical monitoring, rescue, and law enforcement industries was explored. The main impediments to their use in these industries were also discussed. In terms of infrastructure inspection, path flight planning can be used to have one or several drones mapping a certain flat region. The same technique can be applied to map vertical structures. It was determined that the "zig-zag" method was a simple path to use, but if more factors are considered (number of drones, area shape, landing site…), heuristics can be used to optimize the route. For wind turbines, a reduction of 90% in the lost revenue during the inspection could be attained. In addition, inspection costs could go from 0.7% to 0.21%. When it comes to container cranes, a reduction of cost of 70% can be estimated. In the agricultural industry, pesticides sprayed by drones can be used more efficiently compared to EAP spraying methods. Drone mapping can be used along with algorithms to determine the most efficient places to get soil samples from by looking at their color, causing the process to be time-efficient. Unmanned systems can also be used to track livestock by either picking the signal from antennas or by obtaining the signal from the collar the animal is wearing. Drones can provide help to police officers in highly dangerous situations by offering aerial assistance through surveillance and intelligence. Unmanned systems can be used to deliver high values goods in a timely manner, and they can also be employed to detect the reduction of fauna and flora or assess highly hazardous zones. Even though the future is promising for unmanned aircraft systems, there is a lot to be done in terms of improvements to see drones in daily activities. Flight endurance for copter drones must be increased to at least two hours, and their overall price should be decreased by around 15%. This should provide a strong case for companies to shift from their conventional methods.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

References

[1] Zhang F, Maddy J. Investigation of the Challenges and Issues of Hydrogen and Hydrogen Fuel Cell Applications in Aviation 2021. https://doi.org/10.36227/TECHRXIV.14958057.V1.

[2] Wang J, Jia R, Liang J, She C, Xu YP. Evaluation of a small drone performance using fuel cell and battery; Constraint and mission analyzes. Energy Reports 2021;7:9108–21. https://doi.org/10.1016/J.EGYR.2021.11.225.

[3] Maboudi M, Alamouri A, De Arriba López V, Bajauri MS, Berger C, Gerke M. DRONE-BASED CONTAINER CRANE INSPECTION: CONCEPT, CHALLENGES and PRELIMINARY RESULTS. ISPRS Ann Photogramm Remote Sens Spat Inf Sci 2021;5:121–8. https://doi.org/10.5194/ISPRS-ANNALS-V-1-2021-121-2021.

[4] Here's How State DOTs are Using Drones - Operations - Government Fleet n.d. https://www.government-fleet.com/332236/70-of-state-dots-use-drones-heres-how-they-use-them (accessed March 28, 2022).

[5] Huang Y, Hoffmann WC, Lan Y, Wu W, Fritz BK. Development of a Spray System for an Unmanned Aerial Vehicle Platform. Appl Eng Agric 2009;25:803–9. https://doi.org/10.13031/2013.29229.

[6] Li X, Xing L. Use of Unmanned Aerial Vehicles for Livestock Monitoring based on Streaming K-Means Clustering. IFAC-PapersOnLine 2019;52:324–9. https://doi.org/10.1016/J.IFACOL.2019.12.560.

[7] Wallace L, Lucieer A, Watson C, Turner D. Development of a UAV-LiDAR System with Application to Forest Inventory. Remote Sens 2012, Vol 4, Pages 1519-1543 2012;4:1519–43. https://doi.org/10.3390/RS4061519.

[8] Hafeez A, Husain MA, Singh SP, Chauhan A, Khan MT, Kumar N, et al. Implementation of drone technology for farm monitoring & pesticide spraying: A review. Inf Process Agric 2022. https://doi.org/10.1016/J.INPA.2022.02.002.

[9] Akhloufi MA, Couturier A, Castro NA. Unmanned Aerial Vehicles for Wildland Fires: Sensing, Perception, Cooperation and Assistance. Drones 2021, Vol 5, Page 15 2021;5:15. https://doi.org/10.3390/DRONES5010015.

[10] Murphy DW, Cycon J. Applications for mini VTOL UAV for law enforcement. Https://DoiOrg/101117/12336986 1999;3577:35–43. https://doi.org/10.1117/12.336986.

[11] Detecting sources of heat loss in residential buildings from infrared imaging n.d. https://dspace.mit.edu/handle/1721.1/68921 (accessed March 28, 2022).

