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New Developments and Environmental Applications of Drones

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Connecting Different Drone Operations with the Farm Robotic Management



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1 Introduction

Food production has major challenges in productivity, cost-efficiency, and sustainability [1]. Automation and digitalization have been proposed to address productivity needs, but at the same time, they are costly solutions. Recently, the concept of smart farming also called as advanced precision agriculture has emerged as a part of Fourth Industrial Revolution [2, 3]. This includes an increase in automation and robotization.

Drones also called UAVs (unmanned aerial vehicle) can be a crucial part in future farm automation and robotization in agricultural fields. The drone technologies can offer relatively cheap, inclusive, and advanced smart solutions [4]. The approach does not need to have direct contact with crops or soil, and missions are often fully automated already by the manufacturer. By applying drones, farmers can produce accurate measurements on demand of the interested phenomenon and can perform small-scale operations such as pesticide spraying or spreading of fertilizers. From the farmer's point of view, drones are separate semiautonomous robots that can perform specific tasks related to farming. In a review [5], the farming robotics

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were divided to flying drones and land-based robots. According to a review [6], agricultural multirobot systems (MRSs) include aerial robots, ground robots, and manipulators. In both reviews, drones are seen as essential part of agricultural robotization.

In addition to drone technologies, the automation and robotics in arable farming have continuously advanced. There are task-specialized robots [7], general robot platforms that can be adjusted to different tasks, and semiautonomous tractors that can operate with multiple existing tools. While the automation and the number of units increase, the operation management of the robotics becomes essential part. Farming machinery is developing toward digitalized and autonomous systems. The concepts of cloud robotics and digital twin have added capabilities to monitor and control the device robotics [8]. Furthermore, the Internet-of-Robotic-Things (IoRT) concept combined the cloud robotics and IoT domains and allowed managing the robots from IoT platforms [9].

In this study, we connect state-of-the-art drone technologies with the future farm multirobot mission management and take first steps for the integration of the drone technologies. We aim to determine requirements for future drone systems operating in agriculture and find solutions on how to integrate existing state-of-the-art systems into the farm robotic management concept.

2 Material and Methods

We developed eight different drone operation use cases of approximately TRL 7 (technology readiness level) applications. Then, we studied the integration capabilities of the drone technologies with the multirobot mission workflow management included in a mission control center (MCC) approach [10] to enable data flow to traditional farm management system (FMS) managed by the farmer, farm data storage, other robotics, linked AI enterprises, and IoT solutions provided by third parties [10]. The MCC is a project-specific solution that contains heterogeneous robotic mission management and fleet management mandatory for such operations with heterogeneous machinery and drones. Certain limitations that currently exist with the drone technologies such as short operational time due to battery limitations are not strictly considered in the use cases. We are assuming that new developments in the drone industry are solving those problems at some timescale by applying, for example, automatic docking stations.

2.1 Use Cases with Drones

These use cases were the detection of the rapeseed (*Brassica napus*) pests, rapeseed pest control by spraying application, situation awareness of a tractor fleet in grass harvest, weed mapping in grass fields, highbush blueberry (*Vaccinium corymbosum*)

Table 1 Used drones, their primary payloads, target application, and mission type in the studied use cases

Drone platform	Payload	Application	Mission type
DJI Mavic Air 2	Integrated camera	Moving objects	Live video stream
Parrot Anafi	Integrated camera	Rapeseed	Imaging
DJI Phantom 4 RTK	Integrated camera	Vineyards	Mapping
DJI Agras T-16	Integrated spraying unit	Rapeseed	Spraying
DJI Matrice M600 pro	Specim AFX10 (VNIR)	Blueberries	Mapping
DJI Matrice 210 RTK	Zenmuse X5S RGB and MicaSense Rededge	Vineyards	Mapping
DJI Matrice 300 RTK	Zenmuse L1 LIDAR and MicaSense Altum	Vineyards	Mapping
Trinity F90+	MicaSense Altum	Blueberries	Mapping

field disease detection, blueberry yield prediction and irrigation management, and grapevine (*Vitis vinifera*) disease risk mapping. The use cases were carried out in Finland, Spain, and Serbia. By these means, we managed pilots from versatile state-of-the-art drone platforms and tools.

