A Survey of UAS Technologies to Enable Beyond Visual Line Of Sight (BVLOS) Operations

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Abstract: Latest trends, societal needs and technological advances have led to an unparalleled expansion in the use of Unmanned Aerial Systems (UAS) for versatile civilian and military applications, ranging from simple everyday operations, to the supervision in construction sites, even logistics, among others. Unmanned Aerial Vehicles (UAVs), widely known as drones, are the main components of UAS, and are becoming increasingly popular in such operations, since they reduce costs, they facilitate activities and can increase the granularity of surveillance or delivery. Furthermore, they can pave new ways for the implementation of smart-sensing and navigation functionalities, support automation, safety of operations, prognostics and even forensic analyses. Being an emerging technology, several challenges still need to be tackled in order to make UAS suitable for real-world applications, which impose strict performance, dependability and privacy requirements. In the light of the above, this paper provides an in depth survey of current UAS technologies for Beyond the Visual Line of Sight (BVLOS) UAS operations and highlight the main technological challenges and requirements that arise. We also focus on the emerging and future BVLOS UAS features and the technological advances that render their expansion in various industrial sectors promising.

1 INTRODUCTION

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, are the main component of Unmanned Aerial Systems (UAS), which also comprise a ground-based controller, and communication system. UAVs were first introduced as military devices, but soon managed to take a leap in the commercial and civil sector. In the last few years, UAVs are increasingly considered in a wide range of applications for surveillance and safety checks in domains such as construction, mining, agriculture, logistics and product delivery, insurance, and many more (Nouacer et al., 2020). As their popularity is increasing, it is predicted that the global commercial drone's market will grow to 7.13 billion at a CAGR of 19.9 through 2022 (Kovalev et al., 2019). To this end, UAS use is expected to have a significant impact on the quality of life, health, social and economic well-being (Kyrkou et al., 2019). In this direction, Beyond Visual Line of Sight (BVLOS) capabilities are becoming recently a pivotal aspect for the drone industry. The extended levels of autonomy in addition to the increased efficiency of such operations has given potential to even more applications in the field. In the rest of the manuscript, the terms *Unmanned Aerial Vehicle (UAV)* and *drone* are used interchangeably to refer to an unmanned vehicle that is remotely operated by a human or software.

The related literature so far provides useful information for the technological aspects of UAS, the societal and regulatory barriers for their acceptance and forms a useful basis for a similar analysis for BVLOS drone operations. Authors in (Hassanalian and Abdelkefi, 2017) provide a detailed analysis of the various drone types, with emphasis on their capabilities and restrictions. The main types of UAS applications are surveyed in (Rakha and Gorodetsky, 2018) and in (Otto et al., 2018), authors provide an overview of current optimization approaches for civil-drone applications. The recent research efforts on the use of UAVs in transportation, and specifically in road safety, traffic monitoring and highway infrastructure management tasks are surveyed in (Outay et al., 2020). Finally, more interesting applications of UAS integration in smart cities, as well as the en-

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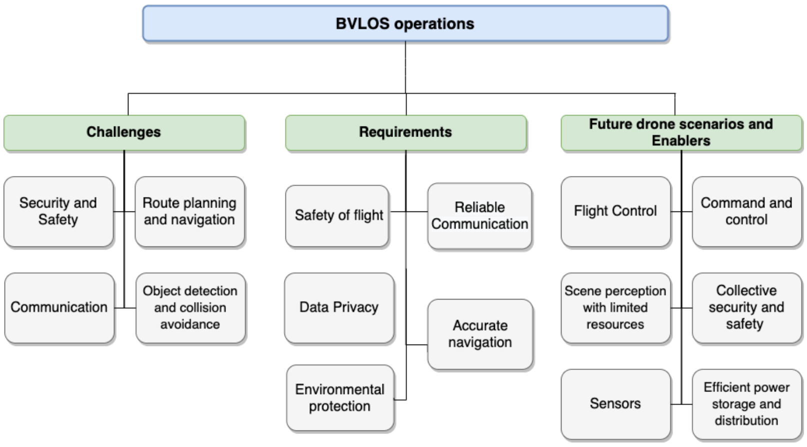

Figure 1: An overview of the challenges, requirements and enablers, for BVLOS drone operations.

abling technologies and issues are explored in (Mohamed et al., 2020).