[12] Schuffert S, Voegtle T, Tate N, Ramirez A. Quality Assessment of Roof Planes Extracted from Height Data for Solar Energy Systems by the EAGLE Platform. Remote Sens 2015, Vol 7, Pages 17016-17034 2015;7:17016–34. https://doi.org/10.3390/RS71215866.

[13] Clark MR, McCann DM, Forde MC. Application of infrared thermography to the non-destructive testing of concrete and masonry bridges. NDT E Int 2003;36:265–75. https://doi.org/10.1016/S0963-8695(02)00060-9.

[14] Fox M, Coley D, Goodhew S, De Wilde P. Thermography methodologies for detecting energy related building defects. Renew Sustain Energy Rev 2014;40:296–310. https://doi.org/10.1016/J.RSER.2014.07.188.

[15] Steffen R, Wolfgang Förstner. On visual real time mapping for unmanned aerial vehicles. 21st Congr. Int. Soc. Photogramm. Remote Sens., 2008.

[16] Volkmann W, Grenville Barnes. Virtual surveying: Mapping and modeling cadastral boundaries using Unmanned Aerial Systems (UAS). Proc. FIG Congr. Engag. Challenges—Enhancing Relev., Kuala Lumpur, Malaysia: 2014, p. 16–21.

[17] Lizarazo I, Angulo V, Rodríguez J. Automatic mapping of land surface elevation changes from UAV-based imagery. Https://DoiOrg/101080/0143116120161278313 2017;38:2603–22. https://doi.org/10.1080/01431161.2016.1278313.

[18] González-Aguilera D, Lagüela S, Rodríguez-Gonzálvez P, Hernández-López D. Image-based thermographic modeling for assessing energy efficiency of buildings façades. Energy Build 2013;65:29–36. https://doi.org/10.1016/J.ENBUILD.2013.05.040.

[19] Xiao S, Tan X, Wang J. A Simulated Annealing Algorithm and Grid Map-Based UAV Coverage Path Planning Method for 3D Reconstruction. Electron 2021, Vol 10, Page 853 2021;10:853. https://doi.org/10.3390/ELECTRONICS10070853.

[20] Yahyanejad S, Rinner B. A fast and mobile system for registration of low-altitude visual and thermal aerial images using multiple small-scale UAVs. ISPRS J Photogramm Remote Sens 2015;104:189–202. https://doi.org/10.1016/J.ISPRSJPRS.2014.07.015.

[21] Rodriguez-Gonzalvez P, Gonzalez-Aguilera D, Lopez-Jimenez G, Picon-Cabrera I. Image-based modeling of built environment from an unmanned aerial system. Autom Constr 2014;48:44–52. https://doi.org/10.1016/J.AUTCON.2014.08.010.