We applied the following drones presented in Table 1. The table shows the brand of the drone, used payloads (typically a camera), the target application, and the mission type for each use case. The imaging mission was a case study, where drones take close range images within 1–2 m from the target field [11, 12] or insect traps. These images are then further analyzed to determine the number of pests within that area. The mission plan and the image transmission can be done offline. The live video stream use case was an extension of situation awareness of a robot tractor, where the drone follows the tractor and sees the surrounding areas without being dependent on any other robot unit. This mission requires real-time communication for the flying operation and for the video output. The pest control use case [12] demonstrated pest control with spraying drone [12] carried out within present aerial regulations meaning that the drone did not spray anything on its mission. The mapping use cases included *Botrytis* detection in vineyards [13, 14], row segmentation for ground vehicles, disease detection, and yield prediction in the highbush blueberry fields.

In the drone mapping use cases, the connection is all about getting the preplanned mission to the drone system and getting the recorded data to the analyzing phase. Most of the drones in the use cases represent brands with the closed system, which is quite typical with commercial drones also for the safety reasons and due to aviation regulations.

2.2 Multirobot Mission Management and Connectivity

In a multirobot scenario in the future farming, several different drones and ground robots can work simultaneously in the same field operating similar or different tasks.

From the supervision point of view, multirobot missions of this kind with several parallel actions might be practical: the transportation and the monitoring of multiple units can be done simultaneously with possible minor efforts. A proposed multirobot agricultural mission workflow management is presented by [10]. The drone systems need to be connected to the robotic mission management layer. This mission management has a workflow model that is used both for controlling the execution of activities and collecting and sharing of data. The model supports Robotics-as-a-service (RaaS) model where a separate company provides robot fleet services for the farmer [10]. If the drones or their control systems are connected to the Internet, the connection is straightforward by implementing the MQTT (Message Queuing Telemetry Transport) client to the robot. MQTT is a standard for IoT Messaging [15]. In case of open Robot Operating System (ROS), this is straightforward [10]. However, drones are often closed solutions. With closed systems, one possibility is to use a gateway that reads the drone messages to the control system and creates respective status messages for the fleet manager with Micro Air Vehicle Communication Protocol (MAVLink) [16] protocol that is a common protocol for communicating with drones. This layer is responsible for the coordination of robot operations on the field. It consists of the fleet manager, the robots, and open-source MQTT broker called Mosquitto [17]. The drones themselves can be autonomous, they execute their own missions, and they can be operated through their dedicated controllers [10]. However, the drone collaboration must be built in into each drone. In addition, a tool for sending simple control commands to the whole robotics fleet or to a single robot is needed.

QGroundControl (QGC) is an open-source software that provides full flight control and mission planning for any MAVLink enabled drone. Rosetta Drone [18] is an Android App that brings the MAVLink protocol to DJI SDK (Software Development Kit) drones available in most of the products that were used in the use cases. Rosetta Drone application is installed to SDK controller and Android, and it is used to apply QGC-application for the drone mission. QGC can be adopted for monitoring multiple robots using MAVlink protocol as well as open drone ID [19] as identifier for separate drones. However, the protocol is currently at the development stage. The protocol is defined so that it is compliant with EU regulations (EN 4709-002) [20].

In the drone solutions where the mission is very specific or the system is completely closed (such as DJI Agras-T16 or Trinity F90+ in our use cases), an additional onboard Android device operating with application MAVLink UDP Android Example [21] can be added to send data to the QGC using the MAVLink protocol. This provides real-time information about the status of the drone but does not provide any communication to the drone itself.

Our selection of drones was based on the availability of tools and their practicality for the planned missions. The missions were operated during the summer 2021 and 2022. Since that, DJI has released a DJI Cloud API [22], where based on MQTT protocol, the third-party platform server can be accessed enabling private protocols. This makes the adaptation feasible for the supported modern drones. The Cloud API feature set access to the cloud server, device management, live streaming, media

management, and path management in real time [23]. It is designed for vertical applications, where applications are created according to a specification provided by the end user. These fit well for our use cases.

