AERIAL: A Meta Review and Discussion of Challenges Toward Unmanned Aerial Vehicle Operations in Logistics, Mobility, and Monitoring

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***Abstract*— There exists a tremendous number of research surveys on various aspects of UAV logistics, mobility and monitoring tasks in the literature. These surveys have been published in distinct venues, often having a significant overlap in goals and key findings. In this study, we provide a meta review across nearly 100 extant UAV surveys and overview papers, extract their key messages, and investigate the extent of being complementary. We develop the AERIAL framework, which aggregates the major challenges on the way to a successful application of UAVs for logistics, mobility, and monitoring. We believe that AERIAL framework and meta review contribute towards a clearer understanding of the scientific UAV landscape challenges and the identification of potential directions for future research studies.**

***Index Terms*— Unmanned air mobility, UAV, meta review.**

I. Introduction

INCREASES in urban traffic demand have resulted in heavy congestion, air pollution, and service cuts around the world [1]. One of the major hopes for solving these societal traffic problems are unmanned aerial vehicles (UAVs), also known as drones, which promise to open the third dimension (i.e., altitude), possibly in support of ground vehicles [2], [3], [4], [5], [6]. It is expected that UAVs will lead to a cost-effective, scalable, and flexible transportation system. The successful application of UAVs, however, comes with various barriers and challenges, such as limited battery capacities, technology acceptance, equipment precision limitations, as well as uncertainties inherent to envisioned operating environments (e.g., weather, geography, objects of interest, and malicious attacks) and social environments (e.g., laws, industry standards and public attitudes). For instance, truck-drone last-mile delivery ideas still face major technical issues concerning charging scheduling [7], [8], battery swaps [9], solutions to scalable routing problems [10], [11], [12] and public acceptance [13]. Accordingly, the application of UAVs for solving societal transportation problems has received tremendous attention in the scientific literature, including, logistics [14], [15], [16], passenger transportation [1], [17], monitoring [18], [19], and communication [20], [21]. Figure 1 visualizes the number of recently published papers on UAVs topics per year, having appeared in the last decade.[1] While the results are an approximation of the real number of papers, we can see an tremendous growth in the extant scientific literature, which in turns leads to tremendous difficulties to maintain an overview on the state-of-the-art regarding UAVs in the context of intelligent transportation systems. We conjecture that the data point for 2021 is actually higher than what would be expected from a linear trend increase. One potential explanation is that more papers have been published during some phases of the COVID-19 pandemic; with researchers bounds to stay at home and having time to finish open research studies. The year 2022 then fits more into the earlier linear trend again.

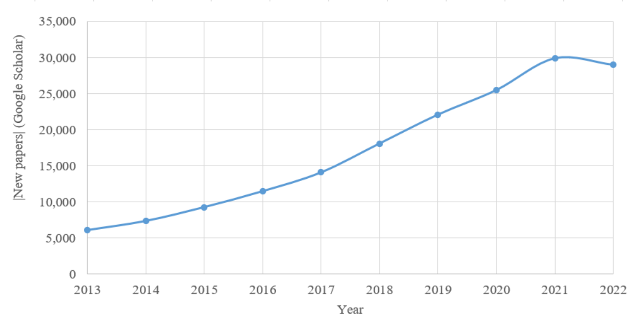

Fig. 1. Number of papers published per year containing the search term *unmanned aerial vehicle*.

Given the vast number of research papers on UAV applications, one can observe an increasing number of research summaries and overview papers, which aim to describe the state-of-the-art and key challenges. Since UAV applications often cover multiple disciplines, attracting attention of scholars and practitioners worldwide, these surveys have appeared in different scientific venues, covering journals, conferences, and other platforms in distinct academic disciplines. Accordingly, the original literature problem has transformed from the paper-level to the survey level, where it is difficult to follow even the broad evolution of research subjects as well as

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[1]The data was obtained by using the search interface from Google Scholar. Example query for the year 2019: https://scholar.google.com/scholar?q=unmanned+aerial+vehicle&hl=de&as_sdt=0%2C5&as_ylo=2019&as_yhi=2019, searching for the term *unmanned aerial vehicle* and restricting the year starting date of publication and ending date of publication between 2013 and 2022, respectively.

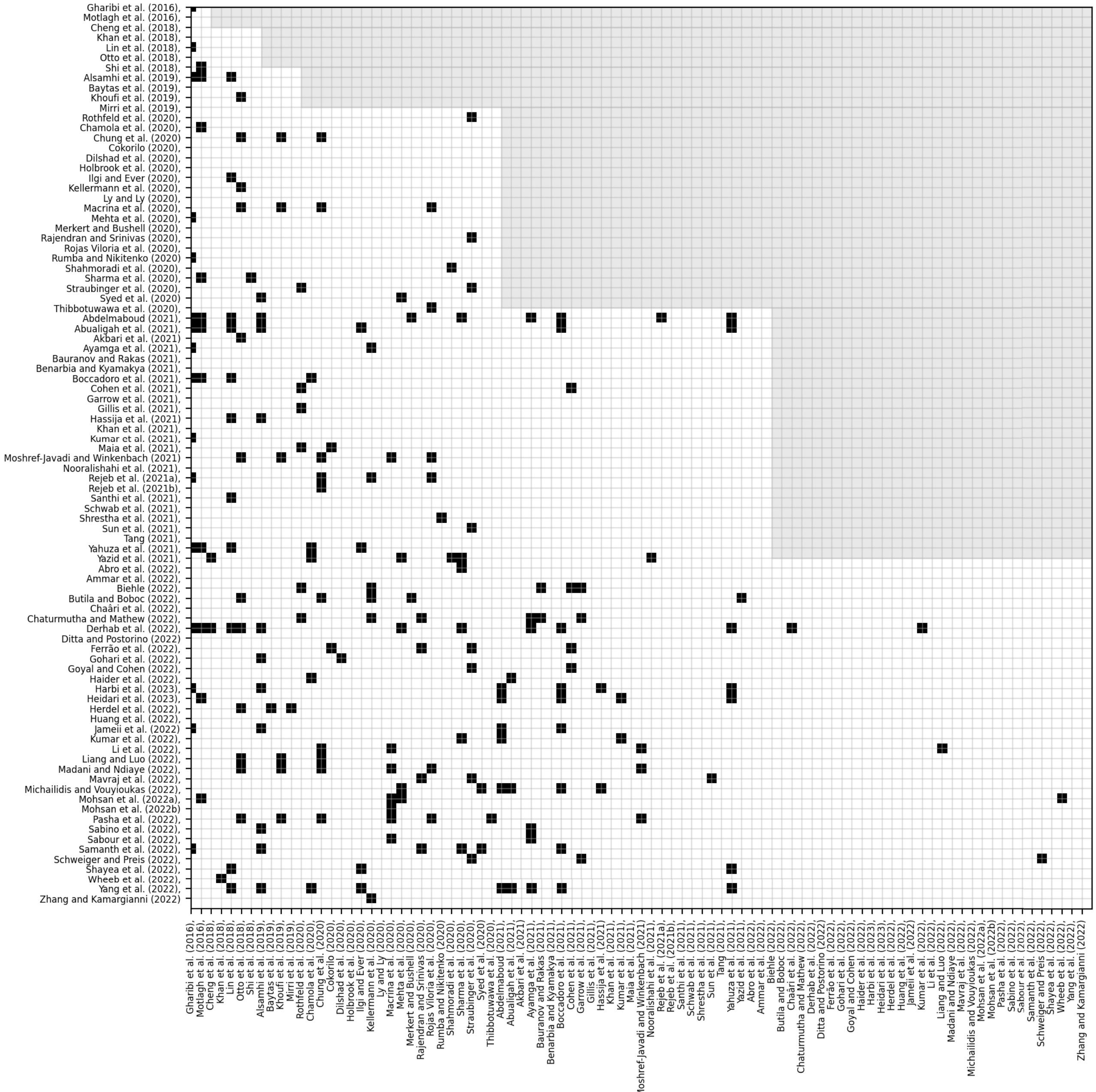

Fig. 2. Matrix visualizing whether one survey (y-axis) cited another survey (x-axis). The grey area highlights survey pairs which cannot cite each other, based on the order of appearance.

the dissemination of novel ideas / trends. Our study aims to address this concern by providing a comprehensive meta review on UAV surveys which have been published between years 2016 and 2022.[2] Overall, we have identified a collection of nearly 100 survey papers on this subject.

To investigate the extent of scientific attribution between the selected survey papers, we visualize a cross-citation matrix in Figure 2. The survey papers are aligned along the two axes, sorted by year, respectively. Each cell in the matrix shows whether one survey (y-axis) cited another survey (x-axis), using black squares inside the grid cell. The data has been obtained by collecting all references in each survey and matching it with the other survey titles and authors. Upon a match, the cell is highlighted in black color. For instance, Alsamhi et al. cites Gharibi et al., but Yang et al. does not cite Gharibi et al. To perfrom a fair evaluation, the grey area indicates impossible citations: Cells in this area cover paper pairs where the potentially citing paper has appeared before the potentially cited paper. The overall matrix, i.e., the non-gray part, is surprisingly sparse, suggesting a relatively weak cross-recognition among survey papers covered in our study. Such a phenomenon is challenging for the scientific process, given that surveys are meant to provide a broad overview of a domain under recognition of the state of the art in the literature. With the present divergent cross-citation among surveys, it can be expected that the research landscape around

[2]Survey papers have been selected by searching keywords (e.g., *unmanned aerial vehicles*, *unmanned air mobility*, *unmanned aircraft systems*, *drones*, *review* and *survey*) on Google scholar. All candidate papers have been post-processed, selecting papers having a focus on review and overview aspects.

