Unmanned Aerial Vehicles Control in Smart Cities

Subjects: Automation & Control Systems

Contributor: Nadir Abbas, Zeshan Abbas, Xiaodong Liu, Saad Saleem Khan, Eric Deale Foster, Stephen Larkin

Smart cities leverage innovative technologies, including the Internet of Things (IoT) and unmanned aerial vehicles (UAVs) , to enhance residents' quality of life. UAV infrastructure in smart cities provides a cost-effective and efficient means of data collection, monitoring, surveillance, and infrastructure assessment. They contribute to better urban planning, resource management, emergency response, public safety, and sustainable development, ultimately improving the quality of life for city residents.

Keywords: unmanned aerial vehicles ; smart cities

1. Introduction

Optimizing age and power consumption in Internet of Things (IoT) applications using unmanned aerial vehicles (UAVs) and their battery recharge is a crucial undertaking for the development of future smart cities [1]. Optimizing the flight paths of UAVs to minimize age and power consumption, while ensuring comprehensive data coverage, holds significant importance. Leveraging UAVs for environmental monitoring presents both challenges and opportunities, particularly in collecting data from remote or inaccessible regions. The effectiveness of UAV systems has been exemplified through various case studies, showcasing their potential impact [2]. Efficient control of UAVs plays a crucial role in the betterment of smart cities. UAVs equipped with advanced control systems can efficiently navigate through urban environments, collecting high-quality data from various sensors. This data is invaluable for smart city applications, such as traffic management, environmental monitoring, and infrastructure assessment. By controlling UAVs effectively, cities can gather accurate and real-time information, enabling informed decision-making and proactive interventions [3][4]. UAVs with efficient control algorithms can optimize the use of available resources in smart cities. For instance, they can monitor utility networks, detect leakages or faults, and assist in maintenance activities. By identifying inefficiencies and potential problems promptly, cities can improve the reliability and sustainability of critical infrastructure systems like water supply, electricity grids, and waste management. UAVs with precise control capabilities can be deployed for surveillance and security purposes in smart cities. They can monitor crowded areas, identify suspicious activities, and provide real-time situational awareness to law enforcement agencies [5]. With efficient control, UAVs can navigate complex urban environments, maintain stable flight paths, and quickly respond to emerging security threats. During emergencies such as natural disasters or accidents, UAVs with efficient control systems can be deployed for rapid response and rescue operations. They can quickly reach inaccessible or hazardous areas, assess the situation, and provide critical information to emergency responders. By streamlining rescue efforts and improving coordination, efficient control of UAVs can save lives and minimize damage in smart cities. UAVs can play a significant role in improving transportation systems within smart cities. With efficient control algorithms, they can support traffic management, monitor congestion, and provide real-time data for route optimization. UAVs can also facilitate last-mile delivery services, reducing traffic congestion and enhancing efficiency in urban logistics [6].

UAVs have emerged as a highly significant technology in the geoscience and remote sensing fields over the past twenty years. They have gained popularity across various applications and have often replaced other platforms due to their versatility and relatively affordable costs. This rise in prominence is evident from the substantial number of scientific papers dedicated to UAVs published across different research communities during this period. According to Scopus, more than 80,000 papers have been published since 2001 using terms like "UAV", "drone", "UAS", and "RPAS" in the title or keywords. The majority of these publications are within the engineering and computer science domains [7]. This growing interest in UAVs from the scientific community is not limited to a single citation indexing database, as other databases also reflect this trend. Furthermore, the UAV business has experienced significant financial growth, with a valuation of several billion dollars per year. Although the majority of the market is currently focused on military applications, the future prospects for UAVs are promising. Economic interests, technological advancements, the miniaturization of onboard sensors, and the development of new algorithms and software have collectively driven the emergence of new applications, which in turn have created new business opportunities. While UAV surveying applications were the initial focus, more advanced applications have emerged, leading to new requirements and further expanding the scope of UAV utilization. Notably, UAV systems capable of rapid, automated, and autonomous geospatial data collection are making significant contributions to the ongoing fourth industrial revolution [8]. Indeed, new and emerging applications of UAVs continue to expand across various industries. Construction and infrastructure monitoring are prime examples of how UAVs are being utilized for aerial inspections, progress tracking, and site surveillance in construction projects. They offer efficient and cost-effective means of obtaining high-resolution imagery, collecting data, and monitoring project developments.