Existing surveys emphasize on remote controlled UAVs, in which the operator has a visual line of sight to the vehicle and navigates the drone from a ground based controlled, using the communication system. The technological advances and the increased demand for drone operations, give rise to the need for UAS that can successfully perform BVLOS operations, with wider autonomy and minimised interaction with the ground control. This work surveys the current state of the art on BVLOS drone operations, and emphasizes on technologies that can support the related projects. It analyses each technology and lists the high and low level requirements that unmanned operation of UAS BVLOS dictates.

The main contributions of this work can be summarized in the following and Figure 1 depicts the main points of this analysis:

- A presentation of the main BVLOS operation challenges and the requirements they raise, with emphasis on the technological requirements.
- A survey of the main BVLOS advances and future scenarios and the main technology enablers that can support them.

To this end, Section 2 summarizes the main survey works in BVLOS drone operations. Section 3 refers to the main tasks and challenges for BVLOS operations and summarizes the high and low-level requirements that are accomodated. Section 4 presents the main technologies needed for the successful delivery of BVLOS operations and presents the key enablers for future BVLOS drone operation scenarios. Finally, in Section 5 we discuss the main findings of this study and the conclusion of this work.

2 RELATED WORK

The integration of BVLOS capabilities in various drone operations is lately attracting more research interest. Although there is a wide range of applications traditionally supported by Visual Line of Sight (VLOS) and Extended Visible Line of Sight (EVLOS) operating modes, BVLOS operations are expected to dominate our skies within the next years, offering a large variety of services, such as inspection of infrastructure, deliveries, human transportation or precision agriculture (Undertaking, 2018).

The three modes depend on the interaction between the UAV and its operator (Sebbane, 2018):

- In VLOS the UAV should always be within the inobstructed view of the pilot (Macias et al., 2019).
- In EVLOS the operator may partly rely on critical flight information from remote observers that are in visual line with the UAV (Bloise et al., 2019).
- In BVLOS the UAV is allowed to operate away from the visual range, based on instrumentation such as on-board cameras and detect-and-avoid technologies.

The choice of the appropriate operation mode depends on the type of application, the distance that can or must be covered, the conditions in the operation spot and in some cases on the criticality of the task. This makes VLOS mostly preferable by hobbyists, real estate agents, cinematographers and TV producers for scene coverage, EVLOS and BVLOS a better choice for inspections and surveying (structural, military, environmental or agricultural), mapping as well as for package delivery and search and rescue missions (Davies et al., 2018).

In the absence of human control for short or longer periods, recent works aim to explore BVLOS modes that endow UAV flights with higher levels of intelligence and greater efficiency. Compared to VLOS or EVLOS operation modes, which require a certain level of human interaction, BVLOS UAVs can dynamically change their flight plan and mission according to prevailing conditions without a human operator. Extended autonomy in BVLOS capabilities enables a drone to cover far greater distances, with a lower cost and a reduced risk to human life. On the other side, BVLOS operations create a new landscape for communication, navigation, and flight under varying conditions. Various BVLOS scenarios for efficient capabilities are explored in (Fang et al., 2018).

During the last few years, a number of interesting studies propose novel methodologies for BVLOS missions and operations in numerous applications (Kato et al., 2019). In this basis, BVLOS missions enable service providers to perform complex operations by data provided from on-board and external instruments. The operator is informed about the position, altitude, speed and direction of flight as well as about all the relevant parameters of the flight body. In addition, UAS flying in BVLOS operation mode can also change control sensors and flight parameters to collect data (Davies et al., 2018).

This work presents the main challenges for BVLOS operations and the requirements that emanate from them. Next, we identify the technological advances that may play a key role as enablers for the deployment of successful BVLOS drone scenarios.

3 BVLOS MAIN CHALLENGES

Security and Safety: Security and safety of flight remain critical issues in unmanned aircraft missions. It is clear that the absence of a clear regulatory framework at national or international level (e.g. for China, the US or EU countries) inhibits the growth of the drone services and aircrafts market, and limits the potential for employment creation in this sector of the economy (Nouacer et al., 2020). Therefore, across the globe, laws and regulations are needed in order to manage drone impacts, particularly in lower airspace (Merkert and Bushell, 2020). Regulatory measures can significantly increase the requirements of operators to build a safety culture into their operations. To this end, the European Aviation Safety Agency (EASA) has developed a regulatory framework that defines the technical and operational requirements for UAS, provides guidelines for safe operation, and addresses privacy, security and data protection issues (Bassi, 2019). Standards and Recommended Practices (SARPs) for BVLOS operations are under development by the International Civil Aviation Organization (ICAO) with adoption foreseen in 2020 leading to operations as from 2023 (Undertaking, 2018).