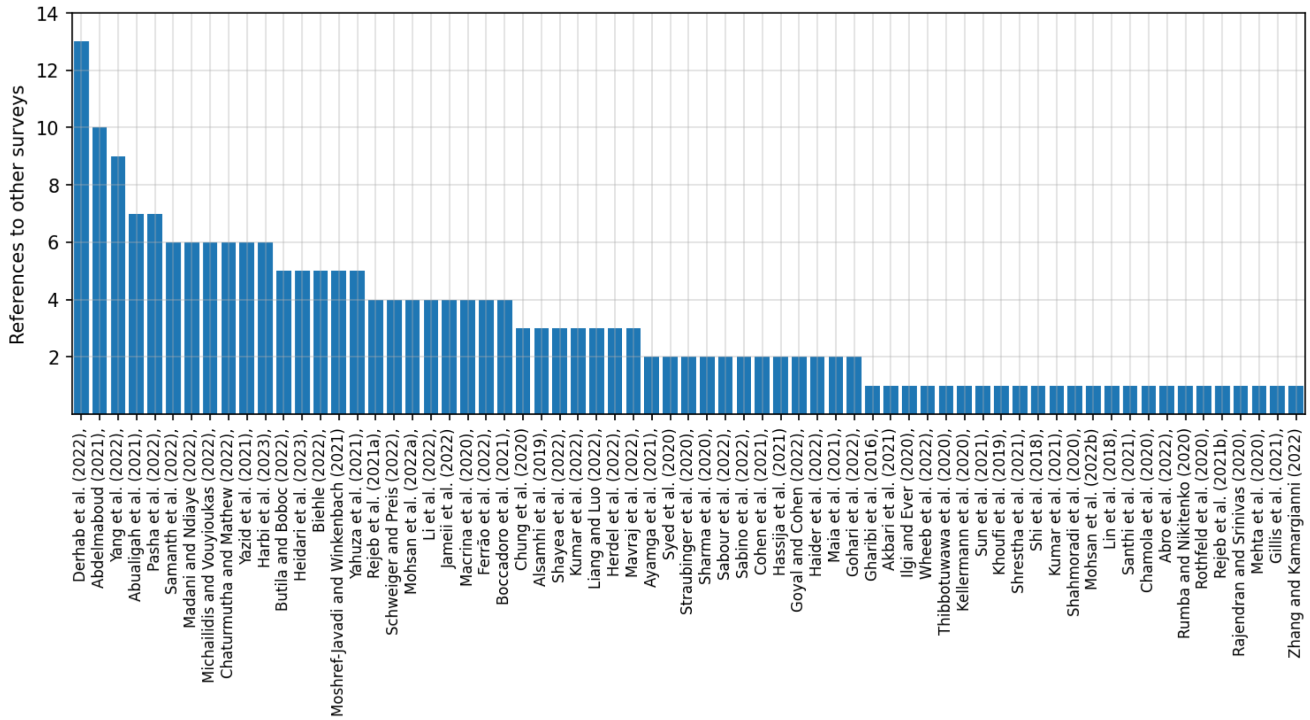

Fig. 3. The number of other survey papers cited by each survey. Nearly 30 surveys do not refer to any other survey (data for these papers is not reported in the figure).

UAV will scatter further in the future. The research community needs to be aware of this problem and identify appropriate mitigation measures. Figure 3 presents the ranking of survey papers based on the number of references to other surveys in our study. We can see that [22] is ranked top for citing 13 other survey papers. While the top-10 ranked surveys do cite ten or more other surveys, the vast majority of surveys seem to not sufficiently locate their placement in the related literature.

Our meta review provides a classification of all survey papers covering six major categories. In this study, we use a technique called t-distributed stochastic neighbor embedding (t-SNE), given its strength to visually present a set of objects originating from a high-dimensional space, by mapping of objects into a two-dimensional space; see [23] for the development of a stochastic neighbor embedding and [24] for a t-distributed variant with the goal of visualization. It is beyond the scope and focus of our study to completely resemble the mechanics underlying t-SNE. In a nutshell, the t-SNE algorithm consists of two individual components. During a first step, a pair-wise probability distribution is created such that highly-similar objects have higher probabilities. In the second step, Kullback-Leibler divergence between the original and a lower-dimension probability distribution is minimized, concerning the locations of elements in a two-dimensional space. The outcome of a t-SNE is a set of objects with two dimensional coordinates. We have chosen to represent each survey paper as an individual vector, whose components correspond to words appearing in the paper. Specifically, we have transformed a collection of papers to a matrix of term frequency-inverse document frequency features, which can be considered a statistical measure intended to identify how important a word is to a specific paper. Based on a two-dimensional representation of the embedding, we have extracted the following six categories: Logistics, Mobility, Monitoring, Path planning, Coordination, and others. Based on the surveys and their key insights, we derive the so-called AERIAL framework of challenges inherent to a successful implementation of UAV services for logistics, mobility, and monitoring. These AERIAL challenges subsume the following six aspects: 1) **A**cceptance and heterogeneities, 2) **E**conomy and demand, 3) **R**eliability and risks, 4) **I**nfrastructure and optimization, 5) **A**utomation and control, and 6) **L**iability. Within our AERIAL framework, we discuss the relationship to the six survey categories, the key challenges, and potential directions for future work. Overall, we believe that our study contributes to the complex status of the UAV-related literature, by guiding researchers from our meta-surveys to specific surveys in distinct venues and from there towards specific research papers.

The remainder of this paper is organized as follows. In Section II, we provide a structured overview on survey papers concerning logistics / cargo, air taxi / passenger transport, and monitoring. Section III complements our meta review by dissecting surveys on coordination and communication aspects of UAV operations. Section IV introduces the AERIAL framework of challenges and its importance for the three major UAV application areas. Section V provides a list of interesting directions for future research. Section VI concludes this study.

II. Surveys Concerning UAV Application Scenarios

In this section, we review surveys of three major application areas for UAV operations. Section II-A reports on survey papers with a strong focus on logistic and cargo / freight applications. Section II-B discusses the extant literature reviews on passenger applications, e.g., urban air taxis. Section II-C

TABLE I
EXTANT SURVEYS ON UAV APPLICATIONS IN LOGISTICS / CARGO

Survey	Time frame	Content type	Scale / Subject	Focus
[34]	2019	Theoretical	M + single truck	Pickup and delivery with hybrid vehicles
[42]	2012-2020	Analytical	M	Agricultural, medical and military drones
[25]	2015-2021	Theoretical	M + multiple trucks	Design / modeling of drone-based delivery
[26]	2011-2020	Theoretical	S / M + SMT	Drone and truck-drone operations
[43]	2016-2019	Theoretical	M	Emerging technologies in drone delivery
[39]	2013-2019	Analytical	M	Socio-technical debate on parcel delivery
[44]	2014-2017	Empirical	M	Opportunities for drones in smart cities
[35]	2014-2019	Theoretical	S / M + SMT	TSP and vehicle routing problems for UAVs
[27]	2021-2022	Theoretical	M + single truck	Models and application scenarios
[36]	2015-2021	Theoretical	S / M + SMT	Drone and truck-drone operations
[28]	2015-2020	Theoretical	S / M + SMT	Drone-aided routing in the last-mile delivery
[37]	2015-2021	Theoretical	S / M + SMT	Drone and truck-drone operations
[29]	2015-2019	Empirical	M	Operational considerations of airborne drones
[30]	2015-2020	Mix	S / M + SMT	Routing problems in drone delivery systems
[31]	2010-2018	Theoretical	S / M	Optimization for drone operations
[32]	2014-2021	Theoretical	S / M + SMT	Drone scheduling problems for cargo delivery
[40]	2008-2020	Analytical	M	Potential applications of humanitarian drones
[41]	2009-2020	Analytical	M	Drones in supply chain and logistics
[33]	2005-2019	Mix	S / M + SMT	UAV routing under external conditions
[38]	2005-2016	Theoretical	S / M + SMT	Categorization of UAV routing problems

M = Multiple drones, S = Single drone, SMT = Single / Multiple Trucks.

reports on the existing surveys regarding monitoring applications. Section II-D summarizes a few other related surveys which do not have a strong focus on either of the three former application areas. Note that the surveys covered in this section have all been published in the year 2016 to 2022; we refer to recent additional papers in our framework section below (Section IV).

A. Logistics / Cargo and Cargo Applications

Traditional logistics are - especially on the last mile - largely based on delivery trucks and smaller scooters. UAV technology is expected to have a groundbreaking impact on logistics: While cheaper and faster logistics are the straightforward benefits, other notable effects include a reduction of costs and the elimination of human resource bottleneck. These potential advantages have led to the publication of various surveys on UAV delivery systems. Table I provides a summary of recent surveys conducted on logistics / cargo delivery. Most of these surveys focus on strategic and operational aspects, see, e.g., [25], [26], [27], [28], [28], [29], [30], [31], [32], and [33]. Another distinct track of surveys is concerned with the development and review of theoretical models and solution techniques about UAV routing optimization, potentially under collaboration with trucks, i.e., the so-called truck-drone routing problem, see, e.g., [25], [26], [27], [28], [30], [32], [33], [34], [35], [36], [37], and [38]. Apart from the focus on optimization, socio-technical considerations and challenges for drone applications are investigated as well [39], [40], [41], [42], [43]. Given our dissection of comprehensive surveys on drone applications in logistics / cargo delivery, we summarize the following directions for future research:

- **Extended models**: Modeling UAV routing problems / truck-drone routing problems requires the consideration of realistic transportation information and constraints, e.g., internal factors (e.g., energy consumption, operation range, and different types of drones) as well as external factors (e.g., environmental conditions, air traffic control and regulations for drone flights). Specifically, energy management of UAV, consisting of energy consumption and recharging strategies, is crucial for effective and safe drone-based delivery. Nonlinear energy consumption rates at different phases should be considered, instead of a constant consumption rate broadly considered in many literatures. Considering the limited battery duration, another important component in drone delivery systems is the recharging station which might be integrated into UAV routing problems.
- **Efficient algorithms**: A variety of exact methods and heuristics have been proposed for solving drone-based delivery models. However, many recent solution approaches focus solely on the effective computation of solutions for small-sized instances. Since the underlying decision / optimization problems are NP-hard, one cannot expect effective exact methods to be working on all input. Nevertheless, if heuristics do not scale up to medium-sized instances either, then there is a limited application in real-world settings. Accordingly, we recommend to devise more efficient methods to solve medium / large-scale UAV routing problems.

