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Internet of Things (IoT): Wireless Communications for Unmanned Aircraft System

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Abstract: In times of technological advancements, the use of aerial vehicles (UAVs), commonly known as drones, has become increasingly prevalent across various commercial and industrial sectors. UAVs find applications in agriculture, filmmaking, law enforcement, package delivery, aerial photography, videography, etc. There are benefits associated with utilizing UAVs. One key advantage is their ability to cover areas quickly and efficiently while accessing locations that may be challenging or hazardous for humans. Wireless communication technologies play a role in ensuring the functioning of Unmanned Aircraft Systems (UAS). Without these technologies, the United States of America would face difficulties communicating with ground control stations or relaying information to operators. This would significantly impede the country's mission execution and overall responsibilities. Wireless communication technologies (WCT) enable the United States to maintain awareness—essential for achieving successful and secure operations. Additionally, wireless technologies allow for Unmanned Aerial Systems (UAS) control, which is crucial for missions carried out in hostile or dangerous environments. The increasing usage of drones has highlighted the need to improve networks in the United States focusing on their ability to work together effectively handle volumes of data and provide reliable broadband connectivity. This research delves into communication technologies, in this domain emphasizing their advantages, limitations, industry standards and potential areas for future investigation to address the challenges revealed by this study.

Keywords: Wireless communications, Drones, A.I. security, Internet of things-IoT, Internet of drones.

Introduction

The Internet of Things (IoT) and innovative technology enhance control, automation, and domain efficiency. IoT is being utilized in many sectors such as healthcare, agriculture, smart cities, military, and other sectors to improve services and operations. As technology advances, it will create opportunities for streamlining processes, enhancing customer experiences and boosting efficiency. The up-to-date total number of IoT devices is expected to triple from about 9.7 billion in 2020 to about 29 billion by 2030. Both consumer markets and business verticals adopt devices extensively. By 2020 it is projected that the consumer market will account for

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than 60% of all connected devices a trend that is anticipated to remain consistent over Drones are among the devices utilized in both public and private sectors. In settings drones have applications including search and rescue missions, mapping land areas, conducting surveys and delivering medical supplies to remote locations. Drones have found applications in the sector including photography delivering goods and agricultural purposes. Looking ahead drones are anticipated to have a substantial impact on our daily lives. Their usage is expected to expand into areas such as search and rescue operations, traffic monitoring and weather observation. Unmanned Aircraft Systems (UAS) have diverse applications, including search and rescue, mapping, photography, and agricultural activities. With increasing internet-based technologies, drones are expected to revolutionize tasks in various fields. Wireless communications are crucial for safe and efficient UAS operations, providing real-time data to enhance decision-making and minimize risks. This article serves as an encompassing introduction to Wireless Communication Technologies for the UAS, exploring their potential applications and future implications in the rapidly expanding IoT landscape.

As unmanned aircraft system (UAS) technology is becoming particularly widespread in the present day, it should not be surprising that this study's objectives are aspirational. As a result, because this article is about Wireless Communication Technologies for the UAS, it ought to perform the function of an all-encompassing introduction to the subject matter.

Wireless Communications Technology History

James C. Maxwell proposed and verified the existence of electromagnetic waves in the 1860s (Kong, 1975; Sengupta, Sarkar, & Magazine, 2003), while Heinrich R. Hertz experimentally validated their presence in 1888 (Vainshtein, 1988). Marconi received Morse code from a spark-gap transmitter 2.4 kilometers away in 1895 (Smith & Pol., 2007). This experiment established wireless communication's essential structure. In wireless communication, the transmitter superimposes target information on a carrier wave, and the receiver extracts it (Lee, Shen, Lee, & Weng, 2016). After that, wireless technologies were created and upgraded for military usage. Broadcasting, one of the primary wireless uses, also increased commercially. Radio and T.V. began in the early half of the 20th century(Sarkar, Mailloux, Oliner, Salazar-Palma, & Sengupta, 2006). Since the late 1980s, wireless communication has been widely used in mobile phones and other mobile terminals as semiconductor and software technologies developed along with the internet's new infrastructure (Seymour & Shaheen, 2011). These change corporate and social models (Seymour & Shaheen, 2011).

