Advancing Industry 5.0 with UAV-Driven Transformations: A Future Prospect

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***Abstract*—The incorporation of Unmanned Aerial Vehicles (UAVs) into Industry 5.0 represents a significant leap forward in industrial automation, taking advantage of their advanced technologies and precise navigation capabilities. This magazine aims to shed light on how UAVs contribute to the objectives of Industry 5.0, focusing on human-machine collaboration, sustainability, resilience, and innovation. The unique benefits that UAVs bring to Industry 5.0 while recognizing the constraints of current methodologies in the literature regarding UAV positioning are discussed. Understanding the challenges in UAV positioning, particularly the inadequacies in signal strength and accuracy within industrial networks, is essential for advancing emerging technologies. Therefore, this study proposes a method to optimize the position and location of UAVs in an industrial environment, specifically focusing on using UAVs as Mobile Base Stations (UMBS) to achieve enhanced signal strength.**

Introduction

An UAV is referred as an aircraft that can fly without a human pilot onboard; hence named *Unmanned Aerial Vehicle*. Over the course of the industrial revolution, UAVs have come a long way. The utilization of UAVs has transformed numerous industry sectors by enhancing productivity, lowering costs and risks, improving site security, adhering to regulations, and protecting workers, particularly during pandemics such as the COVID-19 pandemic. Industry 4.0 has demonstrated considerable promise through the integration of UAVs, but several obstacles still persist in areas such as data processing, customized design, and real-time inventory management. As highlighted in [1], these challenges present multiple dimensions. To fully leverage the potential of UAVs in the emerging environment of Industry 5.0, it is crucial for both research and industry to address these issues in a comprehensive and systematic manner. It is essential to implement advanced UAV technology, establish

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industry standards, automate inventory management processes, and simplify deployment procedures. These approaches have the potential to enhance UAV performance and integration in future industrial applications. For instance, UAV can be used for automated tasks such as inventory management, material handling, and quality control by autonomously navigating through the manufacturing facility to collect data and perform inspections that reduce the need for human intervention [2]. In addition, UAVs equipped with sensors and cameras can enhance production efficiency by monitoring and detecting issues while providing security through surveillance and threat detection. Furthermore, it can be utilized to gain entry to difficult-to-reach manufacturing areas, capture high-quality images, and improve human safety by circumventing the need for risky entries for inspections and maintenance [3]. Owing to ongoing technological advancements, UAVs are expected to become even more crucial in various industries in the future.

Anatomy of a UAV: Essential Components

The fundamental architecture of a UAV comprises several crucial components and systems like the airframe, propulsion system, flight controller, sensors, communication module, and payload. The airframe is known as the UAV's architectural core component that refers to the framework handling the UAV body and wings. It is meticulously engineered for lightweight construction, robustness, and optimal aerodynamic performance to guarantee flight stability. The propulsion system consists of motors for thrust, propellers (turbines) for converting motion to thrust, and electronic speed controllers for motor control. The brain of a UAV system, i.e., the flight controller, is typically fitted with a microcontroller or microprocessor responsible for processing received sensor inputs, calculating motor commands to ensure flight stability, and interfacing with GPS and radio control. Sensors integrated with UAVs are responsible for collecting data for altitude and orientation using an Inertial Measurement Unit, utilizing GPS for accurate navigation, barometers to estimate elevation, and proximity sensors to detect obstacles in the vicinity. Communication modules include telemetry setup for transmitting data to the ground-based station, a radio control system for manual operation, and facilitating remote control and communication between multiple UAVs. Finally, the payload system includes additional sensors or equipment for specific objectives, such as cameras for photography and scientific instruments for data collection and analysis.

Significance of UAVs in Industry 5.0

UAVs hold a substantial significance within the framework of Industry 5.0, which seeks to enhance the digital evolution initiated by Industry 4.0 by promoting meaningful and innovative collaboration between humans and machines. UAVs play a crucial role in facilitating the key objectives of Industry 5.0 by providing innovative solutions and improving productivity across various industrial sectors.

