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UAV-Assisted Emergency Response: An Interdisciplinary Perspective

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Abstract. Unmanned Aerial Vehicles (UAVs) have attracted much attention from industries and academia because of their high accessibility, flexibility, efficiency, and low energy consumption. In the last decade, UAVs have been successfully applied in various emergency scenarios, and many new technologies and approaches have emerged from different disciplines. To facilitate the UAV application and technological development in emergency scenarios, this paper systematically analyzes UAV-assisted emergency response from the perspectives of different disciplines and their interactions. Specifically, an in-depth bibliometric analysis was conducted on the related research papers published in the last twenty years. Then the application scenarios, technological focuses, and open questions were discussed. Results show that UAV-assisted emergency response is a typical interdisciplinary topic that attracts contributions from disciplines including medicine, communication, geology, and transportation. In particular, the interdisciplinarity of the medicine-transportation domain, communication-geology domain, and transportation-communication domain has been widely discussed.

Keywords. Unmanned Aerial Vehicle (UAV), emergency management, disaster response, bibliometric analysis, interdisciplinary perspective

Introduction

With the continuous development of Unmanned Aerial Vehicle (UAV) technology, UAVs are widely used in various fields, such as logistics [1], communication [2], geology [3], and emergency response [4, 5]. For example, UAVs can deliver packages to customers equipped with express boxes [6] and facilitate on-site treatment of out-of-hospital cardiac arrest patients by carrying Automated External Defibrillators (AED) [7]. Subsequently, many researchers have conducted extensive studies on UAVs' underlying technologies and extended applications [8].

To better understand the development of UAVs in these fields, researchers have made significant contributions to the reviews of UAV applications. For example, in the geology discipline, the works on UAV-assisted mining [9], UAV-based remote sensing [3, 10], and UAV-based photogrammetry [11] have been systematically summarized. In the communication discipline, reviews on UAV path planning with 5G communication [2] and UAV Ad Hoc networks [12] have been comprehensively discussed. Meanwhile, some reviews on UAV-assisted emergency response have been conducted from the perspective of disaster management [13] and medicine delivery [14].

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Although previous review systematically summarized the technological development of UAVs in emergency scenarios, it is worth noting that UAV-assisted emergency response is an interdisciplinary topic that requires integrated efforts from engineering disciplines, management sectors, etc. It requires interdisciplinary knowledge to integrate parts of the original disciplines into a broader [15]. Specifically, how to efficiently cope with domain-specific objectives or constraints with the state-of-the-art UAV technologies and how to integrate diverse technologies for cooperative emergency response are still open to be discussed. Therefore, it is vital to conduct interdisciplinary research on UAV-assisted emergency response.

Currently, reviews about UAV-assisted emergency response mainly focus on one discipline, which cannot well capture the interdisciplinary features of UAV-assisted emergency response. To fill this gap, this paper conducts a literature review of UAV-assisted emergency response from an interdisciplinary perspective. A bibliometric analysis is carried out concerning the publication year, keywords, and top contributors. Then, the interdisciplinary research of UAV-assisted emergency response is analyzed, followed by discussions on the main research problems and future perspectives.

The rest of this paper is organized as follows. Section 1 presents data sources and research methodology. Section 2 conducts a bibliometric analysis, and Section 3 analyzes interdisciplinary research domains of the UAV applications in emergency response. Section 4 concludes the paper and proposes future research perspectives.

1. Data resources and methodology

In this work, we focus on the review of international journal papers published between 2002 and 2022. The overall paper searching and selecting process is depicted in Fig. 1. We use 12 groups of keywords related to “UAV” ("UAV", "Unmanned Aerial Vehicle", "Drone") and “Emergency” ("Emergency", "Disaster", "Pandemic", "Healthcare") for topic searching in Web of Science and Scopus. After collecting papers from the two databases, we delete reduplicative and irrelative papers with a brief review by title, keywords, and abstract. Finally, 883 papers are selected for the following analysis.