B. Air Taxi / Passenger Transport Applications

The second major application area of UAV technology concerns air taxis, as on-demand air service for passengers. Table II lists the characteristics of extant surveys related to air taxi / passenger transportation. The listed surveys mostly discuss the prospects for the implementation of UAV application in passenger transport. Moreover, strategical analysis (e.g., safety and market share) and operational analysis (i.e., the components of air taxi transportation system) are representative subjects across these review papers. The former can

TABLE II

EXTANT SURVEYS ON UAV APPLICATIONS IN AIR TAXI / PASSENGER TRANSPORT

Survey	Time frame	Content type	Scale / Subject	Focus
[45]	2014-2021	Analytical	M	Social sustainability aspects
[46]	2015-2022	Analytical	S /M	Security and safety concerns
[47]	2018-2022	Empirical	M	Legislative frameworks and use cases
[48]	2017-2021	Empirical	M (hybrid)	Ambulance service implementation
[39]	2013-2019	Analytical	M	Socio-technical debate
[44]	2017	Empirical	M	Regulations for drones in smart cities
[49]	2013-2020	Mix	M	Current developments
[50]	2007-2020	Mix	M	On-demand aspects of mobility

M = Multiple drones, S = Single drone.

refer to those by [39], [44], [45], and [46], while [48], [49], [50] make reviews concerning the latter. On a conceptual level, [45] discussed the impacts on the social sustainability of air taxi system in Europe. [46] carried out an extensive literature review of air taxi safety and security. [39] summarized advantages and disadvantages when considering drones for passenger transport. Reference [44] elaborated on the necessity of ambulance drones in the smart cities. By applying a Monte Carlo sensitivity analysis, potential operations and social acceptance are reviewed by [48]. Reference [49] discussed demand prediction, network design, and vehicle configuration in the air taxi system. Reference [50] reviewed previous studies from five aspects: demand estimation, vertiport design / location, operational planning, constraint identification, and competitiveness with other modes.

These air taxi-related survey / overview papers unanimously state that a comprehensive analysis will be necessary to explore the implementation of passenger-centric UAV delivery from both strategic and operational perspectives. Stakeholders and policymakers should consider how air taxi system can be best harnessed to offer an efficient and effective service for potential users. The following research areas could be further investigated:

- **Spatial disparities and particularities**: Various surveys point out limitations in the coverage of air taxi studies and the absence of a clear classification across regions in the world. Therefore, it is recommended to perform comprehensive case studies and meta-reviews, which take into consideration demands, social acceptance and regulatory laws as regional particularities.
- **Operation management**: Future studies need to consider strategic, tactical, and operational decisions when designing air taxi systems; an integration of demand estimation with temporal information, air taxi maintenance scheduling and dynamic routing of air taxis is required, with interactions on the actual design. Such dependencies cannot be neglected.

C. Monitoring Applications

Besides cargo / passenger-related applications, UAV technology is beneficial for collecting and processing information about areas of interest, particularly for the surveillance of hard-to-access regions. Given the multi-disciplinary feature, this application attracts researchers from a variety of fields. Table III summarizes the extant surveys about UAV-based monitoring applications. Some of surveys in Table III discuss generic use cases of drone monitoring, see, e.g., [29], [31], [51], [53], [54], [55], [56], and [57]. Other surveys explore how the UAV-based monitoring system applies in one particular industry. For instance, [51] provided a SWOT analysis of drones in precision agriculture where drones were developed for spatio-temporal crop data collection and livestock management. The applicability of traffic monitoring, in the field of traffic engineering, is another direction for UAVs [44], [52]. Furthermore, [58] proposed a comprehensive review of UAV monitoring in the mining industry, where surface, underground and abandoned mines were involved. Conducting systematic reviews or performance analysis is essential to provide a valuable understanding of UAV monitoring in the academic literature. Based on the surveyed studies related to UAV-based monitoring, future research areas may consider the following issues:

- **Effective, public databases**: The growth of drone projects in general, and surveillance projects in particular, around the world leads to a heterogeneous landscape of vehicles and use cases; future studies could develop and publish more databases to test the existing / improved methods when UAV monitoring is performed in various areas.
- **Expanding the scope of uses**: Additional to the proposed industries where UAV-based monitoring applies, researchers and practitioners should assess the prospects for UAV-based monitoring in wider domains. Cinematography and archeology might be the potential industries for drones. Moreover, the under-explored uses in the applied industries could be extended; e.g., how to develop drones to collect pedestrian movements at intersections is an emerging topic recently, which enables better decisions of automatic vehicles for smart cities. Moreover, UAV-based solutions for disaster relief are also very promising research directions.

D. Urban Air Mobility

In this study, we use the term UAM to cover all potential applications of UAVs in an urban agglomeration, including passenger transport, cargo delivery and emergency services in the metropolitan areas. UAM is generally seen as a networked system, consisting of: UAM ground infrastructure, automated MRO (Maintenance, Repair and Overhaul), energy management systems and spatial integration [65]. Table IV

TABLE III
EXTANT SURVEYS ON UAV APPLICATIONS IN MONITORING

Survey	Time frame	Content type	Scale / Subject	Focus
[51]	2005-2020	Empirical	M	Databases from drone videos and images
[42]	2014-2020	Analytical	M	SWOT analysis about agricultural drones
[52]	2014-2021	Empirical	S / M	Urban traffic monitoring and analysis
[53]	2014-2020	Empirical	M	Applications in video surveillance via drones
[54]	2014-2021	Analytical	M	Surveillance drones in smart cities
[44]	2013-2017	Empirical	M	Traffic monitoring using drones
[29]	2015-2019	Empirical	M	Use cases discussion of airborne drones
[55]	2013-2021	Mix	M	UAV application areas
[56]	2008-2021	Empirical	M	UAV-based non-destructive inspection
[31]	2001-2017	Empirical	S / M	Drone operations for data collection
[57]	2005-2019	Mix	M	Applications and classifications of UAVs
[58]	2013-2020	Empirical	M	Drone technology in the mining industry

M = Multiple drones, S = Single drone.

TABLE IV
EXTANT SURVEYS ON URBAN AIR MOBILITY SYSTEMS

Survey	Time frame	Content type	Scale / Subject	Focus
[59]	2002-2021	Mix	M + airspace	Airspace design for UAM
[60]	2014-2021	Empirical	UAM history	Challenges of UAM
[61]	2008-2019	Analytical	4.0 aviation industry	Safety challenges of UAM
[62]	2013-2021	Theoretical	M + UAM integrated	Challenges of UAM systems
[63]	2015-2020	Mix	M + UAM, EV / AV	Meta-analysis of UAM
[64]	2005-2020	Empirical	UAM meta-system	Operational scenarios of UAM
[65]	2010-2021	Empirical	M + ground	Infrastructure for UAM
[66]	2012-2019	Theoretical	M + UAM system	Demand and supply of UAM
[67]	2001-2018	Analytical	M + architecture	UAV traffic management
[68]	2011-2021	Empirical	M + airspace	Urban air traffic management
[69]	2015-2020	Mix	M + urban transport	Developments in UAM

AV = Autonomous ground Vehicles, EV = Electric ground vehicles, M = Multiple drones, S = Single drone.

shows the recent surveys about UAM. Many of these surveys provide a broad overview and discuss challenges, e.g., [60], [61], [62], [63], [64], [66], and [69]. In addition to research on the entire UAM system, there exist surveys on individual components, such as airspace design [59], network design of infrastructure [65], and traffic management [67], [68]. Given the complexity of individual aspects, it seems like there is still a long way to go towards the implementation a full-scale UAM.

III. SURVEYS CONCERNING UAV COORDINATION, CONTROL, AND OTHER SUBJECTS

In this section, we review other surveys which have a more operational focus, e.g., concerning coordination and control tasks, possibly independent of the actual application domain. Section III-A reviews existing surveys on path planning algorithms with UAV applications. Section III-B discusses the extant literature reviews on UAV coordination and communication. Section III-C summarizes other reviews which do not fit any earlier categories.

A. Path Planning

Compared to ground transportation, UAV path planning has an even stricter set of prerequisites and constraints, including safety, environmental adaptability, and maneuverability. Several surveys have reviewed extant work on UAV path planning, as reported in Table V. The vast majority of surveys focuses on solution techniques for improving the precision of path planning using techniques from different domains. For example, [25] summarized new methods based on artificial intelligence and computer vision applied to UAV path planning problems. Reference [70] investigated and compared the state-of-the-art algorithms about trajectory planning and control schemes. As a technical challenge for drone-based delivery systems, [57] reviewed papers about UAV path planning, concluding that the stability and efficiency of UAV operation necessitate algorithms with obstacle avoidance as well as improved trajectory control. In [71], representative, coordination, and non-coordination methods were proposed to design cost-effective and energy-efficient paths for drone delivery. Some surveys conclude that shortcomings of technical support could not guarantee the service level, limiting drone applications. To fill these gaps, future research directions should consist of the following aspects:

- **Reducing computational complexities**: As UAV path planning problems are mostly NP-hard, the underlying computational complexity makes this problem intrinsically difficult. Some surveys suggest adapting offline methods for predetermining the shortest paths. This strategy acts as a preprocessing step in a filter-and-prune framework, having the advantage to reduce the computational requirements.
- **Communication and coordination**: The path planning problem is already challenging in a single drone

TABLE V
EXTANT SURVEYS ON UAV PATH PLANNING

Survey	Time frame	Content type	Scale / Subject	Focus
[25]	2019-2021	Theoretical	S	Implementation feasibility of drone delivery
[70]	2016-2020	Mix	S / M	Path planning and obstacle avoidance
[57]	2015-2020	Mix	M	Applications and classifications of UAVs
[71]	2005-2020	Theoretical	M	Path planning techniques in UAVs

M = Multiple drones, S = Single drone.

setting. In real multi-UAV systems, however, the situation becomes even more complex. Accordingly, the requirements (e.g., MAC protocols in the flying ad hoc networks, wireless protocols and security) raise tremendous communication challenges. Finally, how to communicate and integrate with base stations and satellites is also one timely research area.