Route Planning and Navigation: Efficient navigation and perception of the UAV surroundings is critical in BVLOS operations. Amongst other autonomous features, a UAV operating BVLOS should be able to dynamically revise its path planning strategy according to the environment and through a "Detect Sense and Avoid" (DAA) system, that guarantees collision avoidance and situational awareness (González-Sieira et al., 2020).

To improve the planning efficiency of UAS, many innovative methods have been explored, such as multi-resolution maps (González-Sieira et al., 2020), game theory, and bio-inspired methods, such as swarm optimization algorithms and Potential Fields (Iacono and Sgorbissa, 2018). In latest years, the integration of Artificial intelligence technologies (i.e. Deep Learning/Machine Learning) has thrown spotlight on drone intelligence and automation, endowing UAV applications with a higher degree of robustness and accessibility (Nouacer et al., 2020). Several very interesting studies have explored various AI methods, such as Reinforcement Learning (RL) algorithms in combination with deep learning techniques to efficiently execute navigation tasks in large-scale complex environments (Wang et al., 2019)

Communication: During a mission, it is essential for an UAV to interact with other entities, such as air traffic management systems, ground stations or even other UAVs. In BVLOS operations, there exists a greater need for a UAV to be aware of its surroundings with the use of DAA technology (Davies et al., 2018). In such terms, robust and reliable communication channels as well as efficient data exchange are essential for safe and efficient operations.

Existing cellular networks (including the 5G) or even satellite links may support data exchange in BVLOS applications (Hosseini et al., 2019). However several issues may compromise the reliability of communication between operator and UAV. For instance, long-distance radio communication may impose large propagation delay, high packet-loss ratio, and high power consumption. Moreover, the kinematics of the UAV leads to time-variant network topologies and frequent link outages, that often lead to communication failure(Wang et al., 2017). It is thus important to develop communication protocols and communication loss handling techniques that will guarantee the uninterrupted UAV operation.

Object Detection and Collision Avoidance: As aviation technology is progressing, the unique characteristics of UAS, as flying instruments with high mobility in three-dimensional space and the need for autonomous operation, raise new requirements of vigilant path planning strategies, that can safely navigate drones from origin to destination. One of the most challenging aspects of a UAV mission is to combine autonomous features with an optimal motion planning approach, that guarantees a safe navigation through unknown spaces and obstacles, that may appear dynamically as the route evolves. The main challenge for current collision avoidance systems for drones is the effective and efficient detection of static or moving objects, the identification of their type and the prediction of their trajectory. With this information, collision avoidance systems are able to predict trajectories that will meet in space and time, and consequently change the drone speed and direction in order to avoid it.

In such terms, UAVs operating BVLOS must have the ability to dynamically revise their course and safely change paths, in order to provide conflict-free trajectories through a DAA capability (Krishnan and Manimala, 2020).

Requirements for BVLOS Operations: Recent developments in aviation technology are driving new business opportunities for UAS, particularly in BVLOS operations. As the future integration of drones is expected to rely on high levels of automation and connectivity, the establishment of specific requirements and procedures to ensure safety in the air, as well as on the ground, is critical. In order to offer safe and efficient BVLOS missions, several requirements need to be addressed to ensure the maximum safety for BVLOS operations. It is important to improve the UAS communications technology, in order to support remote command and control, navigation, surveillance, and situation awareness. This will also allow the integration with Air Traffic Management (ATM) systems that will remotely pilot UAVs, and will open the road for autonomous or semi-autonomous flights (Balachandran et al., 2017).

Aviation safety and privacy requirements should also be considered. UAVs should operate with minimum risk to other airspace users, and people on the ground, especially in the highly cluttered airspace of urban areas. Moreover, privacy in terms of data protection of both the operators and their customers should be sustained. Environmental protection is another critical issue in UAS operations (Undertaking, 2018). The impact of drone traffic on the environment, such as emissions, noise, visual pollution and air quality can affect the health and quality of life of citizens and therefore the aviation sector should respond to the major environmental challenges ahead with innovative, smart and environmentally sustainable solutions and technologies.

