Coordination of Drones Swarm for Wildfires Monitoring.

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ABSTRACT

As a result of climate change and global weather patterns, large forest fires are becoming more frequent in different parts of the world. The focus of the presented work is on the creation of a complex coordination and communication framework for a swarm of drones specially tailored for use in preventing and monitoring of forest fires. The presented algorithm has been testing and evaluating using a computer simulation. The testing and validation in relevant environment is scheduled during a pilot demonstration exercise with real personnel and equipment, which will take place in Slovakia on April 2023. The presented work is a part of the SILVANUS EU H2020 project, whose objective is the creation of a climate resilient forest management platform for forest fire prevention and suppression. SILVANUS draws on environmental, technical, and social science experts to support regional and national authorities responsible for forest fire management in their respective countries.

Keywords

Forest fire, Wildfires, Drone, Fire Protection, Fire Monitoring,

INTRODUCTION

Swarm robotics and the unmanned aerial vehicle (UAV) are currently expanding dynamically in many application areas especially in those, where conventional approaches are too expensive or time consuming. One of such areas is the use of UAVs for preventing and monitoring wildfires. The availability of suitable robotic equipment, with sensors and control systems, is a major factor in the development of this type of applications. The current situation in the field of continuous monitoring of forest fires is described in (Steffen, 2020), (Puente-Castro, 2022) and (Tzoumas, 2022) where authors utilize unmanned aircrafts. The paper (Tzoumas, 2022) discusses the relevance of swarms as well as nature-inspired methods for coordinating a swarm of drones. The Finnish Centre for Artificial Intelligence (FCAI, 2023) deals with the challenges of fire monitoring with the use of a swarm of UAVs. Although the FCAI's proposal is an interesting one (both the study and the approach) currently it is untested with real hardware platforms (the Finnish national Fireman project started in 2022). One of the most recent studies (Tzoumas, 2022) in this area deals with long autonomy of drones during a monitoring mission for covering large areas, such as ones of the size of California, to detect wildfires at an early stage. The authors used 20 UAVs in a 24-hour experiment. The 3 known strategies were utilized and a newly developed approach was presented. On the other hand, this solution is not suitable for all topographies and types of deployment environments for instance in those where forests mix with urban areas or in areas with air traffic. An interesting solution is also presented by Li (2019) where a decentralized task allocation algorithm for a group of UAVs to carry out multi-target surveillance missions is described. In addition, a communication malfunction or a position sensor failure can affect the localization of unmanned aerial vehicles in the swarm and cause various damages. Cosar and Harun (2021) describe the use of blockchain technology in the UAV group to increase the accuracy of the position and the integrity of the data.

In this paper we present a possible application of a multi-drone infrastructure in a specific case to be demonstrated during a live forest fire exercise in Slovakia. The paper is organized as follows: in the following chapter, the SILVANUS EU green-deal project (SILVANUS, 2023) is briefly introduced. The next chapter describes the planned flow of activities between individual actors and systems in order to coordinate a group of drones in the Slovak pilot. Considering the project goals, the role of the drones in the pilot will be to monitor the forest area before and during the simulated forest fire. The coordination algorithm service for multi-drone setting is described in a separate section. We conclude with future planned activities and possible directions of research.

THE SILVANUS PROJECT

The SILVANUS is a European Union H2020 project, which delivers an environmentally sustainable and climate resilient forest management platform through innovative capabilities to prevent and combat against the ignition and spread of forest fires. The platform being developed as part of the SILVANUS project complies with requirements of efficient resource utilization and provides a protection against threats of wildfires encountered globally. The project establishes the synergies among environmental, information and computing technology, and societal science experts for enhancing the ability to monitor forest resources, evaluate biodiversity, generate more accurate fire risk indicators and promote effective safety regulations.

The key output of the project is the provision of a climate resilient forest management cloud platform for forest fire prevention and suppression. SILVANUS relies on environmental, technical and social sciences experts to support regional and national authorities responsible for wildfire management in their respective countries. SILVANUS project partners support the civil protection authorities to efficiently monitor forest resources, to evaluate biodiversity, to generate more accurate fire risk indicators, and promote safety regulations among the local population affected by wildfire through awareness campaigns. Consortium of the project includes 49 partners from the European Union, Brazil, Indonesia, and Australia, for a period of 42 months. The project innovations will be validated through 11 pilot demonstrations across Europe (SILVANUS, 2023).