B. Coordination, Communication, and Security

Controlling a system with multiple UAVs, possibly hundreds or more, is very challenging. See Table VI for surveys on related topics. The increasing scales of UAV-related networks raise more requirements on coordination [74], [75], [76], [78], [81], [82], [83], [92], [96], communication [20], [21], [77], [95], [99] and security [80], [84], [85], [88], [89], [91], [94], [97], [98], [101]. Other survey papers covered multiple topics, given the correlation between coordination, communication and security. Reference [72] discussed key requirements of communication, security and privacy, and a parameter-based thematic taxonomy for the Internet of drones (IoD). Reference [93] surveyed methods for physical collision avoidance and obstacle detection, the Internet of things (IoT) equipment applied with UAVs, and challenges in adoption of different communication technologies. References [86] and [87] introduced drone-based quantum computing, quantum satellites for UAV-based networks and communications, quantum attacks and post-quantum cryptography, and the Internet of quantum drones (IoQDs). Reference [22] presented an overview of the IoD and its two-level asset classification, followed by a taxonomy of cyber and physical attacks, and IoD security countermeasures. Reference [79] classified studies on IoD security and Blockchain into three main classes based on Blockchain type. Reference [100] highlighted the IoD architecture and its requirements on safety, a taxonomy of drones with vulnerability levels of security and privacy, attacks on IoD networks, mitigating techniques, and performance evaluation methods / metrics. Reference [90] analyzed issues of security and privacy in UAVs with 5G communication network, as well as research challenges in the integrating of Blockchain and UAV communication networks. Reference [73] covered UAV regulatory standards, structures and techniques of communication, issues and solutions of security. The UAV-related networks have the potential to enhance life quality and promote socio-economic development by performing tasks mentioned in preceding sections in a more efficient, safe and cost-saving manner. Technical and operational supports from researchers and governments are indispensable to promote more joined-up and secure drone-based systems for sophisticated scenarios. Some future research directions are discussed below:

- **Hardware**: Given increased energy consumption for collaborations with requirements of communication and security, renewable and energy-efficient architectures / components should be considered, especially for UAVs remotely controlled and performing long-term or complex tasks. Infrastructures based on novel techniques (e.g., AI, Blockchain, cloudlets and the computation offloading) may be solutions to overcome resource limitations (e.g., storage and computing capacities) in UAV networks.
- **Software**: It is important to construct better and reliable communication protocols and security algorithms as foundations for more complex and concordant drone-networks. High security levels, however, often come with design complexity, which may lead to latency for critical communication, and more computational load and power consumption. Accordingly, UAV systems need to appropriately balance these conflicting requirements.

C. Other Overview Studies

The adoption of drones enables cities to be more efficient, environment-friendly and intelligent. However, it might be influenced by opinions of the public. Although socio-technical considerations have been analyzed in the previous sections, the specific reviews about drones applied to single application is very limited. The factor-focused surveys conclude that how the public perceive the use of drones significantly depends on socio-cultural influences, the potential risks / challenges, motivation to drone applications, and the expected benefits. Accordingly, [102] categorized demographic indicators (age and gender), geographic location, and type of drone mission as the socio-cultural factors. Furthermore, benefits such as application flexibility and cost reduction attract the public to accept the adoption of drones [103]. Overall, it indicates that the public are willing to apply UAVs in specialized areas, however, the oppositions could not be ignored. Accordingly, creating or adapting effective laws may improve the acceptance of drone applications. In general, this kind of survey orienting researchers and decision makers on drone use is devoted to raise concerns about a new technology like UAV. As UAVs have emerged in the recent years, there is still a need for in-depth investigations of public perception. For example, a spatio-temporal analysis could show how the people's attitudes change in different regions and times.

Although many techniques are described to adapt different applications of UAVs, the UAV-related devices still require further research. In details, drone design, monitoring UAV system, vertiport design, and charging techniques

TABLE VI
EXTANT SURVEYS ON UAV COORDINATION, COMMUNICATION, AND SECURITY

Survey	Time frame	Content type	Scale / Subject	Focus
[72]	2014-2021	Empirical	M	Requirements and challenges of IoD
[73]	2012-2022	Empirical	S / M	Communication / security challenges
[74]	2013-2021	Analytical	M + fog-cloud	Deployments and integrations of IoD
[75]	2002-2019	Empirical	M + IoT	Drones and IoT for smart cities
[76]	1992-2021	Empirical	M	Structure of IoD
[77]	2014-2018	Theoretical	M + radio	Air-ground integrated mobile edge networks
[22]	1995-2022	Empirical	M	Issues and countermeasures for IoD security
[78]	1988-2005	Theoretical	M + zones	A conceptual model of IoD
[20]	2003-2021	Empirical	M + WSN	Routing algorithms and challenges for IoD
[79]	1983-2022	Analytical	M	Blockchain technology for IoD security
[80]	1980-2021	Empirical	S / M	Security for drone communication
[81]	2017-2022	Analytical	M	Machine Learning applications in IoD
[82]	2005-2021	Analytical	S / M	Applications for human-drone interaction
[83]	1951-2019	Empirical	S / M + human	Human-autonomy teaming (HAT)
[84]	2008-2020	Empirical	M	Security and privacy challenges for IoD
[85]	2016-2021	Analytical	M	Security for Internet of Flying Things / IoD
[86]	1978-2021	Empirical	M	Technologies for quantum drones
[87]	1982-2022	Empirical	S / M + satellites	Challenges of IoQDs
[88]	2008-2016	Empirical	M	Challenges and solutions of security / privacy
[89]	2005-2020	Empirical	S / M	Cybersecurity in civil UAVs
[90]	2002-2020	Empirical	M	Security issues in 5G-enabled UAV networks
[91]	1983-2022	Empirical	M	Authentication mechanisms for IoD
[92]	1988-2018	Empirical	S / M + human	Human-drone interaction
[93]	1994-2016	Mix	S / M	UAV-based IoT
[94]	1983-2021	Empirical	M + simulators	Security in IoD
[21]	2006-2020	Empirical	M	Communication / networking technologies
[95]	1994-2022	Empirical	S / M	Handover management for drones
[96]	2012-2017	Analytical	M + vehicles	Drone-assisted vehicular networks
[97]	1999-2020	Empirical	M	Techniques for securing UAV applications
[98]	1994-2020	Mix	S / M	Cybersecurity Vulnerabilities for UAM
[99]	1999-2021	Empirical	M	Routing protocols in Flying ad hoc network
[100]	1983-2021	Empirical	M	Safety and attacks on IoD networks
[101]	2006-2022	Empirical	M	Security issues and solutions of IoD

IoD = Internet of Drones; M = Multiple drones; S = Single drone.

TABLE VII
EXTANT SURVEYS ON PUBLIC ACCEPTANCE

Survey	Time frame	Content type	Scale / Subject	Focus
[102]	2014-2020	Mix	M + factor analysis	Public acceptance of drones
[103]	2015-2021	Analytical	M + factor analysis	Adoption of drones

M = Multiple drones, S = Single drone.

TABLE VIII
EXTANT SURVEYS ON DESIGN OF HARDWARE DEVICES

Survey	Time frame	Content type	Scale / Subject	Focus
[104]	2011-2018	Theoretical	M + design	Human-centered design of drones
[105]	2016-2021	Theoretical	M + UAV performance	Computation offloading
[106]	2016-2019	Empirical	M + regulations	Preventing UAV attacks
[107]	2016-2019	Empirical	M + design	Exterior design of drones
[108]	2011-2022	Mix	M + charging	UAV charging techniques
[109]	2018-2022	Empirical	M + charging	Challenges of UAV electrification
[110]	2016-2021	Empirical	infrastructure	Vertiport design and operation
[111]	2017-2021	Theoretical	M + infrastructure	UAV-enabled edge-computing

M = Multiple drones, S = Single drone.

are proposed among the selected review papers, as shown in Table VIII. Reference [104] designed external features, projected graphics, sound and the cultural context of UAVs with numerous human-based factors; the exterior forms (e.g., capacity, size, material and safety) of UAVs were defined in [107]. Monitoring UAVs aims at guaranteeing the safety of drones and their performing tasks. Accordingly, [105], [106], and [111] focused on computation methods for monitoring systems to help the enhanced drones handle complicated missions. Vertiport design is another research area in the above-mentioned surveys, which addresses ground infrastructure design with airspace operation [110]. Considering UAV flight time as a limited characteristic, [108] and [109] review charging techniques: laser power transfer, distributed laser charging, and wireless information / power transfer.

IV. AERIAL Framework

Based on these observations from the summarized UAV surveys above, particularly their main messages and challenges, we summarize the following six key challenges towards the successful application of UAV for logistics, transportation, and monitoring. We name these challenges as AERIAL framework, based on the first letter of each challenge:

1) **Acceptance and heterogeneities**: Regional and cohort-specific public acceptance.
2) **Economy and demand**: High demand uncertainty and potential for fluctuation.
3) **Reliability and risks**: Resource and technological limitations without guarantees.
4) **Infrastructure and optimization**: Scalable algorithms for planning and routing.
5) **Automation and control**: Efficient and effective coordination and communication.
6) **Liability and standardization**: Assignment of responsibilities in case of incidents.

Below, we discuss the challenges inherent to these six items in detail, while providing references into the most-related literature, describing potential mitigation strategies, and highlighting ample potential for future research. It should be noted that these challenges are in no way intended to be complete. They were selected based on the authors perceptions and those obtained from emphases in the existing literature. We have grouped all aspects with the aim to derive a small set of reasonable categories. In this way, there exists the possibility that we neglected a challenge which is not well visible in the existing literature. Future studies can aim at deriving more sophisticated and complete lists of challenges, following a more formal procedure.

A. Acceptance and Heterogeneities

One of the most crucial and fundamental challenges for a successful implementation of UAV services is the acceptance by the general public. Without an acceptance, the UAV service providers are unlikely to create a sufficient user base in order to be profitable and having a large-scale impact on transportation. The reasons for limited public acceptance, or variations thereof, are various and often interact with other key challenges below. One major hurdle for public acceptance is the existence of safety concerns, i.e., the imagination that airborne UAVs cross houses and streets, while putting people and infrastructure at danger. Along these lines, people are often afraid by the impact of additional noise as well as induced privacy concerns, when UAVs are operated over private properties. To summarize, public acceptance is a multifaceted factor that clearly impacts the regulatory environment as well as societal perception of UAV services, both of which are highly heterogeneous across populations and cohorts. For instance, younger people are often more open to new technologies and, therefore, the application and use of UAVs. Engaging with the public, addressing their concerns step by step, and establishing a positive image of UAVs are all critical to ensuring a successful integration of such services into industries and applications. Engagement programs could include safety demonstration events, showcasing the rigorous testing and safety standards in place as well as involving local communities in decision making. Future research should put a stronger emphasis on the identification of heterogeneities and their major drivers. This will help UAV service providers to better plan and prepare for their operations. Please also see the following studies which have been published in the year 2023, after the cutoff in our meta analysis: [112] and [113].