Wireless communication technologies are developing and spreading. Wireless sensor network research and development is accelerating (Abdalkafor & Aliesawi, 2022). New systems are being created that can operate for several years on batteries while configuring their networks. Wireless digital technologies have advanced, and their practical utility for tackling security difficulties like radio interception or interference has progressed. Wireless communication technologies are spreading to fields such as disaster prevention, disaster response, crime prevention, security checks, environmental protection, health and welfare, transport, and logistics, and building monitoring and control (Parikh, Kanabar, & Sidhu, 2010; Ramli & Ahmad, 2011; Yang et al., 2015; Zeng, Zhang, & Lim, 2016; Zheng, You, Mei, Zhang, & Tutorials, 2022). Figure 1 provides an overview of recent wireless communication protocols applied for drones.

Wireless Communication Technologies

Wireless technologies are transforming the operation of unmanned aerial vehicles. With the capacity to communicate data wirelessly, UAVs may now be remotely controlled, allowing for greater operational flexibility and efficiency (Khandal, Jain, & Technology, 2014; H. Kim & Choi, 2016). In addition, wireless technology enables real-time monitoring of UAVs, enabling operators to make decisions and take swift action (Alsemmeari, Bakhsh, & Alsemmeari, 2016; Arya, Bhadoria, & Chaudhari, 2018; Molisch, 2012; Zheng et al., 2022). This strength is crucial in missions where time is of the essence, such as search and rescue missions. At the data link layer, several wireless technologies are now accessible to application developers. Each technology has distinctive qualities that make it attractive and acceptable for use (Beke et al., 2018; C. Chen et al., 2022; J. Chen, Wang, Zhou, Ahmed, & Wei, 2021; Custers, 2016; Nouacer et al., 2020; Savkin, Verma, & Anstee, 2022). Dependability, security, safety, and the absence of guiding cables are just a few of the critical advantages of WCT The many technologies used for wireless communication in IoT devices have been covered by when selecting the most suitable IoT communication-based applications, authors considered the following 7 WCTs (Haider et al., 2022; Kamruzzaman, 2022; Nguyen, Masaracchia, Sharma, Poor, & Duong, 2022; Oberascher, Rauch, Sitzenfrei, & Society, 2022; C. Pu & Zhu, 2022; Shilpa, Radha, & Movva, 2022; Tlili, Mnasri, & Val, 2022; Yu, Das, Park, & Lorenz, 2022). In Table 1, we show the most recently applied WCT technologies for UAS and the related parameters.

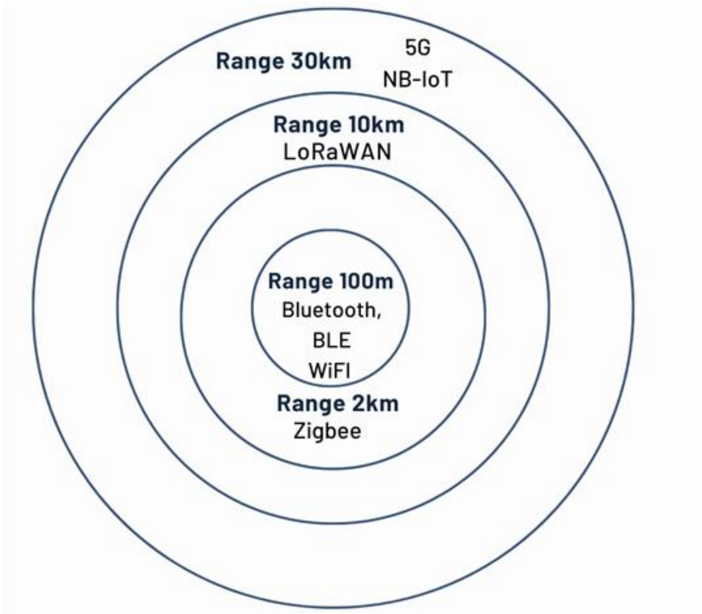

Figure 1. Recentwireless communication protocols for UAVs

Table 1: Popular wireless communication technologies applied for UAS

WCT Tech	Range	Power Use	Frequency/Bandwitch
Bluetooth	10m	Low	2.4 Ghz
Bluetooth Low Energy	8-10m	Very low	2.4 Ghz
Wi-fi	100m	Medium	2.4 Ghz, 5 Ghz
Zigbee	100-1500 m	Low	868 Mhz, 915 Mhz, 2.4 Ghz
LoRaWAN	30km	Low	500 Mhz, 868Mhz, 900 Mhz
Narrow Band-IoT	10km	Low	450 Mhz, 3.5 Ghz,
5G Network	30km	Low-High	200 Khz, 900 Khz