One of the Europe pilot demonstration areas will be Slovakia, especially the area of Podpolanie in the central part of Slovakia, located in the region of Banská Bystrica in district of Detva (Figure 1a). The region is typical for its highland landscape with different land-use patterns of commercial deciduous and mixed coniferous-deciduous forests, meadows, pastures, arable land, and areas with non-forest woody vegetation. A very small part of forest land is owned by municipal and agricultural cooperatives. The north part of a case study area selected for SILVANUS technologies demonstration (almost forest) is under nature protection, particularly it belongs to Protected Landscape Area Poľana – the Poľana Biosphere Reserve (Figure 1b). The area is dominated by the massif of Poľana Mountain that is the highest extinct volcano in Central Europe with an altitude of 1458 m. Elevation range is about 1000 m (the lowest point of 460 m. a.s.l. and the highest of 1458 m. a.s.l.). The whole mountain is part of the Carpathian arc. The mountain thermophile plant and animal species are found in this relatively small area.

The SILVANUS project consists of several work packages and tasks, from the design and implementation of the cloud infrastructure to the collection and storage of distributed data from sensors, social networks and satellites. One of the co-investigating tasks is the coordination of a group of unmanned aerial vehicles (UAV), therefore the planned roles of the UAVs are presented in the individual phases of the Slovak operational scenario.

The Slovak operational scenario consists of three phases):

- **phase A "(Prevention and Preparedness before the wildfire)" Prevention -** currently, the fire monitoring is provided by the field patrols, especially during the declared time of increased fire risk. However, there is also CCTV-based smoke detection and early fire alerting system Forest Watch, which can monitor most of the territory. The fire danger assessment is not provided on the local or regional levels but only on the national level. For this purpose, the meteorological fire danger index (FDI) is used, which is calculated based on the Baumgartner formula. So far, the drones, robots, IoT devices and satellite data are not yet used for the fire prevention purposes in this area. At this stage, the role of the drones is to monitor (continuously or on demand) specific areas in order to help calculate the fire danger index. **Preparedness** - the Slovak legislation for forest fire prevention requires that the users and owners of forests have available: maps of the territory, identified suitable places for pumping the water for firefighting in the territory, for landing helicopters, and fire extinguishing tools placement (defined specific numbers depending on the extent of the territory).
- **phase B "(Monitoring and Detection the wild fire)"** Nowadays only field patrols (foresters) are used for fire monitoring. There is also provided monitoring service by airplanes and helicopters flying over the territory of the Slovak Republic, which when they notice a fire, report it to the air tower and contact the firefighters. Over the territory of the Slovak Republic, a monitoring service is provided using airplanes and helicopters, for reporting fires to the air traffic control tower, which then contacts the firefighters. Until now, foresters do not use any drones for this purpose. During the large wildfire intervention, the firefighters use own drones (total 3 drones are available for the entire Fire and Rescue Services in Slovakia region) for fire spread monitoring in case of the helicopters are not deployed in the same area. The GINA system (GINA, 2023) is used to support spatial navigation in the fire site, which is typically installed on tablets. In this phase, a task for a drone or a set of drones is to monitor specified area (continuously or on demand), where the main input parameters are the fire danger index, the number of available drones and its parameters.
- **phase C "(Restoration and Adaptation after the wild fire)"** For adaptation to climate change, several strategies were developed at the European and national levels, which are further incorporated into forest management plans, however, those are not binding for forest owners and forest users. Control of the implementation of the strategy is carried out by ground patrols. At this phase, the role of the drones is only to create an ortho-photo map with the necessary resolution for further processing. This task is already offered by commercially available systems.

a) b)