4 BVLOS TECHNOLOGY ADVANCES AND ENABLERS

As drones are increasingly considered for a number of applications in diverse areas, it is generally expected that their ubiquity will significantly expand within the next few years. The use of UAVs can bring significant economic savings and environmental benefits, while it can reduce the risk to human life. Recent advances in drone technologies, as well as the existence of a clear regulatory framework can set the ground for a greater adoption of unmanned technology in a wide range of applications. Several key areas have been identified as facilitators of future growth and development for drones(Nouacer et al., 2020), and are analyzed in the following.

Flight Control: The design of reliable and high-performance flight control systems can be a difficult challenge for many reasons, such as unpredictable dynamics (e.g. air flows or rain) that may affect the flight of small UAVs, or the presence of static and moving obstacles in cluttered urban environments that can pose severe limitations to aircraft navigation, etc. (Santoso et al., 2017).

An aircraft autopilot system allows the aircraft control without direct human interaction, reducing operation errors and the work load of human pilots. Such systems handle most of the time-intensive non–decision-making tasks, helping the human pilots to focus on the overall status of the aircraft and flight (Jia et al., 2018). There exist two levels of autonomy for flight-control systems (Aber et al., 2019):

- Autonomous or fully automated mode: In this mode, the aircraft follows a flight-line that has been predefined by the user with flight-planning software. It makes its own decisions during the mission and reacts to unforeseen events without the pilot's intervention.
- Assisted or semi-automated mode: In this case, human intervention is reduced to a minimum (speed and direction control) allowing the pilot to perform complex decision processes and better concentrate on high added-value tasks, such as safety of the flight.

Recent advances in autopilot systems focus on more intelligent approaches of adaptive control technologies that can sustain a higher degree of autonomy during flight and therefore deal with various environmental uncertainties as well as on-board limitations (Santoso et al., 2017). Moreover, demands for sophisticated decision making and cognitive capabilities in current aviation require computationally efficient and robust approaches. To this end current research trends have explored the implementation of fuzzy logic based control techniques (Xie et al., 2019), artificial neural networks (Boutemedjet et al., 2019), genetic algorithms (Mousavi et al., 2019) or swarm intelligence (Dasdemir et al., 2020).

Command and Control: Ensuring a reliable Command and Control (C2) link is essential for safe BVLOS drone operations. The purpose of this two-way link is to provide a secure and reliable communication between the remote pilot ground station and the aircraft, which will allow to manage a secure and effective flight. On one hand, in the uplink, i.e. from a drone to base station (BS), the control link is used to update the Unmanned Aircraft System Traffic Management (UTM) or flight control unit with the drone location, and provide information necessary for the control function decision making. On the other hand, the downlink (i.e. communications towards the drone) allows the control function to change the drone direction and speed accordingly, in order to avoid obstacles or send commands to various on-board sensors(Nguyen et al., 2017). Existing cellular networks (e.g. LTE systems) are a natural candidate to provide C2 link for drone operations. However, several limitations may occur due to the growing bandwidth requirements or interference at high altitude (Nguyen et al., 2017). Moreover, different channel conditions and frequencies of BVLOS operations, with different latency and range, increase the challenges for a reliable communication(Hosseini et al., 2019).

To meet these challenges, other technologies that offer new capabilities are explored. For example, the millimeter wave bands that are deployed in 5G cellular networks offer larger bandwidths that allow faster payload communications. The use of satellite connections may also efficiently complement and extend the coverage and reliability for BVLOS links. However, the choice of satellite orbit, i.e., low-earth orbiting (LEO) or geosynchronous earth orbiting (GEO) may be critical (Kodheli et al., 2017) in this task.

Scene Perception with Limited Resources: Future drone technology is currently undergoing groundbreaking progressive improvement. Scene perception is becoming one of the most critical tasks for safe and accurate drone navigation operations. Apart from the detection of individual objects that may interfere as obstacles to the vehicle root, perception also refers to the understanding of their relative locations, and their tracking in order to predict their future behavior. It also includes the detection of environmental conditions (e.g. wind) that may affect the route of any moving object, including the drone itself.