Bluetooth

Bluetooth wireless technology will replace the interconnect wires between several personal gadgets, such as notebook computers, cell phones, personal digital assistants (P.D.A.s), digital cameras, etc (Bluetooth, 2006). Bluetooth wireless technology intends to act as a ubiquitous, low-cost, user-friendly air interface that will replace the multitude of proprietary cords that individuals must carry and utilize to connect their gadgets (Jianfan Chen et al., 2021; Cho & Shin, 2021). While most personal devices communicate via the RS-232 serial port protocol, proprietary connectors and pin configurations prevent using the same cables to connect devices from various manufacturers and occasionally even the same manufacturer (Christoe, Yuan, Michael, & Kalantar-Zadeh, 2021; Claverie & Esteves, 2021). The primary objective of Bluetooth wireless technology is to provide a flexible cable connector with customizable pin configurations that enable several portable devices to communicate with one another.

This system relies on the IEEE 802.15.1 standard. In addition to other technologies, Bluetooth has four alternative data rate settings to accommodate a variety of transmission distances: 2 Mbps, 1 Mbps, 500 kbps, and 125 kbps (Pierleoni et al., 2021; Z. Pu, Cui, Tang, Wang, & Wang, 2021; Sollie, Gryte, Bryne, & Johansen, 2022).

Bluetooth drones offer several advantages to users. As they use the same technology with many consumer electronics, drones applied Bluetooth technology are more user-friendly. Bluetooth drones are much more affordable than other types of drones, making them a great option for those on a budget(Aguilar, Soria, Arrue, & Ollero, 2017; Kitchen, Chase, Sauter, & Bixler, 2020; Li et al., 2021b; Vucic & Axell, 2022). Bluetooth drones are equipped with advanced sensors, which allow them to navigate in a variety of terrain and environments.

With the smaller and lighter size, Bluetooth drones are extremely portable, allowing them to be taken virtually anywhere (Boccadoro, Santorsola, & Grieco, 2020; Ezuma, 2022; H. Kim & Choi, 2016; J. Kim et al., 2013).

While Bluetooth UAS offer a great deal of flexibility and convenience, they do have some drawbacks which must be considered (Li et al., 2021b; Liu, Noguchi, Liang, & Agriculture, 2019; Mandal et al., 2016). UAS rely on Bluetooth technology can be prone to interference from other electronic devices. This could lead to a loss of communication with the aircraft and a decrease in safety. Due to their reliance on Bluetooth, Bluetooth UAS are not suitable for long distance applications as the signal strength weakens over long distances (Medaiyese, Ezuma, Lauf, & Adeniran, 2022; Medaiyese, Ezuma, Lauf, Guvenc, & Computing, 2022). Bluetooth drones are also limited in their payload capacity, meaning they may not be suitable for heavier applications (Oh, Lim, & Kang, 2022; Soria, Palomino, Arrue, & Ollero, 2017; Swinney & Woods, 2021). Finally, due to their small size, Bluetooth drones as can be easily damaged in windy conditions, making them unsuitable for certain applications (Vucic & Axell, 2022; M. Zhou, Lin, Liang, Du, & Cheng, 2017).

Bluetooth Low Energy (BLE)

The most significant data rate that BLE can accomplish is 1Mbps, which may not always be sufficient for devices like wireless headphones that demand continuous data streaming (Avilés-Viñas et al., 2022; Barsocchi, Girolami, & La Rosa, 2021; Belwafi, Alkadi, Alameri, Al Hamadi, & Shoufan, 2022; Cantizani-Estepa et al., 2022). On the other hand, another internet of thing application requires periodic small data transmissions. BLE can be used to provide wireless control of a UAV, as well as to stream data from the UAV to a ground control station (Cayre et al., 2021; Guruge, Kocer, & Kayacan, 2015; Hashmi & Research, 2021).