Control theory (nonlinear, linear, intelligent control, and hybrid control) is important for UAVs in smart cities. UAVs, or drones, play a crucial role in various applications within smart cities, such as surveillance, delivery services, and infrastructure inspection. Control theory provides the foundation for designing and implementing control algorithms that enable UAVs to navigate, stabilize, and perform tasks autonomously.

In smart cities, UAVs need to operate in complex and dynamic environments, where they must adapt to changing conditions and interact with other systems. Control theory helps in developing control strategies that allow UAVs to respond to environmental changes, avoid obstacles, optimize energy consumption, and ensure safe and efficient operations. Efficient control is essential for UAVs in smart cities as it enables them to operate autonomously, adapt to changing conditions, and perform tasks with precision and efficiency.

2. Important Applications of Unmanned Aerial Vehicles in Smart Cities

UAV infrastructure in smart cities provides a cost-effective and efficient means of data collection, monitoring, surveillance, and infrastructure assessment. They contribute to better urban planning, resource management, emergency response, public safety, and sustainable development, ultimately improving the quality of life for city residents.

UAVs equipped with sensors, cameras, or other data collection devices can capture high-resolution imagery, perform aerial surveys, and collect various types of data. This data is invaluable for urban planning, infrastructure management, environmental monitoring, and decision-making processes in smart cities. UAVs enable efficient and cost-effective data collection, providing accurate and up-to-date information. Drones can inspect critical infrastructure, such as bridges, buildings, power lines, and pipelines. They can reach inaccessible or hazardous areas, allowing for quick and accurate assessment of structural integrity, identification of maintenance needs, and detection of damage or potential risks. Regular inspections using UAVs enhance safety, reduce maintenance costs, and improve the lifespan of infrastructure. Drones are valuable tools in emergency situations. They can be quickly deployed to assess disaster-affected areas, search for missing persons, and provide situational awareness to emergency responders. UAVs equipped with thermal sensors can detect hotspots in fires or identify people in need of rescue. Additionally, they can deliver emergency supplies to remote or inaccessible locations, improving response times and saving lives. UAVs enable efficient monitoring of environmental parameters such as air quality, pollution levels, temperature, and vegetation health. This data aids in identifying environmental challenges, assessing the impact of urban activities, and implementing sustainable solutions. UAVs can support environmental planning, pollution control, and conservation efforts in smart cities. Delivery drones offer an efficient and environmentally friendly alternative for transporting goods within smart cities [9][10]. They can navigate congested areas more easily and reach destinations faster, enabling quick and convenient delivery of packages, medical supplies, or emergency response materials. Delivery drones contribute to reducing traffic congestion, lowering carbon emissions, and enhancing logistics operations.

The advancements in electronics and manufacturing processes have allowed for the miniaturization of controllers, sensors, and processors while retaining their effectiveness. This breakthrough has given rise to compact configurations of UAVs. The potential inherent in this size reduction is vast and offers numerous advantages. In 2016, PwC published the report “Clarity from Above”, revealing that the addressable market value of drone-powered solutions exceeds USD 127 billion, indicating that the drone revolution is causing significant disruptions across a wide range of industries [11]. UAVs, commonly known as drones, have a wide range of applications across various fields due to their versatility, efficiency, and ability to access hard-to-reach areas. Here are some of the key applications of UAVs in different sectors:

2.1. Agriculture

Drones are used for precision agriculture. They can monitor crop health, track livestock, and even assist in planting and spraying crops. They can provide detailed aerial imagery that helps farmers make informed decisions about their crops and livestock [12].