Since UAS missions employ multiple image sensors in the visible or infrared (for nightly operations) spectrum, the main requirement is the smart fusion of multiple sensors (Carrio et al., 2020) in an resource efficient manner that allows very fast detection of moving objects and their distance from the moving drone as well as the separation from the background.

The fusion of multiple sensors and the processing of RGB and stereoscopic images with deep neural network (NN) architectures has been proven beneficial for scene perception tasks with several applications. For this reason, deep NNs are becoming the main solutions for such tasks and field-programmable gate array (FPGA) implementations are used to facilitate real-time object detection tasks on mobile devices (Xu et al., 2018). The increased processing capabilities of such edge devices allow to design and implement distributed processing scenarios, that combine heavy centralised trained deep learning models with lighter or compressed versions on the edge for inference (Chmaj and Selvaraj, 2015). Transfer learning techniques are recently employed to leverage training on the edge (Anwar and Raychowdhury, 2020).

Collective Security and Safety of Drone Operations: Guaranteeing the safe and secure navigation of individual drones, under the current constraints of computational power and storage, may become a really hard task. A solution to the increased processing requirements that real-time scene and environment perception sets for individual drones, can be the collective intelligence of drone fleets (Akram et al., 2017). Drones that exchange information about the scene on air can significantly reduce the overall processing load and lead to safer navigation plans.

In addition to the above, lightweight (cryptographic) protocol designs will provide security solutions for resource and energy-constrained drones. Future scenarios build on the Internet of Drones (IoD), but still lack of efficient data encryption techniques that can scale to the computational capability of drones (Lin et al., 2018). Under the new conditions, access controls and precise navigation plans of drones are replaced with plans comprising smaller hops towards the destination and real-time navigation adjustments to avoid congestion and collisions.

Sensors: There is an obvious need for a UAV to be aware of its surroundings and aware of other air traffic. The rapid development of sensor technologies combined with advances in the miniaturization of instruments and data systems have opened up new potential in UAVs' sensing capabilities. For instance, the integration of GPS and detection sensors can allow compact and robust navigation solutions to determine attitude and location of vehicle, so it can determine its state in a robust way and use appropriate control techniques for autonomy (García et al., 2020). Apart from navigation, UAVs can perform sophisticated data gathering due to various on-board sensors, such as capturing atmospheric or agricultural data (van der Merwe et al., 2020). One major technological breakthrough over the past years is the field of Artificial Intelligence (AI)-based methods, which leverage adaptive capabilities and enhance perception tasks, such as object detection, classification, and scene segmentation (Bijjahalli et al., 2020).

Efficient Power Storage and Distribution: As UAV operations are characterized by limited on-board resources, energy optimization is important. Several factors can be energy consuming during a flight, for instance transmission and reception of data, execution of software functions resource management or flight time optimization(Wang et al., 2020). Moreover UAVs may consume large amounts of propulsion power in order to accelerate, maintain airborne or perform hovering tasks. Recent developments in rechargeable battery cells, super-capacitors and solar cells aim to offer an extension to the flying time of UAVs by increasing the life cycle of battery. Moreover a lot of effort has been put in order to improve the throughput and energy consumption, by optimizing the trajectory and power allocation of UAV. Recent works have also explored UAVs energy optimization by considering both propulsion energy and wireless communication energy, while ensuring satisfactory communication requirements with the ground stations (Amorosi et al., 2018).

5 DISCUSSION AND CONCLUSIONS

The survey of current technology advances and future enablers for UAS operations reveals that there are many promising research results, which can support BVLOS missions and help to align with the regulatory frameworks for flight and operational safety.

Modern UAS autopilot systems use intelligent approaches that adapt to the environmental conditions and to the fused input of sensors, thus adding to their autonomy during the flight and allowing them to cover longer distances without the need of ground control or VLOS supervision. Similar to autonomous vehicles, which ask for human intervention only when the conditions do not allow for a clear decision, autonomous UAS are developed to operate without or with limited human intervention. This limits the need for air-to-ground communication and consequently minimizes the power and the bandwidth consumed for communication and remote control. Even when a connection with a ground station is required, the new 5G cellular networks promise speed improvement and right trade-offs between speed, latency, and cost.

Furthermore, as UAS operations are characterized by limited on-board energy, due to the vehicles' size and weight constraints, energy optimization is crucial for the performance and execution of UAS missions. Recently, FPGAs are gaining the race over GPUs in clearly defined machine vision tasks, since hardware is much faster than software. They lack the flexibility of GPUs and need more time to reprogram or fine tune, but have significantly lower energy consumption, and can be used to accelerate smaller computer vision tasks, such as obstacle detection.