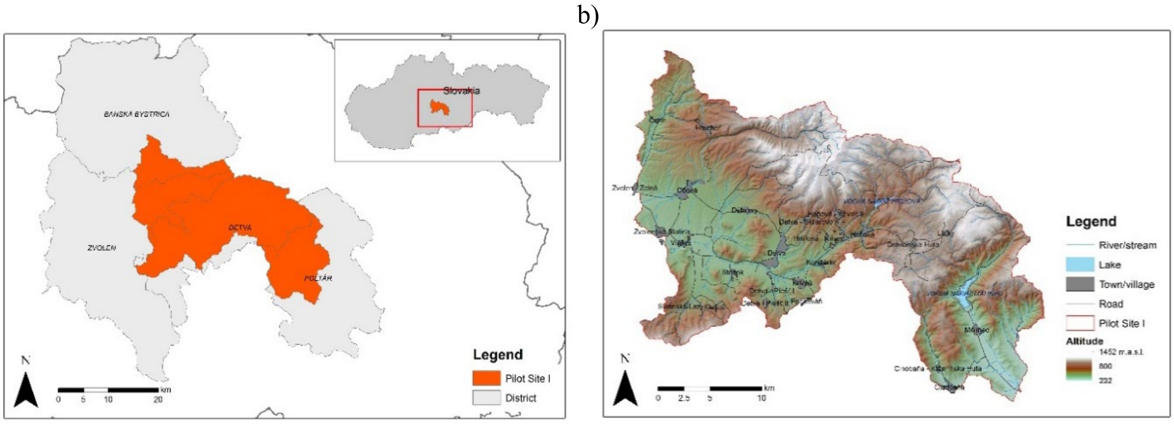

Figure 1. Location of Pilot Slovakia within Slovakia, land cover structure and location of protected area in Pilot Slovakia.

STRUCTURED FLOW CHART WITH FOCUS ON THE USE OF DRONES FOR SELECTED PHASES OF THE SLOVAK PILOT

During and after the fire it is imperative to have information available as quickly as possible while minimizing staff requirements (number, training, experience, etc.). When considering a potential deployment of a swarm of robots (either ground or aerial) all the requirements arising from the given situation and scenario must be considered. Having high-quality unmanned vehicle platforms equipped with communication and sensing capabilities is a prerequisite for solving complex technical problems related to the coordination of the robots' swarm. For the sake of executing the exercise during the pilot demonstration several systems and technologies are planned to be integrated and utilized, namely:

- DJI Mavic drones – commercial drones with interconnected DJI Pilot application with a remote-control system.
- EmerPoll - an agent-based system for coordinating and overseeing data aggregation using real-time polls based on the work of (Balogh, 2016), enacted from individual agents (drone pilots) tailored for the robotic swarm coordination.
- GINA Central[1] and GINA Tablet[2] software – part of a professional C&C platform with a digital collaborative map enabling efficient mission and security management used in Slovakia by firefighters.
- Matlab application for the Coordination Algorithm Service implementation.

Further regulatory and legislative constraints must be considered – such as the one that Slovak legislation requires that every drone providing a monitoring service must be registered with the Transport Authority of the Slovak Republic and controlled only by a pilot with a valid pilot license. As mentioned above a special system called EmerPoll will be customized and used to coordinate and oversee data aggregation from individual drones in the swarm. The EmerPoll has a web interface (called "Dashboard") which will allow to:

- Set up a mission for data collection by a group of drones based on simple semi-structured forms formatted using pre-prepared Templates. An illustrating dashboard formula for creation of a request to monitor an area or pool summary is shown on Figure 2.
- Initiate a mission by submitting and confirming tasks of the mission to/from individual drones.
- Collect and aggregate data from drones.
- Receive events from drones, react, and intervene in case of a critical event.

a) b)