2.2. Construction and Infrastructure

Drones are used for surveying land, inspecting structures, and monitoring construction progress. They can provide high-resolution images and videos that can help in planning, monitoring, and inspecting construction sites [13].

2.3. Disaster Management

Drones can be used in disaster management for search and rescue operations, damage assessment, and delivering emergency supplies. They can reach areas that are difficult or dangerous for humans to access [14].

2.4. Environmental Monitoring and Conservation

Drones are used for wildlife monitoring, forest conservation, and environmental research. They can collect data on wildlife populations, track animal movements, and monitor environmental changes [15].

2.5. Delivery Services

Companies like Amazon and Google are testing drones for delivering goods to customers. Drones can potentially make deliveries faster and more efficient, especially in congested urban areas [16].

2.6. Media and Entertainment

Drones are used for aerial photography and videography in films, news coverage, and sports events. They can capture unique angles and perspectives that would be difficult or impossible to achieve with traditional cameras [17].

2.7. Military and Defense

Drones are used for surveillance, reconnaissance, and combat missions. They can gather intelligence, carry out strikes, and perform other tasks without putting human lives at risk [18].

2.8. Healthcare

Drones are being explored for transporting medical supplies, especially to remote or hard-to-reach areas. They can deliver medicines, vaccines, blood samples, and other medical supplies quickly and efficiently [19].

2.9. Scientific Research

Drones are used in various scientific research fields, including meteorology, geology, and archaeology. They can collect data in hazardous or inaccessible areas, making them a valuable tool for researchers [20].

2.10. Real Estate

Drones are used in the real estate industry to capture aerial views of properties. This provides potential buyers with a better perspective of the property, its surroundings, and features like the roof that is difficult to inspect from the ground [21].

Understanding the types and characteristics of UAVs is essential for comprehending their capabilities and operation means that in order to fully grasp what UAVs are capable of doing and how they function, it is crucial to have knowledge about their specific qualities and physical makeup.

References

1. Eldeeb, E.; de Souza Sant’Ana, J.M.; Pérez, D.E.; Shehab, M.; Mahmood, N.H.; Alves, H. Multi-UAV Path Learning for Age and Power Optimization in IoT with UAV Battery Recharge. IEEE Trans. Veh. Technol. 2022, 72, 5356–5360.
2. Mahmood, A.; Vu, T.X.; Khan, W.U.; Chatzinotas, S.; Ottersten, B. Optimizing Computational and Communication Resources for MEC Network Empowered UAV-RIS Communication. In Proceedings of the 2022 IEEE Globecom Workshops (GC Wkshps), Rio de Janeiro, Brazil, 4–8 December 2022; pp. 974–979.
3. Liu, C.; Ke, L. Cloud assisted Internet of things intelligent transportation system and the traffic control system in the smart city. J. Control Decis. 2023, 10, 174–187.
4. Bucolo, M.; Buscarino, A.; Fortuna, L.; Gagliano, S. Bifurcation scenarios for pilot induced oscillations. Aerosp. Sci. Technol. 2020, 106, 106194.