One of the most important risks for the wide adoption of drones is related to their safe and secure operation. Following the advances of the automotive industry, it is critical to define similar industry-wide frameworks for safety, that guarantee the conformity of UAVs and UAS to the standards, and certifications of the underlying regulatory framework. In order to efficiently address this challenge, it is of crucial importance to create adequate real-world tests and/or laboratory simulations for BVLOS operations enabled by the aforementioned technologies that they represent, being able to support a wide range of civilian and military scenarios. Following methodologies for human-machine corroboration, such as the corroborative *V&V* (verification and validation) workflow presented in (Webster et al., 2020) it would be possible to pass from formal verification scenarios, to simulation-based testing and then to real experiments. The knowledge resulting from such scenarios will support decision-making and development of technology road-maps based on robust future technology assessment. Furthermore, this knowledge will lower the barriers for end users to adopt the BVLOS drone technologies, and obtain new and unforeseen services at more manageable costs and effort.

Although UAS in general are a major technological breakthrough, there are still several factors that impede their adoption. The greatest challenge to the widespread integration of UAS by the society is public acceptance, since such operations raise novel and valid concerns in terms of safety and privacy[1]. Public acceptance is also subject to various concerns over the safety of UAV flights over civilian air space, the environmental disruption and the privacy of sensitive information.

This article surveyed the main BVLOS drone op-

[1]https://core.ac.uk/download/pdf/189596994.pdf

eration challenges an the requirements emerging from them, with an emphasis on the technology aspects. The article also surveyed the main technology advances that will play a critical role in the expansion of BVLOS drone operations in the near future.

Despite all the technology advances regarding the UAS operations, some open issues still need to be investigated, such as positioning, situation awareness, risk detection and avoidance, flight investigation, and energy consumption minimization. Apart from the technology challenges and solutions there are also several societal and regulatory challenges that must be met. A concrete regulatory framework for BVLOS operations must be formally defined, verified and validated, bringing trustful human-machine collaboration in the front. On this basis, one of the most important issues that could be addressed in the future, regarding the BVLOS UAS provided services, is to establish appropriate privacy and security mechanisms.

An in depth study of the legal, regulatory and safety frameworks is among the next plans of our work. Theoretical methodologies that have been used for the formalisation of autonomous agents and frameworks that have been tested in the automotive industry will be examined in order to carefully define a trustworthy process for designing and delivering BVLOS operations.

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REFERENCES

Aber, J. S., Marzolff, I., Ries, J., and Aber, S. E. W. (2019). *Small-format aerial photography and UAS imagery: Principles, techniques and geoscience applications*. Academic Press.

Akram, R. N., Markantonakis, K., Mayes, K., Habachi, O., Sauveron, D., Steyven, A., and Chaumette, S. (2017). Security, privacy and safety evaluation of dynamic and static fleets of drones. In *36th Digital Avionics Systems Conference (DASC)*, pages 1–12. IEEE.

Amorosi, L., Chiaraviglio, L., d'Andreagiovanni, F., and Blefari-Melazzi, N. (2018). Energy-efficient mission planning of uavs for 5g coverage in rural zones. In *2018 IEEE Int. Conf. on Environmental Engineering (EE)*, pages 1–9. IEEE.

Anwar, A. and Raychowdhury, A. (2020). Autonomous navigation via deep reinforcement learning for resource constraint edge nodes using transfer learning. *IEEE Access*, 8:26549–26560.

Balachandran, S., Munoz, C., and Consiglio, M. C. (2017). Implicitly coordinated detect and avoid capability for safe autonomous operation of small uas. In *17th AIAA Aviation Technology, Integration, and Operations Conference*, page 4484.

Bassi, E. (2019). European drones regulation: Today's legal challenges. In *2019 Int. Conf. on Unmanned Aircraft Systems (ICUAS)*, pages 443–450. IEEE.

Bijjahalli, S., Sabatini, R., and Gardi, A. (2020). Advances in intelligent and autonomous navigation systems for small UAS. *Progress in Aerospace Sciences*, 115:100617.