B. Economy and Demand

A second concern for the application of UAV services, particularly for air taxi operations, is the difficulty to predict the exact demand. This holds especially in case of changes to the economy and environment. The uncertainties in technologies, and the fast pace of development, induces a rapid change in potential use cases. For instance, technological advances regarding battery technology can significantly increase the operation range, while novel safety considerations might reduce the range. For passengers, air taxis would be mostly an non-essential service, particularly in urban areas, given the existing ground infrastructure. With downturns in economic strength, consumers are likely to cancel such non-essential services first, which makes the sustainable operation of air taxis a tremendous challenge. Similarly, the UAV industry is tremendously backed by venture capital. In phases of recession, the amount of available investment is significantly lower. Moreover, the ubiquitous threat of regulatory and policy changes by governments, may influence areas like research, development and safety regulations. Finally, other economic changes, such as supply chain disruptions during global events, can affect the availability of core UAV components, leading to delays or increased costs for UAV services. Accordingly, the success of future UAV services is closely linked to the existence of economic stability and growth. Stakeholders of the UAV industry must diligently monitor trends and adapt their strategies while anticipating global and regional economic challenges. Please also refer to the following recent papers: [114], [115], and [116].

C. Reliability and Risks

Presumably the most critical factors for the UAV vision turning reality is to maximize the reliability of the system, while minimizing the risks to (particularly, fatal) disruptions. Given the complexity of the system, similarly to traditional aircraft, the number of sources for system failure are tremendous. For instance, UAVs must be able to maintain stable flight under various environmental conditions, including turbulence and changes of altitudes, without loss of control. Given the autonomous characteristic of UAVs, the risk sensor failure and potential absence of ability for human intervention, makes UAV operations extremely prone to sensor failures, including cameras, LiDAR, and GPS. Accordingly, the implementation of redundant or fail-safe systems are essential to prevent catastrophic outcomes in the event of failures. Notably, such concerns do not only address the hardware of a system, but also the software, where small, rare glitches / bugs may lead to ultimate failure. Such glitches, however, might only show up under extreme conditions, not in lab environments. Moreover, the consequences of a system failure are usually perceived as lethal / excessive. Addressing the above reliability and safety concerns requires a holistic approach that consists of UAV robust design, thorough testing, regular maintenance, and ongoing monitoring of UAV systems. Without a high-level of reliability, it will not be possible to meet certification requirements or build up trust among stakeholders and the public. Please also see: [117], [118], [119], and [120].

D. Infrastructure and Optimization

The major promise that comes with UAVs is the reduction of travel times, mainly due to opening up the third dimension (altitude) and being able to travel directly line-by-sight without congestion. A significant reduction in travel times, however, also requires effective solutions concerning planning and scheduling of UAV operations. Identifying suitable takeoff and landing ports / locations for UAVs is crucial for operational efficiency as well as safety [121]. Here, infrastructure planning problems aim to select sites which are well-equipped, easily accessible, and compliant with safety standards. Many trade-offs need to be made during the selection process, for instance, concerning the integration of the sites into the urban environment, ensuring a harmonious coexistence. Moreover, given the goal to operate UAVs continuously without disruptions due to power or fuel limitations, it is essential to build up a recharging / refueling network, as part of the basic technological infrastructure. At the same time, these infrastructure decisions should enable scalability and a sustainable growth, accommodating increased demand, higher frequencies of flights, and additional service areas in the future, without sacrificing safety or operational efficiency. Accordingly, formulating real-world driven decision and optimization problems for infrastructure choices as well as scheduling / routing, is essential for a successful implementation of UAV operations, while adhering to safety, regulatory, and operational requirements. Very recent related contributions can be found here: [122] and [123].

E. Automation and Control

Operating a single UAV relies on effective automation and control systems for ensuring safe, reliable, and efficient operations. Key aspects of such system include navigation, flight control, mission planning, and emergency procedures. When extending the operation to multiple UAVs, additional aspects need to be considered, e.g., communication, synchronization and collision avoidance. All these elements of the system need to be robust by design. For instance, flight control should lead to feasible maneuvers even under challenging weather conditions. Advanced navigation algorithms need to make use of data from sensor fusion, in order to enhance their ability to navigate in complex environments under partial sensor outage. The implementation of fail-safe mechanisms, which are being triggered under appropriate conditions, such as returning to a safe location or entering a holding pattern upon safety concerns, is vital for minimizing risks. Modern data management and artificial intelligence-based techniques promise to be enablers for such robust automation and control systems. How to develop a well-designed and robust automation and control framework should be investigated in future research across the entire UAV ecosystem. Please also refer to [124] and [117].

F. Liability and Standardization

The final key challenge part of the AERIAL framework concerns the identification and assignment of responsibilities in the event of accidents, incidents, or damages involving UAV operations. This in necessary due to the complex nature of UAV operations, the involvement of multiple stakeholders, and the potential for technical failures and fatal failures. Once such a failure occurs, determining with the failure was due to a design flaw, manufacturing defect, operator error, or external factors can be challenging. This fact will inevitably lead to unclear jurisdictions and responsibilities. Moreover, the complex interactions of hardware and software inside a UAV will lead to additional sources of non-determinism and liability disputes. Furthermore, UAV services presumably often involve multiple parties, including various manufacturers, operators, service providers, and, finally, end-users. Determining liability among these stakeholders requires not only the technical identification of failure sources, but also examining contractual agreements, service level agreements, and warranties. Once there exists a (more) uniform or harmonized set of standards across the majority of jurisdictions, this would allow and facilitate some degree of practical harmonization and predictability for manufacturers as well as operators. Please also see: [125] and [126].

V. Suggestions for Future Work Directions

In this section, we discuss a few directions for future work, which are directly stipulated by the results of our meta review. We hope that these suggestions help the research community to perform a better orchestrated approach for advancing the state-of-the-art of UAV application in the context of intelligent transportation systems.

1) **Sense and Avoid Systems**: The development of effective sense and avoid systems is crucial for ensuring the safe operation of intelligent UAVs in complex and uncertain environments. Advanced sensor technologies like LiDAR, radar, and computer vision are integral components of these systems. Computer vision, powered by machine learning algorithms, will enable UAVs to recognize and respond to visual cues in real-time. Accordingly, researchers need to further explore ways to integrate these sensors seamlessly, enhancing UAVs' ability to perceive their environment and make split-second decisions, ensuring collision-free flights.
2) **Autonomous Navigation**: Autonomous navigation algorithms empower UAVs to make intelligent decisions

while navigating through diverse and unpredictable environments [127]. These algorithms consider factors such as weather conditions, airspace regulations, and the presence of dynamic obstacles. Path planning algorithms, including techniques like A* and Dijkstra's algorithm, help UAVs find optimal routes while avoiding obstacles. Again, machine learning models will be utilized for predicting environmental changes and enabling proactive decision-making [128]. There is a need for research on adaptive algorithms that can dynamically adjust UAVs' paths based on real-time data, ensuring safe and efficient navigation in various scenarios, from urban landscapes to natural terrains; even under disruptive scenarios, as inspired by traditional air transportation [129], [130].

3) **Communication and Control**: Reliable communication systems are fundamental for UAVs to operate autonomously and communicate with ground control stations. Researchers need to focus on developing robust communication protocols that facilitate high data transmission rates, low latency, and secure data exchange. Multi-channel communication systems, including satellite and terrestrial networks, need to be incorporated in order to ensure uninterrupted connectivity, especially in remote or densely populated areas. Additionally, advancements in software-defined radios will enhance the flexibility of communication systems, allowing UAVs to adapt to different frequency bands and communication standards. Research efforts also need to be dedicated to enhancing encryption technology.
4) **Collaborative UAV Networks**: Collaborative UAV networks, so-called swarms or platooning [131], [132], involve multiple UAVs working together cohesively to accomplish complex tasks. Research in this area need to focus on developing algorithms for task allocation, swarm intelligence, and cooperative decision-making. Cooperative decision-making algorithms facilitate consensus among UAVs, allowing them to adjust their actions based on the collective input. These collaborative efforts lead to synchronized movements and actions, enabling UAV swarms to perform tasks such as environmental monitoring, search and rescue, and precision agriculture effectively.
5) **Human-UAV Interaction**: Human-UAV interaction research needs to focus on designing intuitive interfaces for controlling UAVs, especially for operators without technical expertise. Here, especially work on voice and gesture control systems will enable operators to guide UAV movements using hand gestures, providing a natural and immersive interaction experience. Moreover, future studies need to further push the envelope towards the integration of augmented reality interfaces overlay virtual information on the operator's view, enhancing situational awareness and decision-making. The goal is to create seamless interactions between humans and UAVs, empowering users to control and monitor UAVs effortlessly and efficiently.
6) **Data Processing and Analysis**: UAVs generate vast amounts of data from onboard sensors and cameras. There is a need to develop efficient and scalable processing and analysis techniques for the interpretation of data, to enable informed decision-making. Research needs to focus on developing real-time data processing algorithms that handle large datasets quickly and accurately. Machine learning techniques, including deep learning and computer vision algorithms, enable UAVs to recognize patterns, detect objects, and analyze complex visual information. These advancements in data processing and analysis empower UAV operations for the future.

VI. Conclusion

In this section, we conclude our meta review and discuss the findings, hopefully contributing towards a more orchestrated future development of UAV-related research areas. We have conducted a meta review of extant research on UAV-related subjects, motivated by the increasing number of surveys in the literature. In our meta-analysis of UAV surveys, we provide an overview of nearly 100 survey / review papers and investigate their content as well as citation / reference patterns, which are categorized into major application areas. Our meta survey has summarized the various aspects and trends of UAV-related research, contributing a comprehensive analysis and overview.

While our meta review covers an unprecedented number of UAV-related surveys, there are also some limitations in our study, which are summarized below. We have collected existing survey papers by searching for specific keywords, including drone, unmanned aerial vehicles, unmanned air mobility, survey, and review. Nevertheless, some less-related articles might not be included in our meta review. The search scope can be expanded by more specialized derivatives and terms. The transition between clear review papers and other overview papers is sometimes vague, and potentially induces a selection problem when searching and identifying surveys. Future work could further widen the applied selection criteria or use semi-automatic decision techniques for data collection. Surveys in our study were published between 2016 and 2022. Accordingly, we exclude earlier papers and most recent articles in 2023. Other studies could expand the time frame of searching and selecting papers concerning the publishing year, publisher, venue, citations and references.

References

[1] S. Rajendran and J. Zack, "Insights on strategic air taxi network infrastructure locations using an iterative constrained clustering approach," *Transp. Res. E, Logistics Transp. Rev.*, vol. 128, pp. 470–505, Aug. 2019.

[2] C. Lemardelé, M. Estrada, L. Pagès, and M. Bachofner, "Potentialities of drones and ground autonomous delivery devices for last-mile logistics," *Transp. Res. E, Logistics Transp. Rev.*, vol. 149, May 2021, Art. no. 102325.