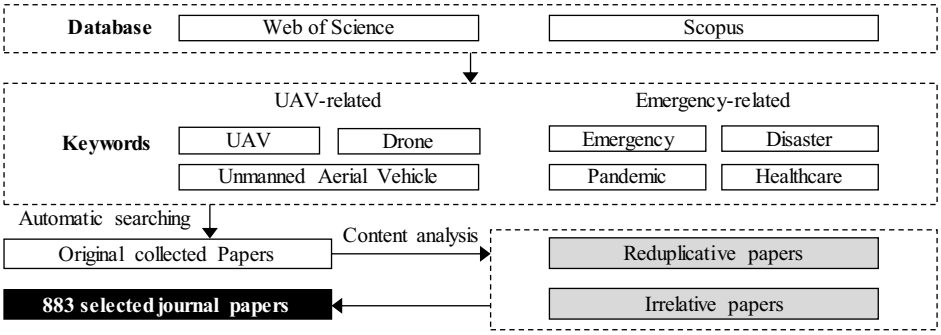

Figure 1. The overall paper searching and selecting process.

2. Bibliometric analysis

In this section, the overall analysis of the selected journal papers is conducted, including publication year, keyword distribution, and top contributors.

2.1. Publication year

The publication year is first examined in this section to understand the development trend for UAV-assisted emergency response.

As Fig. 2 shows, research on UAV-assisted emergency response continuously increasing for 20 years and has increased exponentially since 2015. In 2020-2022, there was a significant increase (nearly doubled) in publications. In 2002, Schawe et al. started with the aerodynamic design and propulsion layout of High Altitude Long Endurance (HALE) UAVs, which could be further served for surveillance in high-altitude areas [16]. Since 2015, extensive literature has been published with the development of UAV technologies [17]. In addition, the rapid increase in 2020-2022 may be driven by the outbreak of COVID-19 [18] and frequent natural disasters [19], in which UAVs could provide contactless delivery and timely responses.

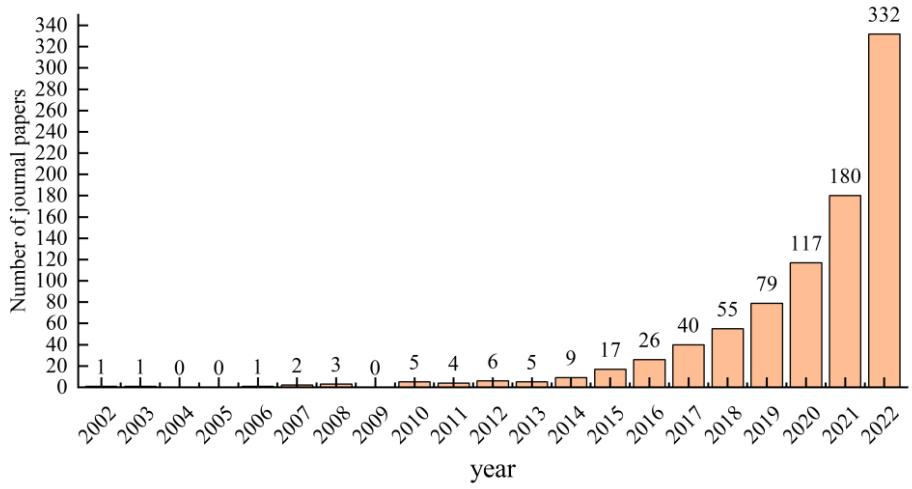

Figure 2. Numbers of journal papers published between 2002 and 2022.

2.2. Keyword distribution

This part discusses the keyword distribution from categories of discipline, application, and method.

Table 1. Keywords distribution among different categories.

Categories	Keywords	Frequency	Categories	Keywords	Frequency
Discipline	Communication	280	Application	Delivery	76
	Engineering	240		Mapping	76
	Medicine	200		Internet of Things	70
	Computer Science	196		Remote Sensing	63
	Geology	75	Method	Networks	184
	Transportation	57		Optimization	135
	-	-		Algorithm	98
	-	-		Management Science	53

Table 1 shows that disciplines such as communication, engineering, medicine, computer science, geology, and transportation have given more attention and technical support to UAV-assisted emergency response. For applications in emergency response,

UAVs play essential roles in delivery, mapping, Internet of Things (IoT), and remote sensing, with keyword frequencies of 76, 76, 70, and 63, respectively. Regarding methodologies adopted, network science, optimization technics, intelligent algorithms, and management science are the most frequently used methods.