- **Human-Centric Industry:** Human requirements and priorities are at the centre of production in Industry 5.0. UAVs aid humans in real-time monitoring and data collection, thereby increasing productivity, safety, and efficiency in sectors like con-struction, agriculture, and logistics due to their aerial capabilities.
- **Sustainable Industry:** UAVs make industries more sustainable by minimizing environmental impact and optimizing resource consumption. For instance, in agriculture, UAVs monitor crop health, diagnose diseases, and optimise pesticide usage and in energy, it can examine and maintain renewable equipment, decreasing manual effort and enhancing maintenance.
- **Resilient Industry:** Manufacturing resilience is emphasized in Industry 5.0, especially during crises. UAVs provide airborne surveillance, search and rescue, and damage assessment in disaster response and recovery. The potential UAVs can quickly gather vital data in crises, and aid informed decisions that improve the overall industrial resilience. The contributions are summarized as follows:

- **UAVs in Industry 5.0:** The paper examines the role of UAVs in realizing the objectives of Industry 5.0 and explores the use of advanced technology to enhance industrial automation and navigation.
- **Identifying UAV applications and Challenges:** Discusses the application of UAVs in Industry 5.0, while simultaneously addressing the constraints of current UAV deployment techniques, particularly in relation to signal strength and precision within industrial communication networks.
- **Optimizing UMBS Placement:** This work proposes a technique for the placement of UMBS using linear regression on various features such as environmental conditions such as temperature,

humidity, weather conditions, and position of the IoT device and UAV to obtain the signal strength between them.

UAV-Based Applications in Industry 5.0

Industry 5.0 provides numerous possibilities for utilizing UAVs in various sectors. Below, the potential applications of UAVs in Industry 5.0 are discussed:

Aerial Inspection and Surveillance

UAVs have the potential to significantly improve efficiency and safety in various industries such as construction, agriculture, disaster relief, and security by providing aerial inspection and surveillance services. It is being employed to monitor infrastructure damage. The authors of [4] proposed the concept of inspecting photovoltaic (PV) plants using UAVs. In extension to the previous work, the authors of [5] diagnosed the power loss in PV plants using UAV thermography, which relates to the temperature distribution over a solar panel. Align with the similar objective, the researchers of [6] suggested UAVs for surveillance purposes, by incorporating a difference-of-difference (DoD) method to identify unusual occurrences and improve border monitoring. The authors claimed that UAV surveillance can be used in no-man zone areas, boundaries, and security borders, as well as in front-liners, along with advanced technique for surveillance applications. This capability enables Industry 5.0 to take proactive steps to comply with significant improvements in the quality and security of the service.

Mining and Exploration

Mining and exploration comprise the extraction and processing of valuable Earth resources. Herein, UAVs are potentially capable of serving various applications. The authors of [7] explored a few applications including mine surveying, drilling and blasting, mine management, mine safety, and mine construction. In addition, the authors proposed a UAV-based multi-hop emergency communication system. UAVs are quite useful in exploring regions where being physically present is challenging. In another study [8], the authors proposed an exploration strategy to explore forests in a decentralized scheme and claimed that this approach is 30% faster than existing state-of-the-art approaches. However, it is important to recognize that UAVs still have few exploration limitations due to poor connectivity and limited energy. Research is ongoing in this field, and in the near future, UAVs may be employed to work alongside humans, thus leading to Industry 5.0.

Precision Agriculture

Precision Agriculture is an innovative farming method that optimizes farming through data and technology, thereby enhancing efficiency and sustainability. Precision Agriculture employs UAVs to gather data and provide agricultural practices with perspectives [9]. UAVs can also be used to detect hogweed, which is a threat to farming crops and dangerous for the health of the common people. As the manual detection of hogweeds is a challenging task, the authors of [10] applied Fully Convolutional Neural Networks (FCNN) and designed a UAV-based approach to accurately detect hogweeds. Furthermore, UAVs are useful for agricultural soil moisture monitoring, which helps farmers to optimize irrigation for water efficiency. However, to address the issues of limited payload capacity and battery life, path planning and the use of secondary power sources are crucial.

Simulation Results and Discussion

This work involves simulating terrestrial Industrial IoT (IIoT) devices and a UAV acting as a Mobile Base Station (UMBS) to transmit data to a central server, as illustrated in Figure 1. These IoT devices generate and store data before transmission. The aim is to maximize the signal strength in decibel-milliwatts (dBm) in order to locate the optimal position and reduce collisions between UMBS, as demonstrated in Figure 1. Factors affecting signal strength include temperature, humidity, weather conditions, UAV altitude, distance between the UAV and the device, and signal strength. IoT devices and UMBS are deployed on a $10m \times 10m$ grid, which operates within a temperature range of $10°$C to $40°$C, and humidity levels ranging from 40% to 95%. The environment also includes three different weather conditions: cloudy, rainy, and sunny. We assume that the system uses QPSK modulation and the UAVs are equipped with omnidirectional antennas. The altitude ranges from $5m$ to $15m$ in the simulation setup. This dataset contains Radio Frequency (RF) signal data collected by Software Defined Radio (SDR) hardware using DragonOS Focal during the period of May 5, 2023 to June 11, 2023[1]. In this dataset, each row represents an observation of an RF signal, with various