[3] G. Zhang, N. Zhu, S. Ma, and J. Xia, "Humanitarian relief network assessment using collaborative truck-and-drone system," *Transp. Res. E, Logistics Transp. Rev.*, vol. 152, Aug. 2021, Art. no. 102417.

[4] X. Qu, Z. Zeng, K. Wang, and S. Wang, "Replacing urban trucks via ground–air cooperation," *Commun. Transp. Res.*, vol. 2, Dec. 2022, Art. no. 100080.

[5] K. Wang, A. Li, and X. Qu, "Urban aerial mobility: Network structure, transportation benefits, and sino-U.S. comparison," *Innov.*, vol. 4, no. 2, Mar. 2023, Art. no. 100393.

[6] K. Wang and X. Qu, "Urban aerial mobility: Reshaping the future of urban transportation," *Innov.*, vol. 4, no. 2, Mar. 2023, Art. no. 100392.

[7] J. Kim, S. Kim, J. Jeong, H. Kim, J.-S. Park, and T. Kim, "CBDN: Cloud-based drone navigation for efficient battery charging in drone networks," *IEEE Trans. Intell. Transp. Syst.*, vol. 20, no. 11, pp. 4174–4191, Nov. 2019.

[8] V. Hassija, V. Saxena, and V. Chamola, "Scheduling drone charging for multi-drone network based on consensus time-stamp and game theory," *Comput. Commun.*, vol. 149, pp. 51–61, Jan. 2020.

[9] A. Asadi and S. N. Pinkley, "A stochastic scheduling, allocation, and inventory replenishment problem for battery swap stations," *Transp. Res. E, Logistics Transp. Rev.*, vol. 146, Feb. 2021, Art. no. 102212.

[10] Z. Liu, X. Li, and A. Khojandi, "The flying sidekick traveling salesman problem with stochastic travel time: A reinforcement learning approach," *Transp. Res. E, Logistics Transp. Rev.*, vol. 164, Aug. 2022, Art. no. 102816.

[11] M. Moshref-Javadi, S. Lee, and M. Winkenbach, "Design and evaluation of a multi-trip delivery model with truck and drones," *Transp. Res. E, Logistics Transp. Rev.*, vol. 136, Apr. 2020, Art. no. 101887.

[12] M. R. Salama and S. Srinivas, "Collaborative truck multi-drone routing and scheduling problem: Package delivery with flexible launch and recovery sites," *Transp. Res. E, Logistics Transp. Rev.*, vol. 164, Aug. 2022, Art. no. 102788.

[13] W. Yoo, E. Yu, and J. Jung, "Drone delivery: Factors affecting the public's attitude and intention to adopt," *Telematics Informat.*, vol. 35, no. 6, pp. 1687–1700, Sep. 2018.

[14] X. He, F. He, L. Li, L. Zhang, and G. Xiao, "A route network planning method for urban air delivery," *Transp. Res. E, Logistics Transp. Rev.*, vol. 166, Oct. 2022, Art. no. 102872.

[15] M. Amine Masmoudi, S. Mancini, R. Baldacci, and Y.-H. Kuo, "Vehicle routing problems with drones equipped with multi-package payload compartments," *Transp. Res. E, Logistics Transp. Rev.*, vol. 164, Aug. 2022, Art. no. 102757.

[16] S. Meng, X. Guo, D. Li, and G. Liu, "The multi-visit drone routing problem for pickup and delivery services," *Transp. Res. E, Logistics Transp. Rev.*, vol. 169, Jan. 2023, Art. no. 102990.

[17] J. Pons-Prats, T. Živojinović, and J. Kuljanin, "On the understanding of the current status of urban air mobility development and its future prospects: Commuting in a flying vehicle as a new paradigm," *Transp. Res. E, Logistics Transp. Rev.*, vol. 166, Oct. 2022, Art. no. 102868.

[18] C. Fang, Z. Han, W. Wang, and E. Zio, "Routing UAVs in landslides monitoring: A neural network heuristic for team orienteering with mandatory visits," *Transp. Res. E, Logistics Transp. Rev.*, vol. 175, Jul. 2023, Art. no. 103172.

[19] L. Shen et al., "Synergistic path planning of multi-UAVs for air pollution detection of ships in ports," *Transp. Res. E, Logistics Transp. Rev.*, vol. 144, Dec. 2020, Art. no. 102128.

[20] S. K. Haider, A. Nauman, M. A. Jamshed, A. Jiang, S. Batool, and S. W. Kim, "Internet of Drones: Routing algorithms, techniques and challenges," *Mathematics*, vol. 10, no. 9, p. 1488, Apr. 2022.

[21] A. Sharma et al., "Communication and networking technologies for UAVs: A survey," *J. Netw. Comput. Appl.*, vol. 168, Oct. 2020, Art. no. 102739.

[22] A. Derhab et al., "Internet of Drones security: Taxonomies, open issues, and future directions," *Veh. Commun.*, vol. 39, Feb. 2023, Art. no. 100552.

[23] G. E. Hinton and S. Roweis, "Stochastic neighbor embedding," in *Proc. Adv. Neural Inf. Process. Syst.*, vol. 15, 2002, pp. 857–864.

[24] L. Van der Maaten and G. Hinton, "Visualizing data using t-SNE," *J. Mach. Learn. Res.*, vol. 9, no. 11, pp. 1–27, 2008.

[25] T. Benarbia and K. Kyamakya, "A literature review of drone-based package delivery logistics systems and their implementation feasibility," *Sustainability*, vol. 14, no. 1, p. 360, Dec. 2021.

[26] S. H. Chung, B. Sah, and J. Lee, "Optimization for drone and drone-truck combined operations: A review of the state of the art and future directions," *Comput. Oper. Res.*, vol. 123, Nov. 2020, Art. no. 105004.

[27] Y. Li, M. Liu, and D. Jiang, "Application of unmanned aerial vehicles in logistics: A literature review," *Sustainability*, vol. 14, no. 21, p. 14473, Nov. 2022.

[28] G. Macrina, L. D. P. Pugliese, F. Guerriero, and G. Laporte, "Drone-aided routing: A literature review," *Transp. Res. C, Emerg. Technol.*, vol. 120, Nov. 2020, Art. no. 102762.

[29] R. Merkert and J. Bushell, "Managing the drone revolution: A systematic literature review into the current use of airborne drones and future strategic directions for their effective control," *J. Air Transp. Manage.*, vol. 89, Oct. 2020, Art. no. 101929.

[30] M. Moshref-Javadi and M. Winkenbach, "Applications and research avenues for drone-based models in logistics: A classification and review," *Expert Syst. Appl.*, vol. 177, Sep. 2021, Art. no. 114854.

[31] A. Otto, N. Agatz, J. Campbell, B. Golden, and E. Pesch, "Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones: A survey," *Networks*, vol. 72, no. 4, pp. 411–458, Dec. 2018.

[32] J. Pasha et al., "The drone scheduling problem: A systematic state-of-the-art review," *IEEE Trans. Intell. Transp. Syst.*, vol. 23, no. 9, pp. 14224–14247, Sep. 2022.

[33] D. R. Viloria, E. L. Solano-Charris, A. Muñoz-Villamizar, and J. R. Montoya-Torres, "Unmanned aerial vehicles/drones in vehicle routing problems: A literature review," *Int. Trans. Oper. Res.*, vol. 28, no. 4, pp. 1626–1657, Jul. 2021.

[34] A. B. Ammar, T. M. Loukil, and M. Cheikh, "A survey on the hybrid vehicle routing problem: Literature review," in *Proc. 14th Int. Colloq. Logistics Supply Chain Manage. (LOGISTIQUA)*, May 2022, pp. 1–6.

[35] I. Khoufi, A. Laouiti, and C. Adjih, "A survey of recent extended variants of the traveling salesman and vehicle routing problems for unmanned aerial vehicles," *Drones*, vol. 3, no. 3, p. 66, Aug. 2019.

[36] Y.-J. Liang and Z.-X. Luo, "A survey of Truck–Drone routing problem: Literature review and research prospects," *J. Oper. Res. Soc. China*, vol. 10, no. 2, pp. 343–377, Jun. 2022.

[37] B. Madani and M. Ndiaye, "Hybrid truck-drone delivery systems: A systematic literature review," *IEEE Access*, vol. 10, pp. 92854–92878, 2022.

[38] A. Thibbotuwawa, G. Bocewicz, P. Nielsen, and Z. Banaszak, "Unmanned aerial vehicle routing problems: A literature review," *Appl. Sci.*, vol. 10, no. 13, p. 4504, Jun. 2020.

[39] R. Kellermann, T. Biehle, and L. Fischer, "Drones for parcel and passenger transportation: A literature review," *Transp. Res. Interdiscipl. Perspect.*, vol. 4, Mar. 2020, Art. no. 100088.

[40] A. Rejeb, K. Rejeb, S. Simske, and H. Treiblmaier, "Humanitarian drones: A review and research agenda," *Internet Things*, vol. 16, Dec. 2021, Art. no. 100434.

[41] A. Rejeb, K. Rejeb, S. J. Simske, and H. Treiblmaier, "Drones for supply chain management and logistics: A review and research agenda," *Int. J. Logistics Res. Appl.*, vol. 26, no. 6, pp. 708–731, Jun. 2023.

[42] M. Ayamga, S. Akaba, and A. A. Nyaaba, "Multifaceted applicability of drones: A review," *Technolog. Forecasting Social Change*, vol. 167, Jun. 2021, Art. no. 120677.

[43] K. Huang, K. Kockelman, and K. M. Gurumurthy, "Innovations impacting the future of transportation: An overview of connected, automated, shared, and electric technologies," *Transp. Lett.*, vol. 15, no. 6, pp. 490–509, Jul. 2023.

[44] M. A. Khan, B. A. Alvi, A. Safi, and I. U. Khan, "Drones for good in smart cities: A review," in *Proc. Int. Conf. Elect., Electron., Comput., Commun., Mech. Comput. (EECCMC)*, 2018, pp. 1–6.

[45] T. Biehle, "Social sustainable urban air mobility in Europe," *Sustainability*, vol. 14, no. 15, p. 9312, Jul. 2022.

[46] I. G. Ferrão, D. Espes, C. Dezan, and K. R. L. J. C. Branco, "Security and safety concerns in air taxis: A systematic literature review," *Sensors*, vol. 22, no. 18, p. 6875, Sep. 2022.