Bloise, N., Primatesta, S., Antonini, R., Fici, G. P., Gaspardone, M., Guglieri, G., and Rizzo, A. (2019). A survey of unmanned aircraft system technologies to enable safe operations in urban areas. In *ICUAS 2019*, pages 433–442. IEEE.

Boutemedjet, A., Samardžić, M., Rebhi, L., Rajić, Z., and Mouada, T. (2019). Uav aerodynamic design involving genetic algorithm and artificial neural network for wing preliminary computation. *Aerospace Science and Technology*, 84:464–483.

Carrio, A., Tordesillas, J., Vemprala, S., Saripalli, S., Campoy, P., and How, J. P. (2020). Onboard detection and localization of drones using depth maps. *IEEE Access*, 8:30480–30490.

Chmaj, G. and Selvaraj, H. (2015). Distributed processing applications for uav/drones: a survey. In *Progress in Systems Engineering*, pages 449–454. Springer.

Dasdemir, E., Köksalan, M., and Öztürk, D. T. (2020). A flexible reference point-based multi-objective evolutionary algorithm: An application to the uav route planning problem. *Computers & Operations Research*, 114:104811.

Davies, L., Bolam, R. C., Vagapov, Y., and Anuchin, A. (2018). Review of unmanned aircraft system technologies to enable beyond visual line of sight (bvlos) operations. In *2018 Int. Conf. on Electrical Power Drive Systems (ICEPDS)*, pages 1–6. IEEE.

Fang, S. X., O'Young, S., and Rolland, L. (2018). Development of small uas beyond-visual-line-of-sight (BVLOS) flight operations: System requirements and procedures. *Drones*, 2(2):13.

García, J., Molina, J. M., and Trincado, J. (2020). Real evaluation for designing sensor fusion in UAV platforms. *Information Fusion*, 63:136–152.

González-Sieira, A., Cores, D., Mucientes, M., and Bugarín, A. (2020). Autonomous navigation for uavs managing motion and sensing uncertainty. *Robotics and Autonomous Systems*, 126:103455.

Hassanalian, M. and Abdelkefi, A. (2017). Classifications, applications, and design challenges of drones: A review. *Progress in Aerospace Sciences*, 91:99–131.

Hosseini, N., Jamal, H., Haque, J., Magesacher, T., and Matolak, D. W. (2019). Uav command and control, navigation and surveillance: A review of potential 5g and satellite systems. In *2019 IEEE Aerospace Conference*, pages 1–10. IEEE.

Iacono, M. and Sgorbissa, A. (2018). Path following and obstacle avoidance for an autonomous uav using a depth camera. *Robotics and Autonomous Systems*, 106:38–46.

Jia, Y., Guo, L., and Wang, X. (2018). Real-time control systems. In *Transportation Cyber-Physical Systems*, pages 81–113. Elsevier.

Kato, N., Kawamoto, Y., Aneha, A., Yaguchi, Y., Miura, R., Nakamura, H., Kobayashi, M., Henmi, T., Akimoto, O., Kamisawa, Y., et al. (2019). Location awareness system for drones flying beyond visual line of sight exploiting the 400 mhz frequency band. *IEEE Wireless Communications*, 26(6):149–155.

Kodheli, O., Guidotti, A., and Vanelli-Coralli, A. (2017). Integration of satellites in 5g through leo constellations. In *GLOBECOM 2017-2017 IEEE Global Communications Conference*, pages 1–6. IEEE.

Kovalev, I., Voroshilova, A., and Karaseva, M. (2019). Analysis of the current situation and development trend of the international cargo uavs market. In *Journal of Physics: Conference Series*, volume 1399, page 055095. IOP Publishing.

Krishnan, P. and Manimala, K. (2020). Implementation of optimized dynamic trajectory modification algorithm to avoid obstacles for secure navigation of UAV. *Applied Soft Computing*, 90:106168.

Kyrkou, C., Timotheou, S., Kolios, P., Theocharides, T., and Panayiotou, C. (2019). Drones: augmenting our quality of life. *IEEE Potentials*, 38(1):30–36.

Lin, C., He, D., Kumar, N., Choo, K.-K. R., Vinel, A., and Huang, X. (2018). Security and privacy for the internet of drones: Challenges and solutions. *IEEE Communications Magazine*, 56(1):64–69.

Macias, M., Barrado, C., Pastor, E., and Royo, P. (2019). The future of drones and their public acceptance. In *2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)*, pages 1–8. IEEE.

