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Drone Usage in industrial fields

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Abstract

Drones are increasingly used across industrial environments for monitoring, inspection, and safety-related tasks. While their ability to cover large areas and collect high-quality data provides significant operational advantages, most industrial deployments still rely on manual piloting, limiting scalability and efficiency. This paper examines the distinction between autonomous, semi-autonomous, and non-autonomous drone operations and highlights the benefits of integrating drones into industrial software systems such as maintenance, security, and monitoring platforms. By analyzing typical use cases, including solar field inspection, surveillance of industrial sites, and early fire detection in open-cast mining areas, this work discusses when autonomous and integrated systems offer measurable advantages and when manual operation remains more suitable. In addition, regulatory constraints for unmanned aerial vehicle (UAV) operations are considered, with a focus on the risk-based classification into open, specific and certified categories. The findings show that recurring and predictable missions benefit most from autonomous and integrated approaches, while irregular or highly dynamic scenarios still require human intervention. Due to the frequent use of Beyond Visual Line of Sight (BVLOS) operations in industrial contexts, autonomous drone missions typically fall into the specific category, requiring structured risk assessment and operational documentation. Overall, integrated autonomous drones can significantly reduce labor effort, increase data availability, enable compliant BVLOS operations and improve decision-making in industrial workflows.

1 Introduction

In recent years, drones have become omnipresent in public awareness and in the media. The industry has also shown growing interest in unmanned aerial systems. The inspection of large solar parks, monitoring of extensive industrial machinery and other applications show the significant potential UAVs can offer for improving efficiency. However, the industry rely still for many scenarios on a human pilot, which makes these operations costly and labor-intensive. Especially in recurring missions, autonomous flights could provide many benefits like reproducible procedures, reduced operating expenses through a decreased need for specialized personnel [1].

2 Industrial Use of Drones

Typical industrial applications of drones span a broad spectrum of monitoring, inspection and surveillance tasks [2]. For instance, drones are increasingly used to monitor the condition and performance of large solar fields. Drones can cover extensive areas quickly and with help of a thermal camera identify defects in PV-Installations like for example hotspots, outages and Strings [3]. They can also have an important role in the surveillance of construction sites and company sites as support for security personnel by providing aerial perspectives that enable more effective detection of unauthorized access, hazardous situations and criminal actions. For example a combination of Camera surveillance, motion detectors and a drone with a drone-dock can be used to protect construction sites from material theft. Another use-case for drones can be as an early fire detection in open-cast coal mining areas. Their drones can be equipped with thermal sensors to identify potential ignition points and embers to report potential fires before they become critical [4].

Despite their suitability for recurring tasks in large areas, most drone missions today are still performed under direct control of a human pilot, which limits the level of possible automation and scalability in industrial workflows.

3 Autonomous and Integrated Drones

Drones can be called autonomous, when they are capable of executing missions without direct human control. They rely on pre-programmed flight paths, sensors and mission-based decision-making to navigate and complete their missions. That includes also the deployment of the drone itself. This is mostly accomplished by the use of drone docks. The functionality for the docks include maintaining a connection to the internet, charging and housing the drone while not on a mission, often collecting weather data for pre-flight checks and sometimes providing processing capabilities for the missions.

A drone can also operate semi-autonomous, when a mission is pre-planned and deployed directly on the drone. The pilot then only has to start the mission and monitor the flight.

The integration of a drone describes a drone system that is connected to broader industrial systems like maintenance management, security systems and monitoring platforms [5]. This enables for example an automatic data collection with processing and possible triggering of follow-up actions like calling the fire department when a fire is detected. Two Paths can be identified for an integrated drone, time critical events and data analysis. The detection of a fire is for example a time critical event, where the collected data is less important than the alarm of the fire department and the control Center. In case of data analysis, the quality of the collected data is more important than a quick notification. A daily cartography of a construction site can be an example for this.

In **Figure 1** a possible path from the drone collected data to their endpoints in the control Center as well into the industrial systems is shown for an integrated drone. In contrast **Figure 2** shows the path for the data, when the drone is not integrated. In this case there is a time delay between the collecting of the data and upload to the processing server over the computer of the drone pilot. Because of this delay, the processed data is not current and therefore not needed in the control Center [6].