5. Javaid, S.; Saeed, N.; Qadir, Z.; Fahim, H.; He, B.; Song, H.; Bilal, M. Communication and Control in Collaborative UAVs: Recent Advances and Future Trends. IEEE Trans. Intell. Transp. Syst. 2023, 24, 5719–5739.
6. Gohari, A.; Ahmad, A.B.; Rahim, R.B.A.; Supa'at, A.S.M.; Razak, S.A.; Gismalla, M.S.M. Involvement of surveillance drones in smart cities: A systematic review. IEEE Access 2022, 10, 56611–56628.
7. Mohsan, S.A.H.; Othman, N.Q.H.; Li, Y.; Alsharif, M.H.; Khan, M.A. Unmanned aerial vehicles (UAVs): Practical aspects, applications, open challenges, security issues, and future trends. Intell. Serv. Robot. 2023, 16, 109–137.
8. Mozaffari, M.; Saad, W.; Bennis, M.; Nam, Y.-H.; Debbah, M. A tutorial on UAVs for wireless networks: Applications, challenges, and open problems. IEEE Commun. Surv. Tutor. 2019, 21, 2334–2360.
9. Tastemirov, A.; Lecchini-Visintini, A.; Morales, R.M. Complete dynamic model of the Twin Rotor MIMO System (TRMS) with experimental validation. In Proceedings of the 39th European Rotorcraft Forum, Moscow, Russia, 3–6 September 2013.
10. Geraci, G.; Garcia-Rodriguez, A.; Giordano, L.G.; López-Pérez, D.; Björnson, E. Understanding UAV cellular communications: From existing networks to massive MIMO. IEEE Access 2018, 6, 67853–67865.
11. Giacomossi, L.; Dias, S.S.; Brancalion, J.F.; Maximo, M.R.O.A. Cooperative and decentralized decision-making for loyal wingman UAVs. In Proceedings of the 2021 Latin American Robotics Symposium (LARS), 2021 Brazilian Symposium on Robotics (SBR), and 2021 Workshop on Robotics in Education (WRE), Natal, Brazil, 11–15 October 2021; pp. 78–83.
12. Pan, E.; Xu, H.; Yuan, H.; Peng, J.; Xu, W. HIT-Hawk and HIT-Phoenix: Two kinds of flapping-wing flying robotic birds with wingspans beyond 2 meters. Biomim. Intell. Robot. 2021, 1, 100002.
13. Ahmed, F.; Mohanta, J.C.; Keshari, A.; Yadav, P.S. Recent Advances in Unmanned Aerial Vehicles: A Review. Arab. J. Sci. Eng. 2022, 47, 7963–7984.
14. Orozco, R.G. Mixed sensitivity control: A non-iterative approach. Syst. Sci. Control Eng. 2020, 8, 441–453.
15. Ramalakshmi, A.P.S.; Manoharan, P.S. Non-linear modeling and PID control of twin rotor MIMO system. In Proceedings of the 2012 IEEE International Conference on Advanced Communication Control and Computing Technologies (ICACCCT), Ramanathapuram, India, 23–25 August 2012; pp. 366–369.
16. Ahmad, U.; Anjum, W.; Bukhari, S.M.A. H2 and H∞ controller design of twin rotor system (TRS). Intell. Control Autom. 2013, 4, 27843.
17. John, L.; Mija, S.J. Robust H∞ control algorithm for twin rotor MIMO system. In Proceedings of the 2014 IEEE International Conference on Advanced Communications, Control and Computing Technologies, Ramanathapuram, India, 8–10 May 2014; pp. 168–173.
18. Chaudhary, S.; Kumar, A. Control of twin rotor mimo system using 1-degree-of-freedom PID, 2-degree-of-freedom PID and fractional order PID controller. In Proceedings of the 2019 3rd International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, 12–14 June 2019; pp. 746–751.
19. Wen, P.; Li, Y. Twin rotor system modeling, de-coupling and optimal control. In Proceedings of the 2011 IEEE International Conference on Mechatronics and Automation, Beijing, China, 7–10 August 2011; pp. 1839–1842.
20. Hernandez, B.; Steven, O.H.; Angelo, M.L.; Giraldo, E. Rls estimation and sliding mode control with integral action for a twin rotor mimo system. In Proceedings of the 2019 IEEE 4th Colombian Conference on Automatic Control (CCAC), Medellin, Colombia, 15–18 October 2019; pp. 1–6.
21. Song, D.; Li, X.; Peng, Z. Mixed sensitivity H-infinity control of an adaptive optics system. Opt. Eng. 2016, 55, 094106.