2.3. Top contributors

In this part, top contributors are analyzed to address the main contributors worldwide.

Table 2. Top-10 contributors over the period.

Author	Papers	Discipline	Department
Claesson, A.	7	Transportation, medicine	Department of Medicine
Hollenberg, J.	6	Transportation, medicine	Department of Medicine
Munawar, H. S.	6	Communication, geology	School of Built Environment
Nordberg, P.	6	Transportation, medicine	Department of Medicine
Ringh, M.	6	Transportation, medicine	Department of Medicine
Svensson, L.	6	Transportation, medicine	Department of Medicine
Wang, J.	6	Communication, geology	National Engineering Research Center for Information Technology in Agriculture
Wang, L.	6	Communication, geology	National Engineering Research Center for Information Technology in Agriculture
Kumar, N.	5	Communication	Department of Computing and IT
Chan, T. C. Y.	5	Transportation, medicine	Department of Mechanical and Industrial Engineering

On the one hand, a statistical analysis is conducted on the published journal papers of each author (see Table 2). Claesson, Hollenberg, Nordberg, Ringh, and Svensson are the most contributed authors to the UAV-assisted emergency response, with six collaborative papers published related to out-of-hospital-cardiac-arrest response with UAVs from 2016. Furthermore, it is noted that they are all from the Department of Medicine in Karolinska, with a close collaboration relationship. Claesson et al. first investigated the feasibility and efficiency of emergency response by UAVs carrying an AED [20]. Subsequently, a bunch of research on the delivery time of UAVs [21], the efficiency of UAVs searching for drowning people [22], and efficient solutions [23] were conducted sequentially and logically. In addition, Munawar contributed much to the UAVs' application, with the topic of detecting natural disasters [24], analyzing bushfires [25], and delivering medical supplies [26]. Besides, Wang and Wang from the National Engineering Research Center for Information Technology in Agriculture significantly contributed to communication technology using UAVs to detect potential disasters [27]. Meanwhile, it is found that the disciplines these authors studied mainly concentrated on intersections between transportation and medicine, and communication and geology.

On the other hand, the countries of the papers are analyzed. As Fig. 3 shows, China, the United States, India, and Italy are the countries with the most papers published on this topic. Specifically, there are 135 papers from China and 47 from the United States.

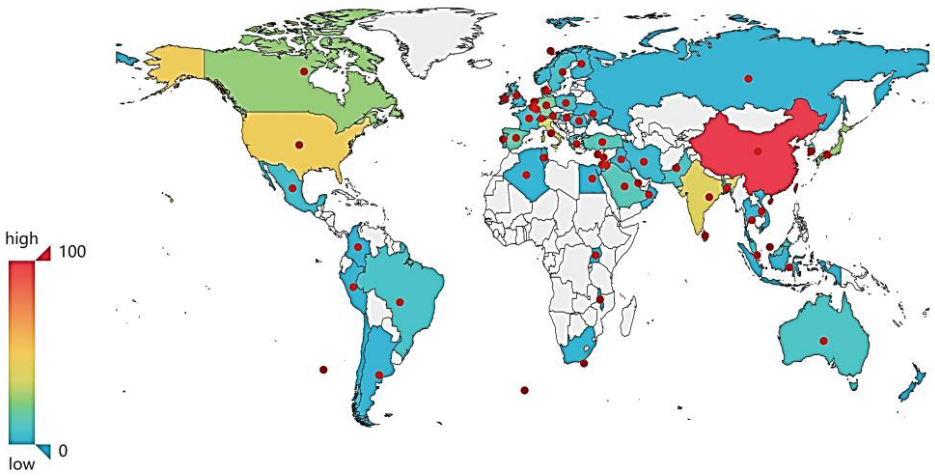

Figure. 3: Top contributors by countries.