Merkert, R. and Bushell, J. (2020). Managing the drone revolution: A systematic literature review into the current use of airborne drones and future strategic directions for their effective control. *Journal of Air Transport Management*, 89:101929.

Mohamed, N., Al-Jaroodi, J., Jawhar, I., Idries, A., and Mohammed, F. (2020). Unmanned aerial vehicles applications in future smart cities. *Technological Forecasting and Social Change*, 153:119293.

Mousavi, S., Afghah, F., Ashdown, J. D., and Turck, K. (2019). Use of a quantum genetic algorithm for coalition formation in large-scale uav networks. *Ad Hoc Networks*, 87:26–36.

Nguyen, H. C., Amorim, R., Wigard, J., Kovacs, I. Z., and Mogensen, P. (2017). Using lte networks for UAV command and control link: A rural-area coverage analysis. In *2017 IEEE 86th Vehicular Technology Conference (VTC-Fall)*, pages 1–6. IEEE.

Nouacer, R., Hussein, M., Espinoza, H., Ouhammou, Y., Ladeira, M., and Castiñeira, R. (2020). Towards a framework of key technologies for drones. *Microprocessors and Microsystems*, page 103142.

Otto, A., Agatz, N., Campbell, J., Golden, B., and Pesch, E. (2018). Optimization approaches for civil applications of unmanned aerial vehicles (uavs) or aerial drones: A survey. *Networks*, 72(4):411–458.

Outay, F., Mengash, H. A., and Adnan, M. (2020). Applications of unmanned aerial vehicle (uav) in road safety, traffic and highway infrastructure management: Recent advances and challenges. *Transportation research part A: policy and practice*, 141:116–129.

Rakha, T. and Gorodetsky, A. (2018). Review of unmanned aerial system (UAS) applications in the built environment: Towards automated building inspection procedures using drones. *Automation in Construction*, 93:252–264.

Santoso, F., Garratt, M. A., and Anavatti, S. G. (2017). State-of-the-art intelligent flight control systems in unmanned aerial vehicles. *IEEE Transactions on Automation Science and Engineering*, 15(2):613–627.

Sebbane, Y. B. (2018). *Intelligent autonomy of UAVs: advanced missions and future use*. CRC Press.

Undertaking, S. J. (2018). European atm master plan: Roadmap for the safe integration of drones into all classes of airspace. *SESAR Joint Undertaking: Brussels, Belgium*.

van der Merwe, D., Burchfield, D. R., Witt, T. D., Price, K. P., Sharda, A., Mącik, M., Gryta, A., Frąc, M., Dwivedi, S. L., Goldman, I., et al. (2020). Drones in agriculture. *Advances in Agronomy*, 160:1.

Wang, C., Wang, J., Shen, Y., and Zhang, X. (2019). Autonomous navigation of uavs in large-scale complex environments: A deep reinforcement learning approach. *IEEE Transactions on Vehicular Technology*, 68(3):2124–2136.

Wang, J., Jiang, C., Han, Z., Ren, Y., Maunder, R. G., and Hanzo, L. (2017). Taking drones to the next level: Cooperative distributed unmanned-aerial-vehicular networks for small and mini drones. *Ieee vehIcular technology magazIne*, 12(3):73–82.

Wang, X., Hu, J., and Lin, H. (2020). An intelligent uav based data aggregation strategy for iot after disaster scenarios. In *Proceedings of the 2nd ACM MobiCom Workshop on Drone Assisted Wireless Communications for 5G and Beyond*, pages 97–101.

Webster, M., Western, D., Araiza-Illan, D., Dixon, C., Eder, K., Fisher, M., and Pipe, A. G. (2020). A corroborative approach to verification and validation of human–robot teams. *The International Journal of Robotics Research*, 39(1):73–99.

Xie, Y., Savvaris, A., and Tsourdos, A. (2019). Fuzzy logic based equivalent consumption optimization of a hybrid electric propulsion system for unmanned aerial vehicles. *Aerospace Science and Technology*, 85:13–23.

Xu, X., Wang, T., Lu, Q., and Shi, Y. (2018). Resource constrained cellular neural networks for real-time obstacle detection using FPGAs. In *2018 19th International Symposium on Quality Electronic Design (ISQED)*, pages 437–440. IEEE.