An autonomous and integrated drone is both able to execute missions without direct human control and is connected to the industrial systems to use, process and react to the collected data. This offers clear advantages in repetitive and standardized missions such as the routine inspection of solar fields or industrial machinery where it reduces labor costs, improves efficiency by creating maintenance plans and ensures consistent results through the repetitiveness.

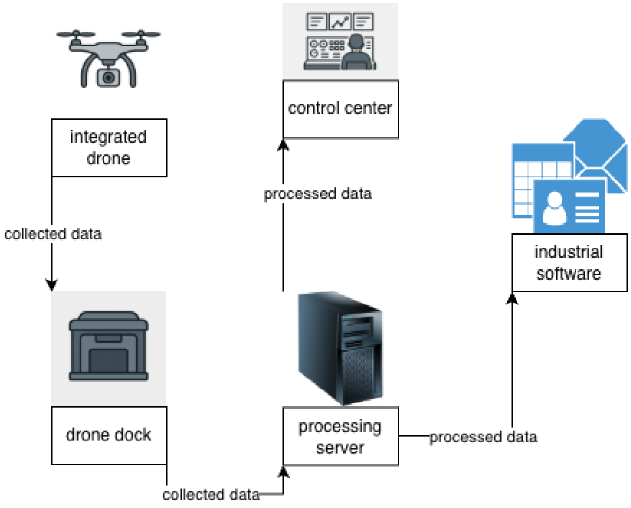

Figure 1 Shows the path of the data from collection on the drone to their endpoints in the industrial systems and the control Center for an integrated drone.

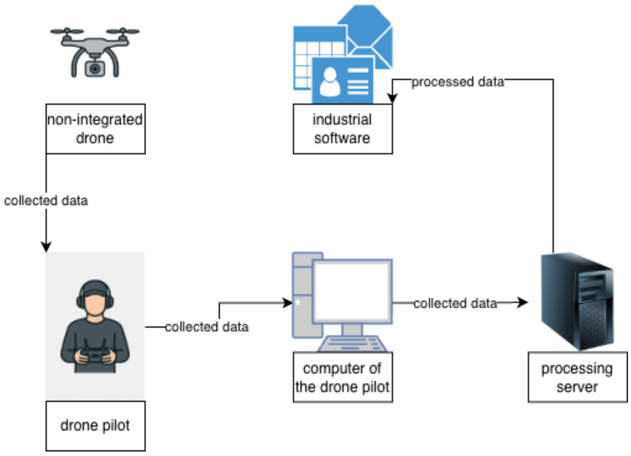

Figure 2 Shows the path of the data from collection on the drone to their endpoints in the industrial systems and the control Center for a non-integrated drone.

4 Autonomous BVLOS Drone Operations and Regulatory Classification

UAV operations are regulated using a risk-based classification framework, which groups missions into different operational categories depending on their complexity and associated safety risks. This framework defines the applicable technical, operational and organizational requirements for drone operations and ensures a proportionate level of regulatory oversight. The three categories: open, specific and certified differ significantly in terms of operational limitations, approval requirements and certification obligations. These categories are also presented in Figure 3.

OPEN

Meet all criteria
- < 25 kg
- Not overhead assemblies of people
- < 120 m AGL
- VLOS
- No dangerous goods

SPECIFIC

Meet at least one criterion:
- > 25 kg
- > 120 m AGL or special airspace
- BVLOS

CERTIFIED

Meet at least one criterion:
- Over assemblies of people
- Transport of dangerous goods
- Transport of people

Figure 3 Overview of the regulatory categories for UAV operations (open, specific and certified) and their key operational criteria. [7]

4.1 Open Category

The open category is the least restrictive regulatory category for UAV operations and is intended for low-risk scenarios. Operations in this category must meet all defined criteria, including a maximum take-off mass of less than 25kg, operation below 120m above ground level (AGL) and flights conducted exclusively in Visual Line of Sight (VLOS).

Furthermore, flights in the open category are not permitted over assemblies of people and must not involve the transport of dangerous goods. Due to these strict limitations, operations in the open category are restricted to simple mission profiles with low operational complexity and do not require prior authorization from aviation authorities.