3. Interdisciplinary research domains

Based on the above analysis, this part mainly focuses on the discussion in communication, medicine, geology, and transportation disciplines and their interactions.

3.1. Overall Interdisciplinary analysis

Aiming at understanding the research progress of interdiscipline in UAV-assisted emergency response, the interdisciplinary research papers on communication, transportation, and geology are analyzed in this part (see Table 3).

Table 3. Interdisciplinary research among communication, medicine, transportation, and geology.

Number of papers	Communication	Medicine	Transportation	Geology
Communication		12	15	49
Medicine	12		54	3
Transportation	15	54		0
Geology	49	3	0	

Table 3 shows that the main interdisciplinarity domains are medicine-transportation (54 papers), communication-geology (49 papers), and transportation-communication (15 papers). Particularly, interactions between medicine and transportation are extensively studied, considering efficient medicine delivery supported by transportation technics. In addition, the interdisciplinarity of geology and communication is primarily investigated considering effective geologic mapping and surveillance supported by communication.

3.2. Medicine-Transportation domain

Since medical transportation is extremely time-pressured while there are many uncertain factors such as traffic jams and detours in road transportation, it is appropratie to use UAVs for assistance in emergencies. The interaction between medicine and transportation has been extensively studied since 2019, including AED delivery [7], medicine transportation [28], testing kits transportation [29], blood transportation [30],

etc. In these applications, empirical studies, path planning problems, network design problems, and collaborative UAVs and other transports are the most prevalent problems.

In recent years, many researchers have tried to analyze the feasibility [31], performance [32], and effect [33] of UAV-assisted medicine transportation through numerous case studies and simulations. After being verified feasible in some pilot studies, the application of UAVs in medical transportation becomes popular in recent years, especially during the pandemic. More researchers have begun investigating the UAV scheduling problem, such as UAV deployment for improving response efficiency [34] and UAV route planning for timely medical transportation [29]. In addition, cooperation such as truck-UAV [6] and human-UAV [14] also received attention to maximize the advantages of UAVs in medical transportation.

The medicine-transportation domain is increasingly developing with progressive attention and efforts. However, contemporary studies of the medicine-transportation domain mainly focus on response efficiency. The goal of UAV-assisted medicine-transportation systems is not only response efficiency but also humanitarian-related objectives (fairness and safety) and system-related objectives (robustness, resilience, and reliability). Therefore, it is recommended to investigate advanced technologies in the medicine-transportation domain, such as resilient truck-UAV collaboration systems.

3.3. Communication-Geology domain

Remote sensing is a critical geologic technology that utilizes collected data to surveil disaster-affected areas [35]. In recent years, UAVs have been extensively applied to assist remote sensing because of their flexibility. To achieve real-time and accurate surveillance, various communication technologies are applied to assist remote sensing information acquisition. Thus, the interaction between communication and geology attracts much attention from researchers in communication and geology disciplines. In this domain, UAVs are frequently adopted in sensing data collection and processing.

For sensing data collection, UAVs are utilized in two ways. On one hand, assisted with device-to-device communication, UAVs are responsible for collecting data from geologic sensors, which are mainly deployed to surveil the geologic changes for a long time in remote areas that wireless communication networks cannot cover [36]. In this circumstance, UAVs collect data from sensors and deliver data to the base station (BS) to support emergency response [37]. On the other hand, UAVs can execute remote sensing tasks after being equipped with sensing devices. Considering collaborative multi-UAV systems, allocating heterogeneous tasks (such as sensing and data delivery) among distributed UAVs is possible to improve the quality of remote sensing [38].

UAVs also perform as data transmission and computing nodes for sensing data processing. On one hand, UAVs can transmit real-time data to Mobile Edge Computing (MEC) servers, thus ensuring efficient data processing [39]. On the other hand, UAVs also serve as computing nodes, providing computing support for remote disaster-affected areas and reducing the latency caused by data transmission [40]. As a result, geology-related tasks, such as surveillance and mapping, can be accelerated.