[47] D. Gillis, M. Petri, A. Pratelli, I. Semanjski, and S. Semanjski, "Urban air mobility: A state of art analysis," in *Proc. Int. Conf. Comput. Sci. Appl.*, Cagliari, Italy, Sep. 2021, pp. 411–425.

[48] R. Goyal and A. Cohen, "Advanced air mobility: Opportunities and challenges deploying eVTOLs for air ambulance service," *Appl. Sci.*, vol. 12, no. 3, p. 1183, Jan. 2022.

[49] S. Rajendran and S. Srinivas, "Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities," *Transp. Res. E, Logistics Transp. Rev.*, vol. 143, Nov. 2020, Art. no. 102090.

[50] X. Sun, S. Wandelt, M. Husemann, and E. Stumpf, "Operational considerations regarding on-demand air mobility: A literature review and research challenges," *J. Adv. Transp.*, vol. 2021, pp. 1–20, Feb. 2021.

[51] Y. Akbari, N. Almaadeed, S. Al-Maadeed, and O. Elharrouss, "Applications, databases and open computer vision research from drone videos and images: A survey," *Artif. Intell. Rev.*, vol. 54, no. 5, pp. 3887–3938, Jun. 2021.

[52] E. V. Butilă and R. G. Boboc, "Urban traffic monitoring and analysis using unmanned aerial vehicles (UAVs): A systematic literature review," *Remote Sens.*, vol. 14, no. 3, p. 620, Jan. 2022.

[53] N. Dilshad, J. Hwang, J. Song, and N. Sung, "Applications and challenges in video surveillance via drone: A brief survey," in *Proc. Int. Conf. Inf. Commun. Technol. Converg. (ICTC)*, Oct. 2020, pp. 728–732.

[54] A. Gohari, A. B. Ahmad, R. B. A. Rahim, A. S. M. Supa'at, S. A. Razak, and M. S. M. Gismalla, "Involvement of surveillance drones in smart cities: A systematic review," *IEEE Access*, vol. 10, pp. 56611–56628, 2022.

[55] S. A. H. Mohsan, M. A. Khan, F. Noor, I. Ullah, and M. H. Alsharif, "Towards the unmanned aerial vehicles (UAVs): A comprehensive review," *Drones*, vol. 6, no. 6, p. 147, Jun. 2022.

[56] P. Nooralishahi et al., "Drone-based non-destructive inspection of industrial sites: A review and case studies," *Drones*, vol. 5, no. 4, p. 106, Sep. 2021.

[57] M. H. Sabour, P. Jafary, and S. Nematiyan, "Applications and classifications of unmanned aerial vehicles: A literature review with focus on multi-rotors," *Aeronaut. J.*, vol. 127, no. 1309, pp. 466–490, Mar. 2023.

[58] J. Shahmoradi, E. Talebi, P. Roghanchi, and M. Hassanalian, "A comprehensive review of applications of drone technology in the mining industry," *Drones*, vol. 4, no. 3, p. 34, Jul. 2020.

[59] A. Bauranov and J. Rakas, "Designing airspace for urban air mobility: A review of concepts and approaches," *Prog. Aerosp. Sci.*, vol. 125, Aug. 2021, Art. no. 100726.

[60] A. P. Cohen, S. A. Shaheen, and E. M. Farrar, "Urban air mobility: History, ecosystem, market potential, and challenges," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 9, pp. 6074–6087, Sep. 2021.

[61] O. Cokorilo, "Urban air mobility: Safety challenges," *Transp. Res. Proc.*, vol. 45, pp. 21–29, Jan. 2020.

[62] C. C. Ditta and M. N. Postorino, "New challenges for urban air mobility systems: Aerial cooperative vehicles," in *Intelligent Distributed Computing XIV*. Cham, Switzerland: Springer, 2022, pp. 135–145.

[63] L. A. Garrow, B. J. German, and C. E. Leonard, "Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research," *Transp. Res. C, Emerg. Technol.*, vol. 132, Nov. 2021, Art. no. 103377.

[64] F. D. Maia and J. M. L. da Saúde, "The state of the art and operational scenarios for urban air mobility with unmanned aircraft," *Aeronaut. J.*, vol. 125, no. 1288, pp. 1034–1063, Jun. 2021.

[65] G. Mavraj et al., "A systematic review of ground-based infrastructure for the innovative urban air mobility," *Trans. Aerosp. Res.*, vol. 2022, no. 4, pp. 1–17, Dec. 2022.

[66] R. Rothfeld, A. Straubinger, M. Fu, C. Al Haddad, and C. Antoniou, "Urban air mobility," in *Demand for Emerging Transportation Systems*. Amsterdam, The Netherlands: Elsevier, 2020, pp. 267–284.

[67] R. Rumba and A. Nikitenko, "The wild west of drones: A review on autonomous-UAV traffic-management," in *Proc. Int. Conf. Unmanned Aircr. Syst. (ICUAS)*, Sep. 2020, pp. 1317–1322.

[68] R. Shrestha, I. Oh, and S. Kim, "A survey on operation concept, advancements, and challenging issues of urban air traffic management," *Frontiers Future Transp.*, vol. 2, p. 1, Apr. 2021.

[69] A. Straubinger, R. Rothfeld, M. Shamiyeh, K.-D. Büchter, J. Kaiser, and K. O. Plötner, "An overview of current research and developments in urban air mobility—Setting the scene for UAM introduction," *J. Air Transp. Manage.*, vol. 87, Aug. 2020, Art. no. 101852.

[70] M. T. R. Khan, M. M. Saad, Y. Ru, J. Seo, and D. Kim, "Aspects of unmanned aerial vehicles path planning: Overview and applications," *Int. J. Commun. Syst.*, vol. 34, no. 10, Jul. 2021, Art. no. e4827.

[71] K. Santhi, B. Valarmathi, and T. Chellatamilan, "Multi-cloud path planning of unmanned aerial vehicles with multi-criteria decision making: A literature review," in *Operationalizing Multi-Cloud Environments*. PA, USA: Springer, 2021, pp. 31–63.

[72] A. Abdelmaboud, "The Internet of Drones: Requirements, taxonomy, recent advances, and challenges of research trends," *Sensors*, vol. 21, no. 17, p. 5718, Aug. 2021.

[73] G. Abro, S. Zulkifli, R. Masood, V. Asirvadam, and A. Laouiti, "Comprehensive review of UAV detection, security, and communication advancements to prevent threats," *Drones*, vol. 6, no. 10, p. 284, Oct. 2022.

[74] L. Abualigah, A. Diabat, P. Sumari, and A. H. Gandomi, "Applications, deployments, and integration of Internet of Drones (IoD): A review," *IEEE Sensors J.*, vol. 21, no. 22, pp. 25532–25546, Nov. 2021.

[75] S. H. Alsamhi, O. Ma, M. S. Ansari, and F. A. Almalki, "Survey on collaborative smart drones and Internet of Things for improving smartness of smart cities," *IEEE Access*, vol. 7, pp. 128125–128152, 2019.

[76] P. Boccadoro, D. Striccoli, and L. A. Grieco, "An extensive survey on the Internet of Drones," *Ad Hoc Netw.*, vol. 122, Nov. 2021, Art. no. 102600.

[77] N. Cheng et al., "Air-ground integrated mobile edge networks: Architecture, challenges, and opportunities," *IEEE Commun. Mag.*, vol. 56, no. 8, pp. 26–32, Aug. 2018.

[78] M. Gharibi, R. Boutaba, and S. L. Waslander, "Internet of Drones," *IEEE Access*, vol. 4, pp. 1148–1162, 2016.

[79] Y. Harbi, K. Medani, C. Gherbi, O. Senouci, Z. Aliouat, and S. Harous, "A systematic literature review of blockchain technology for Internet of Drones security," *Arabian J. Sci. Eng.*, vol. 48, no. 2, pp. 1053–1074, Feb. 2023.

[80] V. Hassija et al., "Fast, reliable, and secure drone communication: A comprehensive survey," *IEEE Commun. Surveys Tuts.*, vol. 23, no. 4, pp. 2802–2832, 4th Quart., 2021.

[81] A. Heidari, N. J. Navimipour, M. Unal, and G. Zhang, "Machine learning applications in Internet-of-Drones: Systematic review, recent deployments, and open issues," *ACM Comput. Surv.*, vol. 55, no. 12, pp. 1–45, Dec. 2023.

[82] V. Herdel, L. J. Yamin, and J. R. Cauchard, "Above and beyond: A scoping review of domains and applications for human-drone interaction," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2022, pp. 1–22.

[83] J. Holbrook et al., "Enabling urban air mobility: Human-autonomy teaming research challenges and recommendations," in *Proc. AIAA Aviation Forum*, 2020, p. 3250.

[84] G. S. Ilgi and Y. K. Ever, "Critical analysis of security and privacy challenges for the Internet of Drones: A survey," in *Drones Smart-Cities*. Amsterdam, The Netherlands: Elsevier, 2020, pp. 207–214.

[85] S. M. Jameii, R. S. Zamirnaddafi, and R. Rezabakhsh, "Internet of flying things security: A systematic review," *Concurrency Comput., Pract. Exper.*, vol. 34, no. 24, Nov. 2022, Art. no. e7213.

[86] A. Kumar et al., "Survey of promising technologies for quantum drones and networks," *IEEE Access*, vol. 9, pp. 125868–125911, 2021.

[87] A. Kumar, D. A. de Jesus Pacheco, K. Kaushik, and J. J. P. C. Rodrigues, "Futuristic view of the internet of quantum drones: Review, challenges and research agenda," *Veh. Commun.*, vol. 36, Aug. 2022, Art. no. 100487.

[88] C. Lin, D. He, N. Kumar, K. R. Choo, A. Vinel, and X. Huang, "Security and privacy for the Internet of Drones: Challenges and solutions," *IEEE Commun. Mag.*, vol. 56, no. 1, pp. 64–69, Jan. 2018.

[89] B. Ly and R. Ly, "Cybersecurity in unmanned aerial vehicles (UAVs)," *J. Cyber Secur. Technol.*, vol. 5, no. 2, pp. 120–137, Apr. 2021.

[90] P. Mehta, R. Gupta, and S. Tanwar, "Blockchain envisioned UAV networks: Challenges, solutions, and comparisons," *Comput. Commun.*, vol. 151, pp. 518–538, Feb. 2020.

[91] E. T. Michailidis and D. Vouyioukas, "A review on software-based and hardware-based authentication mechanisms for the Internet of Drones," *Drones*, vol. 6, no. 2, p. 41, Feb. 2022.