3 Results

As results, we present our data integration methodologies. There are four identified solutions for the integration (Fig. 2): (A) connecting drone autopilot directly enabling real-time data flow with third-party; (B) connecting the ground station with the third-party applications making it the most reliable with the flying operation; (C) connecting payload to third-party application directly or via ground station, this solution may be incomplete in relation to data; and (D) connecting the data processing service. This does not enable real-time communication but is more or less the state-of-the-art solution. Figure 1 shows the MQTT connection possibilities and the connectivity within the drone missions.

The following Table 2 presents the mission integration methodology, enabling tools and classified solution (A–D). All the drones ended up with different solutions.

In the solution A, the DJI drone remote controller is connected with Android smartphone that has the custom controller software running. This controller software is connected to mission management via MQTT broker and is also able to stream live video from the drone to RTMP (Real-Time Messaging Protocol) video streaming service. The SDK allows controlling the drone and reports the real-time GNSS (global navigation satellite system) position of the drone. The target position comes via MQTT. In the solution B, the QGroundControl software communicates with MAVLink protocol with the drone. In the solution C, external onboard Android payload manages the real-time connection with MAVLink protocol to

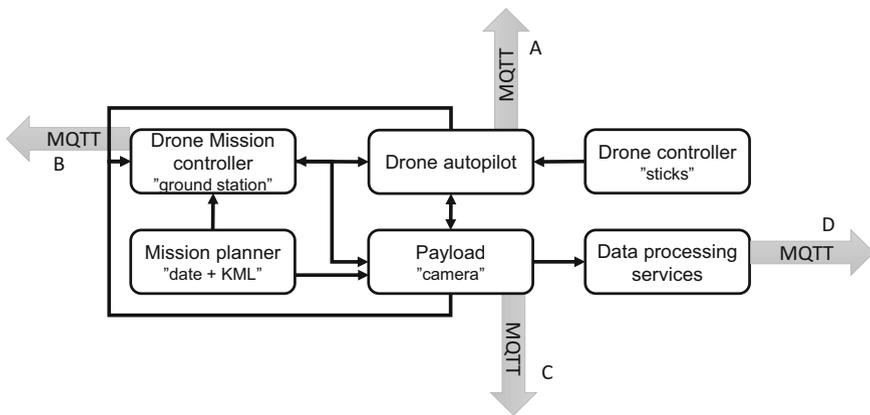


Fig. 1 General connectivity within the drone mission and the MQTT options

Table 2 Integration solutions for different drones and use cases

Drone platform	Tool	Mission integration methodology	Enabling tools	Data output	Solution
DJI Mavic Air 2	Integrated camera	Custom software	SDK, Custom APP	MQTT	A
Parrot Anafi	Integrated camera	QGC	Additional gamepad	SD card	B, D
DJI Phantom 4 RTK	Integrated camera	QGC	UX SDK, Rosetta Drone	SD card	B, D
DJI Agras T-16	Integrated spraying unit	QGC	Onboard Android, MAVLink UDP	QGC data export	C
DJI Matrice M600 pro	Specim AFX10 (VNIR)	QGC, separate camera mission	Android SDK	RJ45-cable, specific software	B, D
DJI Matrice 210 RTK	Zenmuse X5S RGB & MicaSense Rededge	Cloud API	UX SDK	SD card, Orthomosaic assessment tool	B, D
DJI Matrice 300 RTK	Zenmuse L1 LIDAR & MicaSense Altum	Cloud API	DJI Pilot 2	SD card, Orthomosaic assessment tool, Cloud API	B
Trinity F90+	MicaSense Altum	QGroundcontrol	MAVLink	SD card, Orthomosaic assessment tool	C