Overall, UAVs have a wide range of applications in communication and geology. Once merged with new communication technologies, remote sensing will greatly help emergency response. Researchers can further study the UAV scheduling problem (such as deployment and path planning), wireless resource allocation problem, and sensing task allocation problem to achieve real-time and accurate remote sensing.

3.4. Transportation-Communication domain

Taking incomplete information and urgent rescue tasks in the affected areas into account, some researchers considered the collaborative multi-UAV network for relief distribution. This fosters the interdisciplinary studies between transportation and communication.

With the above concerns, one of the most well-known research problems in the transportation-communication domain is the integrated information transmission and path planning problem for UAVs. Gao et al. used the cooperative UGV-UAV for emergency resource delivery. They investigated how to accept the operation order from the commander and how to generate a nested vehicle routing planning of the cooperative UGV-UAV by developing an intelligent task understanding module and a mixed integer linear programming [41]. Furthermore, Zafar et al. designed a distributed method for heterogeneous UAV fleets to communicate and schedule the relief operations for flood rescue, promising a more effective solution for disaster relief [42].

UAV communication network design for transportation also attracts many attentions from the academia. Micheletto et al. proposed a Flying Real-Time Network to support communication during disaster relief efforts [43]. Tang et al. developed a multi-objective optimization algorithm for muti-UAV emergency task planning [44].

In conclusion, the interaction of transportation and communication emphasizes the issues of path planning and UAV network design. With the communication support of the multi-UAV system, the performance of relief transportation with incomplete and dynamic information can be further improved.

3.5. Others

In addition to the three interdisciplinary domains, the medicine-communication and medicine-geology domains have been studied to a small extent.

Researchers have paid attention to telehealthcare regarding the interaction between medicine and communication to support out-of-hospital cardiac arrest rescue. On one hand, UAVs collect and transmit real-time spatiotemporal data and healthcare data with communication technology support [45-47]. On the other hand, UAVs help construct intelligent wearable device networks by assisting data transmission, computing offloading, and wireless power transfer [48].

In the medicine-geology domain, some works investigated surveillance technologies for infectious diseases. For example, Fornace et al. proposed that using UAVs to collect spacial information could benefit the research of infectious disease epidemiology and public health in 2014 [49]. During the COVID-19 pandemic, Masmoudi et al. studied the compelling image-capturing method and UAV trajectory design algorithm for UAVs, thus alerting them in case of unusual outdoor activities [50].

In general, researchers have started to focus on the interactions between medicine and other disciplines, which promotes the development of UAV-assisted intelligent telehealthcare, especially out-of-hospital cardiac arrest. Therefore, further discussion and exploration could benefit the emerging interdisciplinary domains of medicine-communication and medicine-geology.

4. Conclusions

In this paper, we have reviewed the UAV-assisted emergency response from an interdisciplinary perspective. Specifically, a bibliography analysis of UAV-assisted emergency response is presented based on the collected journal papers from 2002 to 2022, highlighting the year distribution, keyword distribution, and top contributors. In addition, interdisciplinary research domains are investigated from three streams: the medicine-transportation domain, the communication-geology domain, and the transportation-communication domain. Meanwhile, it is found that different interdisciplinary domains in UAV-assisted emergency response lie in several similar and important research problems, such as UAV network design and path planning.

However, research on interdisciplinary domains in UAV-assisted emergency response is still developing. In future, researchers can collaborate with colleagues from different departments and areas about UAV-assisted emergency response. In addition, some open issues are raised to better address UAV-assisted emergency response. First, new evaluation indicators could be designed to make trade-off between the objectives of different disciplines, such as the trade-off between fairness and efficiency in medicine-transportation domain and trade-off between exploration and exploitation in communication-geology domain. Second, it is necessary to explore the potential of novel collaborative mode (e.g., truck-UAV collaboration, human-UAV interactions) in UAV-assisted emergency response. Third, efforts can be made to develop intelligent decision-making methods for UAV-assisted emergency response under uncertain and dynamic scenarios.

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