Bluetooth Low Energy has a much lower latency than other types of wireless connections, which is vital for a drone to respond quickly to commands (Li et al., 2021a; Li et al., 2021b; Lodeiro-Santiago, Santos-González, & Caballero-Gil, 2016; Lodeiro-Santiago, Santos-Gonzalez, Caballero-Gil, Caballero-Gil, & Computing, 2020; Loke, Alwateer, & Abeysinghe Achchige Don, 2016). By utilizing BLE technology, these drones are more energy efficient, meaning they can fly for longer periods of time. Additionally, BLE UAVs/drones can communicate with other devices, allowing for more efficient data transfer and remote management (Loke et al., 2016; Long, 2021; Nishiura & Yamamoto, 2021; Nyholm, 2020). BLE drones are also able to transmit data faster and with greater accuracy. This strength makes them ideal for surveillance, mapping, aerial reconnaissance, and asset monitoring applications (Long, 2021; Rajakaruna et al., 2019; Singh & Swaminathan, 2022). BLE UAS can be easily integrated with other enterprise systems, allowing for seamless data exchange and faster decision-making (Rajakaruna et al., 2018; Stute, Heinrich, Lorenz, & Hollick, 2021; Vucic & Axell, 2022). BLE drones are more secure and can be easily tracked, providing greater peace of mind for users. UAV BLE offer a wide range of benefits and can be utilized to greater flexibility in flight paths and can be used in applications where traditional drones may not be as effective.

BLE technology for drones can provide many advantages, but there are also some potential disadvantages. The range of Bluetooth Low Energy UAS is typically limited to around 30 meters, which can be an issue if the drone needs to travel farther than that (Singh & Swaminathan, 2022; Vucic & Axell, 2022; Xu & Systems, 2022). Furthermore, the battery life of Bluetooth Low Energy UAS can be considerably shorter than other technologies, which can be a concern for applications with long flight times. Besides that, the cost of Bluetooth Low Energy UAS is typically much more expensive than other solutions, which can be a challenge for those with limited budgets (Rajakaruna et al., 2018; Singh & Swaminathan, 2022; Xu & Systems, 2022). Overcoming these disadvantages of BLE includes using a reliable and robust communication protocol and ensuring that the design accounts for potential interference. Finally, it’s important to ensure the system is thoroughly tested, maintained correctly, and meets the necessary performance requirements to operate reliably in real-world conditions (Tan et al., 2020). These steps allow BLE UAS systems to overcome their disadvantages and provide reliable, cost-effective solutions.

Wi-Fi

The term "Wi-Fi Wireless Fidelity," commonly known as Wi-Fi, is widely utilized as a wireless technology to connect various electronic devices through wireless area networks (WAN). This facilitates data transmission, including images and videos, over the network, making Wi-Fi drones ideal for live streaming and real-time data collection applications. W.N.I.C. can be either internal expansion cards or external USB or PCI devices, enabling computers to communicate wirelessly with one another through Wi-Fi or Bluetooth technology.

W.N.I.C.s play a crucial role in controlling drones, allowing remote control or formation flying.(de Carvalho Bertoli, Pereira, & Saotome, 2021).

Wi-Fi drones can also be susceptible to interference, leading to potential difficulties in control. Technological advancements in radar, GPS, and tracking technologies can aid in detecting and avoiding other aircraft in proximity (Khan, Hamila, Kiranyaz, & Gabbouj, 2019; Meesriyong, Wongwirat, & Namuduri, 2020; Nožica, Blažević, & Keser, 2021; Rubbestad & Söderqvist, 2021). Taking a proactive approach to safety and security will contribute to the reliable and responsible operation of Wi-Fi UAS.

Zigbee

Zigbee has gained popularity as a wireless technology option due, to its power consumption. This makes it a great choice for applications like UAS, where energy efficiency's crucial in the design process. While Zigbee UAS offers advantages for applications it's important to address some drawbacks. One concern is its nature, which means devices from manufacturers may not work together seamlessly. Zigbee can also be susceptible to interference from devices affecting its performance (Jia & Song, 2022; Katende, 2022; Krishna & engineering, 2017).

Table 2. Notable studies used Zigbee to conduct unmanned aircraft systems.