[1]https://www.kaggle.com/datasets/suraj520/rf-signal-data

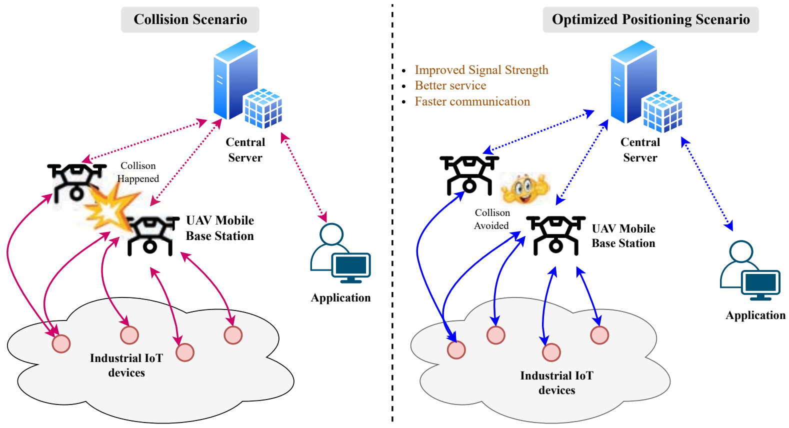

Figure 1: Topology for UAV placement.

features describing its behaviour and environment. UAVs initially identify the best position and altitude within the area. Subsequently, they enable precise predictions for optimal UAV placement by utilizing optimized algorithm, enhancing data signal strength and Quality of Service (QoS).

Figure 2 depicts the variation in signal strength between the UAV and IoT devices. It can be observed that optimal positioning exhibits a higher level of signal strength compared to randomized positioning. Similarly, Figure 3 illustrates the average signal strength while varying the temperature in various environmental conditions. It can be observed that as temperature increases, signal strength decreases regardless of weather conditions. This phenomenon arises due to the influence of temperature on the characteristics and propagation of electromagnetic waves, which serve as the medium for wireless signal transmission. Elevated temperatures have the potential to induce a decrease in air density, resulting in a diminished capacity for the efficient t ransmission o f e lectromagnetic waves. Therefore, signal intensity can diminish with an increase in temperature. This suggests that UAVs should be strategically placed in areas with lower temperatures to maximize signal strength.

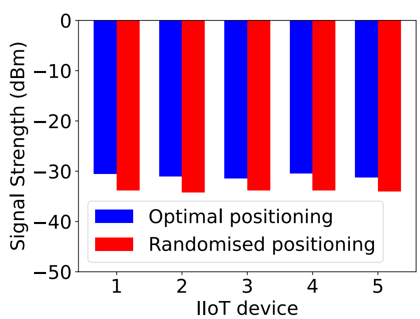

Figure 2: Signal strength in both optimal positioning and randomized positioning scenarios.

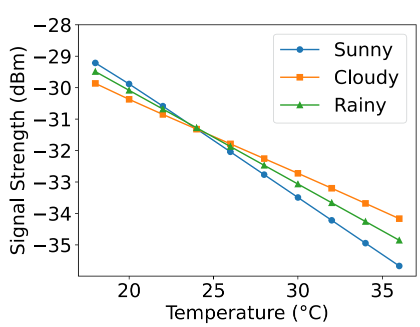

Figure 3: Variation of average signal strength with respect to temperature for different weather conditions.

Challenges and Research Directions

The challenges and evolving landscape of UAV technology, which is driving the industrial revolution, must be recognized in order to effectively achieve the objectives of Industry 5.0. By addressing the challenges discussed below, the full potential of UAVs can be realized.

Regulatory Hurdles

The literature on promoting Industry 5.0 using UAV-driven transformations frequently identifies numerous regulatory challenges. These include the need for stringent safety regulations, privacy concerns, and seamless integration with existing infrastructure. The lessons learned from these challenges can be invaluable in shaping strategies for overcoming them. Additionally, there is need for harmonization of regulations across different countries, the requirement for clear and transparent use of UAVs, and the need for robust cybersecurity measures to protect against potential threats. In anticipation of future regulatory challenges, the emergence of new regulations surrounding the use of UAVs in autonomous driving is expected. Future research could concentrate on standardizing regulations for UAVs globally, establishing a fair and consistent environment. Developing clear accountability measures for UAV usage and cybersecurity research tailored to UAVs are crucial areas. This addresses potential threats in autonomous driving scenarios and exploring these directions helps overcome challenges in the evolving UAV landscape.