[92] S. Mirri, C. Prandi, and P. Salomoni, "Human-drone interaction: State of the art, open issues and challenges," in *Proc. ACM SIGCOMM Workshop Mobile AirGround Edge Comput., Syst., Netw., Appl.*, Aug. 2019, pp. 43–48.

[93] N. Hossein Motlagh, T. Taleb, and O. Arouk, "Low-altitude unmanned aerial vehicles-based Internet of Things services: Comprehensive survey and future perspectives," *IEEE Internet Things J.*, vol. 3, no. 6, pp. 899–922, Dec. 2016.

[94] S. Samanth, K. V. Prema, and M. Balachandra, "Security in Internet of Drones: A comprehensive review," *Cogent Eng.*, vol. 9, no. 1, Dec. 2022, Art. no. 2029080.

[95] I. Shayea et al., "Handover management for drones in future mobile networks—A survey," *Sensors*, vol. 22, no. 17, p. 6424, Aug. 2022.

[96] W. Shi, H. Zhou, J. Li, W. Xu, N. Zhang, and X. Shen, "Drone assisted vehicular networks: Architecture, challenges and opportunities," *IEEE Netw.*, vol. 32, no. 3, pp. 130–137, May 2018.

[97] F. Syed, S. K. Gupta, S. Hamood Alsamhi, M. Rashid, and X. Liu, "A survey on recent optimal techniques for securing unmanned aerial vehicles applications," *Trans. Emerg. Telecommun. Technol.*, vol. 32, no. 7, Jul. 2021, Art. no. e4133.

[98] A. C. Tang, "A review on cybersecurity vulnerabilities for urban air mobility," in *Proc. AIAA Scitech Forum*, Jan. 2021, p. 773.

[99] A. H. Wheeb, R. Nordin, A. A. Samah, M. H. Alsharif, and M. A. Khan, "Topology-based routing protocols and mobility models for flying ad hoc networks: A contemporary review and future research directions," *Drones*, vol. 6, no. 1, p. 9, Dec. 2021.

[100] M. Yahuza et al., "Internet of Drones security and privacy issues: Taxonomy and open challenges," *IEEE Access*, vol. 9, pp. 57243–57270, 2021.

[101] W. Yang, S. Wang, X. Yin, X. Wang, and J. Hu, "A review on security issues and solutions of the Internet of Drones," *IEEE Open J. Comput. Soc.*, vol. 3, pp. 96–110, 2022.

[102] H. Sabino et al., "A systematic literature review on the main factors for public acceptance of drones," *Technol. Soc.*, vol. 71, Nov. 2022, Art. no. 102097.

[103] Y. Zhang and M. Kamargianni, "A review on the factors influencing the adoption of new mobility technologies and services: Autonomous vehicle, drone, micromobility and mobility as a service," *Transp. Rev.*, vol. 43, no. 3, pp. 407–429, May 2023.

[104] M. A. Baytas, D. Çay, Y. Zhang, M. Obaid, A. E. Yantaç, and M. Fjeld, "The design of social drones: A review of studies on autonomous flyers in inhabited environments," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, May 2019, pp. 1–13.

[105] R. Chaâri, O. Cheikhrouhou, A. Koubâa, H. Youssef, and T. N. Gia, "Dynamic computation offloading for ground and flying robots: Taxonomy, state of art, and future directions," *Comput. Sci. Rev.*, vol. 45, Aug. 2022, Art. no. 100488.

[106] V. Chamola, P. Kotesh, A. Agarwal, N. Gupta, and M. Guizani, "A comprehensive review of unmanned aerial vehicle attacks and neutralization techniques," *Ad Hoc Netw.*, vol. 111, Feb. 2021, Art. no. 102324.

[107] K. M. Chaturmutha and D. J. Mathew, "Factors influencing the exterior design of autonomous passenger drones: Literature review," *Proc. Design Soc.*, vol. 2, pp. 2087–2096, May 2022.

[108] S. A. H. Mohsan, N. Q. H. Othman, M. A. Khan, H. Amjad, and J. Żywiołek, "A comprehensive review of micro UAV charging techniques," *Micromachines*, vol. 13, no. 6, p. 977, Jun. 2022.

[109] A. Schwab, A. Thomas, J. Bennett, E. Robertson, and S. Cary, "Electrification of aircraft: Challenges, barriers, and potential impacts," Nat. Renew. Energy Lab. (NREL), Golden, CO, USa, Tech. Rep. NREL/TP-6A20-80220, 2021.

[110] K. Schweiger and L. Preis, "Urban air mobility: Systematic review of scientific publications and regulations for vertiport design and operations," *Drones*, vol. 6, no. 7, p. 179, Jul. 2022.

[111] Y. Yazid, I. Ez-Zazi, A. Guerrero-González, A. El Oualkadi, and M. Arioua, "UAV-enabled mobile edge-computing for IoT based on AI: A comprehensive review," *Drones*, vol. 5, no. 4, p. 148, Dec. 2021.

[112] M. Miron, D. Whetham, M. Auzanneau, and A. Hill, "Public drone perception," *Technol. Soc.*, vol. 73, May 2023, Art. no. 102246. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0160791X23000519

[113] N. Tepylo, A. Straubinger, and J. Laliberte, "Public perception of advanced aviation technologies: A review and roadmap to acceptance," *Prog. Aerosp. Sci.*, vol. 138, Apr. 2023, Art. no. 100899. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0376042123000155

[114] H. Ale-Ahmad and H. S. Mahmassani, "Factors affecting demand consolidation in urban air taxi operation," *Transp. Res. Rec., J. Transp. Res. Board*, vol. 2677, no. 1, pp. 76–92, Jan. 2023, doi: 10.1177/03611981221098396.

[115] H. Kim and K. Yee, "Potential UAM demand forecast and analysis: Application to Seoul metropolitan area," in *Proc. AIAA Aviation Forum*, 2023, p. 4210, doi: 10.2514/6.2023-4210.

[116] Q. Long, J. Ma, F. Jiang, and C. J. Webster, "Demand analysis in urban air mobility: A literature review," *J. Air Transp. Manage.*, vol. 112, Sep. 2023, Art. no. 102436. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0969699723000790

[117] S. Javaid et al., "Communication and control in collaborative UAVs: Recent advances and future trends," *IEEE Trans. Intell. Transp. Syst.*, vol. 24, no. 6, pp. 5719–5739, Mar. 2023.

[118] K. Meng et al., "UAV-enabled integrated sensing and communication: Opportunities and challenges," *IEEE Wireless Commun.*, early access, 2023, doi: 10.1109/MWC.131.2200442.

[119] L. Xing and B. W. Johnson, "Reliability theory and practice for unmanned aerial vehicles," *IEEE Internet Things J.*, vol. 10, no. 4, pp. 3548–3566, Feb. 2023.

[120] Y. Xu, S. Wandelt, and X. Sun, "IMMUNER: Integrated multimodal mobility under network disruptions," *IEEE Trans. Intell. Transp. Syst.*, vol. 24, no. 2, pp. 1480–1494, Feb. 2023.

[121] W. Kai, A. Jacquillat, and V. Vaze, "Vertiport planning for urban aerial mobility: An adaptive discretization approach," *Manuf. Service Oper. Manage.*, vol. 24, no. 6, pp. 3215–3235, Nov. 2022.

[122] N. Cheng et al., "AI for UAV-assisted IoT applications: A comprehensive review," *IEEE Internet Things J.*, vol. 10, no. 16, pp. 14438–14461, May 2023.

[123] A. Hemmati, M. Zarei, and A. Souri, "UAV-based Internet of Vehicles: A systematic literature review," *Intell. Syst. With Appl.*, vol. 18, May 2023, Art. no. 200226. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2667305323000510

[124] C. Dinelli et al., "Configurations and applications of multi-agent hybrid drone/unmanned ground vehicle for underground environments: A review," *Drones*, vol. 7, no. 2, p. 136, Feb. 2023. [Online]. Available: https://www.mdpi.com/2504-446X/7/2/136

[125] M. Osiecki, A. Fortonska, and E. Ksiazek-Janik, "Criminal liability for unlawful usage of unmanned aircraft vehicles in selected countries of the world," in *Proc. Int. Conf. Unmanned Aircr. Syst. (ICUAS)*, Jun. 2023, pp. 903–910.

[126] M. C. Scheau, M. V. Achim, L. Găbudeanu, V. L. Văidean, A. L. Vîlcea, and L. Apetri, "Proposals of processes and organizational preventive measures against malfunctioning of drones and user negligence," *Drones*, vol. 7, no. 1, p. 64, Jan. 2023. [Online]. Available: https://www.mdpi.com/2504-446X/7/1/64

[127] Y. Xu et al., "Machine-Learning-Assisted optimization of aircraft trajectories under realistic constraints," *J. Guid., Control, Dyn.*, vol. 46, no. 9, pp. 1814–1825, Sep. 2023.

[128] M.-W. Li, D.-Y. Xu, J. Geng, and W.-C. Hong, "A ship motion forecasting approach based on empirical mode decomposition method hybrid deep learning network and quantum butterfly optimization algorithm," *Nonlinear Dyn.*, vol. 107, no. 3, pp. 2447–2467, Feb. 2022.

[129] Y. Ding, S. Wandelt, G. Wu, Y. Xu, and X. Sun, "Towards efficient airline disruption recovery with reinforcement learning," *Transp. Res. E, Logistics Transp. Rev.*, vol. 179, Nov. 2023, Art. no. 103295.

[130] Y. Xu, S. Wandelt, and X. Sun, "A distributionally robust optimization approach for airline integrated recovery under in-flight pandemic transmission risks," *Transp. Res. Part C: Emerg. Technol.*, vol. 152, Jul. 2023, Art. no. 104188.

[131] Q. Wang, C. Xu, S. Leng, and S. Pollin, "When autonomous drones meet driverless cars," in *Proc. 16th Annu. Int. Conf. Mobile Syst., Appl., Services*, Jun. 2018, p. 514.

[132] Y. Wiseman, "Autonomous vehicles," in *Research Anthology on Cross-Disciplinary Designs and Applications of Automation*. Hershey, PA, USA: IGI Global, 2022, pp. 878–889.

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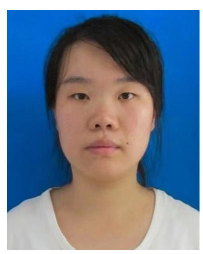

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