Authors	Title	Experiment	Empirical results
Zhou et al.(Q. Zhou, Wang, Yu, Huang, & Zhou, 2019)	"Unmanned patrol system based on Kalman filter and ZigBee positioning technology”	Estimate each UAV's location and exchange telemetry data between the aircraft and ground base.	Following use of a Kalman filter, the estimation is reliable.
Sineglazov and Daskal(Sineglazov & Daskal, 2017)	"Unmanned aerial vehicle navifation system based on IEEE 802.15. 4 standard radiounits"	UAV navigation system based on IEEE 802.15.4 radio equipment.	A wireless network can be used to make a prediction as to where a UAV is.
Bacco et al.(Bacco, Berton, Gotta, & Caviglione, 2018)	“IEEE 802.15.4 air-ground UAV communications in smart farming scenarios"	This study creates a test to assess the performance of IEEE 802.15.4 while considering a sensor network made up of fixed ground sensors and a UAV.	The transmission range between the ground nodes and the UAV is only around one third of its nominal value due to aerial mobility.
Ueyama et al.(Ueyama et al., 2014)	"Exploiting the use of unmanned aerial vehicles to provide resilience in wireless sensor networks"	A UAV system to increase wire-free sensor network resilience and lessen the impact of malfunctioning nodes or nodes damaged by natural disasters	Transporting UAVs to the disaster region and utilizing them as a router or data mule can help to reduce fault-related issues.
Mushtaq et al.(Mushtaq et al., 2015)	"Innovative conceptualization of Fly-By-Sensors (F.B.S.) flight control systems using ZigBee wireless sensors networks"	This research uses a fly-by-sensors (F.B.S.) control system, which is frequently employed for the main associated observation of in-flight operations.	The advantages of using ZigBee technology for regulating and monitoring the controlling function are highlighted by the authors: affordable price, low power consumption, dependable operatio n.
Nasution et al.(Nasution, Siregar, & Yasir, 2017)	"UAV telemetry communications using ZigBee protocol"	This study is a development of a UAV test system using the ZigBee protocol	Information can be successfully transferred from a UAV to a ground base where messages can contain up

To overcome these challenges organizations, need to prioritize the development of technologies that can minimize latency and interference problems. At the time efforts should focus on improving the range and accuracy of data transmission. Establishing cybersecurity protocols is critical to safeguarding UAS data and networks from threats posed by malicious actors. By investing in these areas, we can effectively minimize any impacts. Enhance the overall capabilities of Zigbee technology, for U.A.S applications. Table 2 shows some notable studies used Zigbee to conduct unmanned aircraft systems, their experiment design, and empirical results.

LoRaWAN

Long Range Wide Area Network (LoRaWAN) was developed to cater to the needs of Internet of Things (IoT) applications ensuring they meet requirements such as power efficiency, affordability, dynamics, dependability, and duplex communication. Many drones lack communication technologies that can cover areas while conserving power. Hence the focus of this investigation is to create a communication system with a range that consumes energy. Considering its power consumption LoRa emerges as one of the wireless physical layer technologies. Leveraging LoRaWAN in Unmanned Aerial Systems (UAS) enables the establishment of a range and low power wireless network. However, it should be noted that a limitation of LoRaWAN UAS Is their range— 10 kilometers before requiring proximity to a LoRaWAN gateway(Bianco, Mejia-Aguilar, & Marrocco, 2022; bin Edi, Abd Rashid, Ismail, & Cengiz, 2022; Calabrò & Giuliano, 2021; Cardoso et al., 2022). This constraint limits their applicability in long distance scenarios. Additionally, they have speeds with a maximum capability of around 20 kilometers, per hour1. Nonetheless there are measures to mitigate these drawbacks and ensure efficient utilization of LoRaWAN UAS systems.

Narrow Band-IoT

The " band" aspect of NB IoT refers to a radiofrequency used to communicate with these devices. NB IoT is primarily intended for areas with coverage such as basements or rural regions and for devices that don't require significant data usage like heart monitors or security sensors. Developed by 3GPP to cater to a range of devices and services, NB IoT is specifically designed for Internet of Things (IoT) applications that demand low bandwidth and long battery life. It operates on a spectrum ensuring quality of service (QoS) and security(Elijah et al., 2018; Kavuri, Moltchanov, Ometov, Andreev, & Koucheryavy, 2020; Malik, Bilandi, Gupta, & Engineering, 2022; Popli, Jha, & Jain, 2021).

NB IoT finds application in scenarios, including smart meters, asset tracking systems, security setups, environmental monitoring solutions and much more. Its low power consumption and extended battery life make it ideal for applications that involve periodic data transmissions. It caters to use cases requiring data rates and/or long-lasting battery performance, like smart meters, asset tracking systems and industrial monitoring setups.