[22] Borrmann D, Nüchter A, Dakulović M, Maurović I,

Petrović I, Osmanković D, et al. A mobile robot based system for fully automated thermal 3D mapping. Adv Eng Informatics 2014;28:425–40. https://doi.org/10.1016/J.AEI.2014.06.002.
[23] Deng C, Wang S, Huang Z, Tan Z, Liu J. Unmanned aerial vehicles for power line inspection: A cooperative way in platforms and communications. J Commun 2014;9:687–92. https://doi.org/10.12720/JCM.9.9.687-692.
[24] Kabbabe Poleo K, Crowther WJ, Barnes M. Estimating the impact of drone-based inspection on the Levelised Cost of electricity for offshore wind farms. Results Eng 2021;9:100201. https://doi.org/10.1016/J.RINENG.2021.100201.
[25] Yallappa D, Veerangouda M, Maski D, Palled V, Bheemanna M. Development and evaluation of drone mounted sprayer for pesticide applications to crops. GHTC 2017 - IEEE Glob Humanit Technol Conf Proc 2017;2017-January:1–7. https://doi.org/10.1109/GHTC.2017.8239330.
[26] Wang G, Lan Y, Qi H, Chen P, Hewitt A, Han Y. Field evaluation of an unmanned aerial vehicle (UAV) sprayer: effect of spray volume on deposition and the control of pests and disease in wheat. Pest Manag Sci 2019;75:1546–55. https://doi.org/10.1002/PS.5321.
[27] Puri V, Nayyar A, Raja L. Agriculture drones: A modern breakthrough in precision agriculture. Https://DoiOrg/101080/0972051020171395171 2017;20:507–18. https://doi.org/10.1080/09720510.2017.1395171.
[28] Huuskonen J, Oksanen T. Soil sampling with drones and augmented reality in precision agriculture. Comput Electron Agric 2018;154:25–35. https://doi.org/10.1016/J.COMPAG.2018.08.039.
[29] Behjati M, Mohd Noh AB, Alobaidy HAH, Zulkifley MA, Nordin R, Abdullah NF. LoRa Communications as an Enabler for Internet of Drones towards Large-Scale Livestock Monitoring in Rural Farms. Sensors 2021, Vol 21, Page 5044 2021;21:5044. https://doi.org/10.3390/S21155044.
[30] Spinoni J, Barbosa P, Cherlet M, Forzieri G, McCormick N, Naumann G, et al. How will the progressive global increase of arid areas affect population and land-use in the 21st century? Glob Planet Change 2021;205:103597. https://doi.org/10.1016/J.GLOPLACHA.2021.103597.
[31] Rosenfeld A, Maksimov O. Optimal cruiser-drone traffic enforcement under energy limitation. Artif Intell 2019;277:103166. https://doi.org/10.1016/J.ARTINT.2019.103166.
[32] Rosenfeld A. Are drivers ready for traffic enforcement drones? Accid Anal Prev 2019;122:199–206. https://doi.org/10.1016/J.AAP.2018.10.006.
[33] Pulver A, Wei R, Mann C. Locating AED Enabled Medical Drones to Enhance Cardiac Arrest Response Times. Https://DoiOrg/103109/1090312720151115932 2016;20:378–89.
[34] Murray CC, Chu AG. The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery. Transp Res Part C Emerg Technol 2015;54:86–109. https://doi.org/10.1016/J.TRC.2015.03.005.
[35] Poikonen S, Wang X, Golden B. The vehicle routing problem with drones: Extended models and connections. Networks 2017;70:34–43. https://doi.org/10.1002/NET.21746.
[36] Hong I, Kuby M, Murray A. A Deviation Flow Refueling Location Model for Continuous Space: A Commercial Drone Delivery System for Urban Areas. Adv Geogr Inf Sci 2017:125–32. https://doi.org/10.1007/978-3-319-22786-3_12.
[37] Yu K, Budhiraja AK, Tokekar P. Algorithms for Routing of Unmanned Aerial Vehicles with Mobile Recharging Stations. Proc - IEEE Int Conf Robot Autom 2018:5720–5. https://doi.org/10.1109/ICRA.2018.8460819.
[38] Kim SH. Choice model based analysis of consumer preference for drone delivery service. J Air Transp Manag 2020;84:101785. https://doi.org/10.1016/J.JAIRTRAMAN.2020.101785.
[39] Yang B, Hawthorne TL, Hessing-Lewis M, Duffy EJ, Reshitnyk LY, Feinman M, et al. Developing an Introductory UAV/Drone Mapping Training Program for Seagrass Monitoring and Research. Drones 2020, Vol 4, Page 70 2020;4:70. https://doi.org/10.3390/DRONES4040070.
[40] Colomina I, Molina P. Unmanned aerial systems for photogrammetry and remote sensing: A review. ISPRS J Photogramm Remote Sens 2014;92:79–97. https://doi.org/10.1016/J.ISPRSJPRS.2014.02.013.
[41] Drones: a force for good when flying in the face of disaster | Humanitarian response | The Guardian n.d. https://www.theguardian.com/global-development/2015/jul/28/drones-flying-in-the-face-of-disaster-humanitarian-response (accessed March 28, 2022).
[42] Researchers using drones to detect noxious gas released by explosions | RIT n.d. https://www.rit.edu/news/researchers-using-drones-detect-noxious-gas-released-explosions (accessed March 28, 2022).
[43] Capolupo A, Pindozzi S, Okello C, Fiorentino N, Boccia L. Photogrammetry for environmental monitoring: The use of drones and hydrological models for detection of soil contaminated by copper. Sci Total Environ 2015;514:298–306. https://doi.org/10.1016/J.SCITOTENV.2015.01.109.
[44] Rabajczyk A, Zboina J, Zielecka M, Fellner R. Monitoring of Selected CBRN Threats in the Air in Industrial Areas with the Use of Unmanned Aerial Vehicles. Atmos 2020, Vol 11, Page 1373 2020;11:1373. https://doi.org/10.3390/ATMOS11121373.