4.2 Special Category

The specific category covers UAV operations that exceed at least one limitation of the open category. This includes operations with an aircraft mass greater than 25 kg, flights above 120m AGL or within special or controlled airspace, as well as Beyond Visual Line of Sight (BVLOS) missions.

Because these operations introduce increased operational complexity and risk, they cannot be conducted under the open category framework. Instead operations in the specific category require a structured risk assessment as an operational manual and formal authorization by the competent authority, allowing more advanced and flexible mission profiles while maintaining an appropriate level of safety.

4.3 Certified Category

The certified category applies to UAV operations that meet at least one high-risk criterion, such as flights over assemblies of people, the transport of dangerous goods or the transport of people. These operations are considered comparable to manned aviation in terms of safety impact and potential consequences.

As a result, the certified category is subject to the most stringent regulatory requirements, including aircraft certification, operator certification and, where applicable, remote pilot licensing. Due to the extensive certification effort involved, this category is reserved for highly safety-critical operations and is not typically used for conventional BVLOS drone missions.

4.4 Operational Manual

For operations conducted outside the open category, particularly within the specific category, the development of a comprehensive operations manual is mandatory. The operations manual serves as a central document describing the concept of operations, operational procedures, system architecture, safety measures, emergency procedures and the allocation of responsibilities.

This document is a key requirement for regulatory approval and demonstrates that identified risks are adequately mitigated. In the context of BVLOS operations, the operations manual plays a crucial role in ensuring safe, standardized and compliant mission execution.

4.5 Autonomous BVLOS Drone Operations

Autonomous integrated drones are operated in Beyond Visual Line of Sight (BVLOS) missions, meaning that the remote pilot is unable to maintain direct visual contact with the aircraft at all times. BVLOS operations typically rely on technical systems such as sensors, communication links and automation to ensure safe navigation, separation from other airspace users and mission execution.

Due to the BVLOS nature of autonomous drone operations, compliance with the open category is not possible. Consequently, these missions must be conducted under the specific category, which mandates the development of a comprehensive operations manual.

5 Integrated Autonomous Flights vs. Semi-Autonomous Flights vs. non-Autonomous Flights

Industrial applications can be sorted into two categories: recurring scenarios and one or few time scenarios.

When a task for a drone is a one or few time event, the costs for integration are greater than the advantages afterwards. In this case, a drone can be used semi-autonomous when the flight path of the mission is predictable before the flight, so that the drone can be deployed by the pilot and then fly the mission on its own. If the flightpath of the mission is unclear or the mission needs a human pilot, then the non-autonomous Flight is the only option.

6 Conclusion

Drones can be useful in many industrial applications, ranging from monitoring and surveillance to data collection. The degree of automation for the drone missions depends mainly on the mission itself. If the task is recurring and predictable, a suitable level of automation can be achieved through autonomous drone flights based on pre-planned missions. The data collected by the drone can be used for direct reactions, such as intruder detection for perimeter security or automatically alerting the fire department in the event of fire detection. Integrating the drone into industrial systems can provide significant benefits. These benefits include a reduction in specialized personnel requirements, lower labor costs and highly reproducible operational procedures.

In addition to technical and organizational aspects, regulatory constraints play a decisive role in the design and deployment of autonomous drone systems. UAV operations are governed by a risk-based classification framework comprising the open, specific and certified categories, each imposing different operational limitations and approval requirements. Due to the use of BVLOS operations, autonomous integrated drone missions cannot be conducted within the open category and must therefore be assigned to the specific category.

As a consequence, such operations require a structured risk assessment and the preparation of a comprehensive operations manual. This documentation forms the basis for regulatory approval and ensures that operational risks are adequately addressed, particularly in complex BVLOS scenarios. The regulatory framework therefore directly influences both the technical design and the operational integration of autonomous drone systems.

The two paths of an integrated drone system remain an important design consideration. When a mission is based on detecting time-critical events, direct integration of the drone into operational systems is essential to prevent delays. The data analysis path, on the other hand, is most suitable when the quality of processing and analysis is more important than immediate response time.

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