NB IoT is a next generation version of the LTE standard that has been developed specifically for use, in spectrum. One of the advantages of NB IoT is its ability to greatly improve power consumption and spectral efficiency while still offering the coverage and capacity benefits as LTE. This makes it an ideal technology for applications that require lasting battery life and operate in difficult to access areas(Song, Zhang, Ji, Jiang, & Li, 2020; Wang, Chang, Fan, & Sun, 2020). However, it's worth noting that NB IoT does have some drawbacks, such as data rates, limited range and shorter battery life compared to types of UAS. To address these limitations one possible solution is to utilize a wider bandwidth. By doing more data can be. Received, leading to an overall enhancement, in data quality.

5G Network

The 5G network is seen as an advancement in technology offering speed and reliability. It achieves this by utilizing radio waves, which allows for data capacity and faster speeds. However, it's important to note that due to its susceptibility to interference and limited signal range additional technologies like beamforming and MIMO are needed to optimize signal direction and transmission. Unmanned aerial vehicles (UAVs) can benefit from 5G by enabling high speed communication with latency resulting in coordination for swarm operations and safer missions. Time video streaming and fast data transmission play a role in applications such as search and rescue missions, delivery services, surveillance operations and mapping.

While there are advantages to using 5G for UAVs we must also acknowledge the associated costs of deployment and infrastructure challenges as drawbacks. Nevertheless these challenges can be mitigated by leveraging existing infrastructure resources utilizing spectrum bands effectively and collaborating with service providers specializing in 5G for UAVs. By planning and executing strategies effectively we can overcome these obstacles. Unlock the full potential of 5G for UAV technology while reducing deployment costs. Another approach to address the disadvantages of 5G is, by using spectrum allocation methods.(Damodaram, Reddy, Giri, Manikandan, & Engineering, 2022; Fu, Zhao, Su, & Jian, 2018; Ghazal & Engineering, 2021). Utilizing a 5G solution can greatly enhance network performance. To ensure implementation of 5G technology it is crucial to invest in cutting edge 5G UAS Technology and collaborate with 5G UAS Service providers. These measures will not make the technology more accessible. Also overcome any deployment challenges that may arise(Ning et al., 2021; Popli et al., 2021)[-105].

Conclusions

Remarkable Findings

In this paper, we presented the history of wireless communications and seven wireless communications technologies which have been applied for UAS surveillance, wildlife surveys, military training, weather monitoring, and local law enforcement. Wireless communication technologies are essential for enabling the UAS to do their jobs more effectively, safely, and efficiently. They serve as a link for facilitating communication between components of the UAS including ground stations, payloads, and sensors. This enables the collection and transmission of data. Additionally, the utilization of communication technologies on UAS Platforms has numerous advantages. These technologies eliminate the need for wiring, making the UAS Lighter and more efficient. As wireless communication technologies advance and become more advanced it is highly probable that UAS Operations will continue to reap their benefits in the years.

Wireless communication technologies for the UAS have been widely adopted in the past few years due to their potential to provide reliable, low-cost communications for various applications. Additionally, more research is needed to develop techniques to ensure secure data transmission and communication links resilient to various forms of interference. Finally, research is required to establish energy-efficient communication protocols that can operate with the limited power sources of the UASs. Filling these research gaps will ensure that UASs can provide reliable and secure communication services.

Future Research and Future Trends

Research trends focus on developing reliable and robust wireless communication systems for UAS operations. Research is being conducted in signal processing and communications protocols for UAS communication links. In addition, scientists are currently conducting studies to enhance the effectiveness and dependability of communication connections for systems (UAS). They are exploring technologies, like software defined radio input multiple output (M.I.M.O.) and cognitive radio to achieve this goal. The main research areas include signal processing algorithms, communication protocols, and network optimization. Additionally, researchers are exploring the potential of wireless communications for UAS operations in reconnaissance, surveillance, and search and rescue operations.

The advancements in communications for aerial systems (UAS) have been remarkable in recent years and it's just the start. Ongoing research in this field involves enhancing flight control algorithms, expanding transmission range, and ensuring data transfer. This progress aims to enable secure transmission of data volumes facilitating more intricate missions and operations. Wireless communications technologies are rapidly advancing, and with that, the options for UAS are increasing. These technologies will also help to ensure the safe operation of these vehicles in airspace that is heavily populated by other aircraft.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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