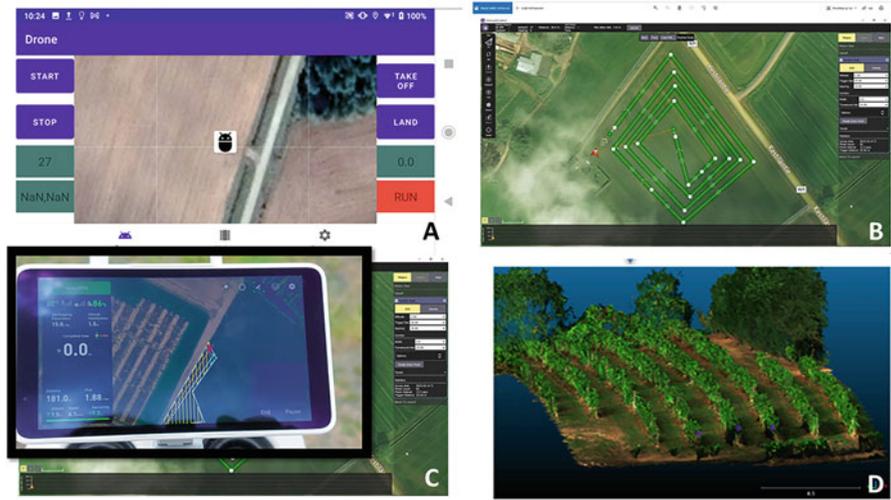


Fig. 2 Screen captures of different connectivity (a–d) methodologies applied in the use cases

QGroundcontrol without having a true connection to the drone itself. In the solution D, collected data is manually transferred to the processing tools and then further delivered to farm management or for other purposes.

Figure 2 presents the screen captures of different use cases presenting the concrete applications. (A) The custom drone controller on an Android device, (B) QGC operating pest imaging mission, (C) spraying drone controller screen and QGroundcontrol operating with additional Android payload, (D) 3D model of a vineyard ready for further analysis.

4 Discussion and Conclusions

Our aim was to determine requirements for future drone systems operating in agriculture robotics and find solutions on how to integrate them into the farm robotic management concept. For this, we needed the management concept including mission control center (MCC) concept for the robotics [10]. We found out four ways to integrate the drones: connecting drone autopilot directly, connecting the ground station with the third-party applications, connecting payload to third-party application, or connecting the data processing service. Third-party applications and middleware were required to connect state-of-the-art drone technologies with the future robotic mission management. These solutions made the operation more complicated which is not desirable in the aviation as more components may fail or can be incompatible in exceptional situations. Fortunately, the evolution of drone technologies is heading in the favorable direction, where third-party participation is

enabled without directly impacting the flying mission execution. This is also a good direction from the multirobot integration perspective.

When heterogeneous robotic systems are considered in the farming environment, the option for MCC approach is simply the robotic integration in task level (single contractor solutions) and not in farm level. With that approach, separate closed solutions for drone technologies would be enough. But like connecting heterogeneous farm machinery as the idea behind ISOBUS standardization, the interoperability is constantly needed where no farm is like other.

Safety aspects in drone missions can be highly critical especially in the prototyping phase. Involving third-party applications in the mission execution itself is not favorable. Although the critical data can be accessed in real time, the execution can be unreliable. For this, it is good that manufacturers are starting to provide interfaces for the mission management. On the other hand, drones and their operation are a special case in the world of robotic fleet operations in the agriculture and may need additional requirements since the nature of the operation.

As the need for enabling real-time access to the drone mission of third parties has already emerged, future robotic mission management may take advantage of it. Within this development, it is important to take account the robotic control needs within heterogeneous robotic fleets. Such needs are real-time connectivity to the drone control, telemetry data, the connection to the payload such as video stream, still images or work actuator, and connection to general mission control coordinating multiple heterogeneous units in the agricultural operations.

Future work should first focus on defining the interface requirements for the drone industry. Most of state-of-the-art drones are designed for certain operations or tasks that will not be the exact same if the operation is part of field robotics. For example, there would not be a dedicated supervisor, and in addition, online communication with other units and mission management are needed. At current state, current legislation, safety, and current drone capabilities are dominating the related discussions.

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