Technological Constraints

The study on integration of UAVs in Industry 5.0 emphasizes the need for continuous training and development initiatives to effectively implement cutting-edge technologies, as well as the financial investment required for these technologies. The transition from traditional preventive maintenance to predictive preservation methods, facilitated by smart detectors, IoT devices, and tailored software, presents new complexities in maintenance strategies. To tackle these challenges and efficiently usage of UAVs, companies should focus on investing in comprehensive training and development programs that develop both technical and soft skills. Additionally, they should allocate resources to advanced maintenance and predictive preservation techniques to reduce the potential risks associated with emerging artificial intelligence and automation. Smart detectors, IoT devices, and customized software play a crucial role in real-time monitoring and predicting of UAVs failures in industrial environment. Establishing trust and confidence is essential for successful adoption, and companies should prioritize transparency, collaboration, and responsiveness to build trust in their technologies.

Data Management and Security

The development of UAV Industry 5.0 has led to an increase in the complexity of data management, which presents challenges in terms of storage, processing, and analysis of large amounts of data. Balancing data demands with flight operations is crucial, as UAV sensors and cameras have limited storage and processing capabilities due to weight, power, and size constraints. This requires the development of lightweight solutions. Federated Learning can help address real-time data processing issues by allocating tasks to UAVs. Additionally, the forthcoming 6G technology, featuring increased data transmission speeds and reduced latency, offers potential solutions to communication obstacles, data management and augments the capacities of UAVs in the Industry 5.0 landscape.

UAVs in Industry 5.0 have promising applications, but they also pose various security challenges. Cyberattacks and physical threats must be prevented to ensure the safety and integrity of the system. Strong encryption, physical security measures, and adherence to cybersecurity policies can help mitigate these risks. To ensure the safety and security of UAV activities in a constantly changing security environment, it is crucial to monitor and update them. Experienced operators are necessary to respond to attacks and secure communication lines to prevent data interception. Blockchain and cloud computing can also assist in addressing these issues. Cloud computing can scale data edge devices, while blockchain technology can track corporate network transactions and assets. These technologies can help integrate UAVs into Industry 5.0 and protect and efficiently manage data. However, the use of these technologies also raises new challenges, such as secure data transfer and increased complexity in data management. To overcome these obstacles and enhance UAV integration into Industry 5.0, ongoing research and development are needed.

Beyond Visual Line of Sight Operations

UAVs typically cover areas under 5 square km. Beyond Visual Line of Sight (BVLOS) drone flight can boost commercial application profitability. Including millimeter-wave (mmWave) technology helps overcome line-of-sight (LOS) challenges, especially with techniques like beamforming. The authors of [11] surveyed on current achievements in the integration of 5G mmWave communications into UAV-assisted wireless networks. Additionally, safety in BVLOS activities is challenging. In BVLOS operations, the pilot or operator can only observe the UAV through remote video or automated systems. This raises the risk of aircraft accidents and property damage, especially in shared airspace. To address security concerns, BVLOS operations require advanced detect-and-avoid (DAA) capabilities which enable drones to identify obstacles and air traffic and change course swiftly. Attempting to satisfy payload, dimensions, and power constraints can also be challenging, especially given the extended flight distances and duration anticipated from BVLOS drones [12]. Unmanned Aerial Systems sector has great potential with BVLOS operations, but safety, regulatory, technical, and airspace management issues must be addressed.

Conclusion

The integration of UAVs into Industry 5.0 represents a significant s tep f orward i n i ndustrial automation. This magazine examines the various ways in which UAVs can support the objectives of Industry 5.0, including promoting human-machine collaboration, fostering sustainability and resilience, and driving innovation. While UAVs hold great potential for Industry 5.0, it is crucial to address the challenges that they face to fully realize their potential. This study also emphasizes the importance of optimizing the positioning of UAVs within industrial networks through simulation frameworks to maximize the received signal strength at UAV mobile stations.

Enhancing and surmounting the current barriers is a crucial objective for the future advancement of this field that involves devising extensive airspace management, security, and regulatory frameworks to safely and effectively integrate UAVs into industrial environments.

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