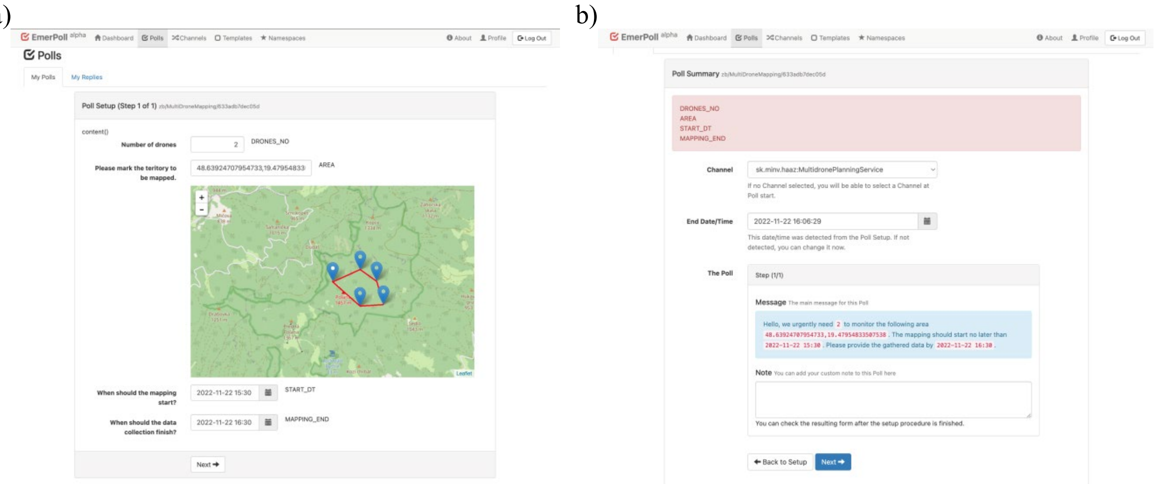

Figure 2. Dashboard formula for creation of a request to monitor an area a) and pool summary of the created pool for MultiDrone Planning service b).

The Dashboard also considers the fact, that Slovak legislation currently requires each drone to be supervised by a single pilot. The pilots of individual drones will be incorporated into a mission by inputting or confirming the changes in paths and missions with their drones as well as overseeing the drones as required by the respective legislation. Although the primary overall aim of the presented approach is to provide fully autonomous swarm navigation in order to make the Dashboard usable in real-world conditions pilots must be considered as well. Simplified flow diagram for drone coordination for the pilot demonstration during the exercise is shown in the Figure 3.

[1] https://www.ginasoftware.com/gina-central, https://3mon.sk/portfolio/item/gina-centrala/

[2] https://www.ginasoftware.com/gina-tablet , https://3mon.sk/portfolio/item/gina-tablet/

The description of the steps from the Figure 3 are the following:

- *Step 1* - The user (commander or operator from the command center) creates a request to map a specific geographic area marked on a map (Figure 2a).
- *Step 2 and 3* - EmerPoll creates a poll to Coordination Algorithm Services subscribed to a MultidronePlanningService channel. For the described case only one planning agent is considered while in the future multiple planning agents providing alternative plans for splitting the mission between multiple drones are intended.
- *Step 4* - The Coordination Algorithm service (described in more detail in the following section) processes the parametrized request and generates the output – a temporal plan (partial missions) for provided number of drones and pilots. Technically the responses received to the MultidronePlanningService are set of routes coded in a KML[3] format.
- *Step 5* - Upon receiving individual partial missions EmerPoll sends out another poll to distribute the partial missions (*.kml files) between available subscribed pilots. The poll assigns partial plans to individual drone pilots.
- *Step 6* - Drone pilots receive their flight plans and start the mapping/monitoring with semi-automatic photo/video footage (camera control, such as direction, zoom or shutter control should be the part of the plan).
- *Step 7* - Upon completion of the partial or whole planned flight the collected data are returned to EmerPoll for aggregation.
- *Step 8* - The poll is closed for a drone pilot either by providing photo/video footage from the assigned partial mission or by a brief failure report.
- *Step 9* - EmerPoll aggregates all the received data from drone pilots and can additionally submit data for further pre-processing.
- *Step 10* - EmerPoll transfers the collected data through the SILVANUS platform to the GINA central tool for visualization. The GINA Central stitches the received image together and generates a map layer to be shown on a tactical map for further command and control. The GINA system allows live tactical coordination between entities and field units over the same map– for instance every firefighting truck in Slovakia is equipped with GINA Tablet software.

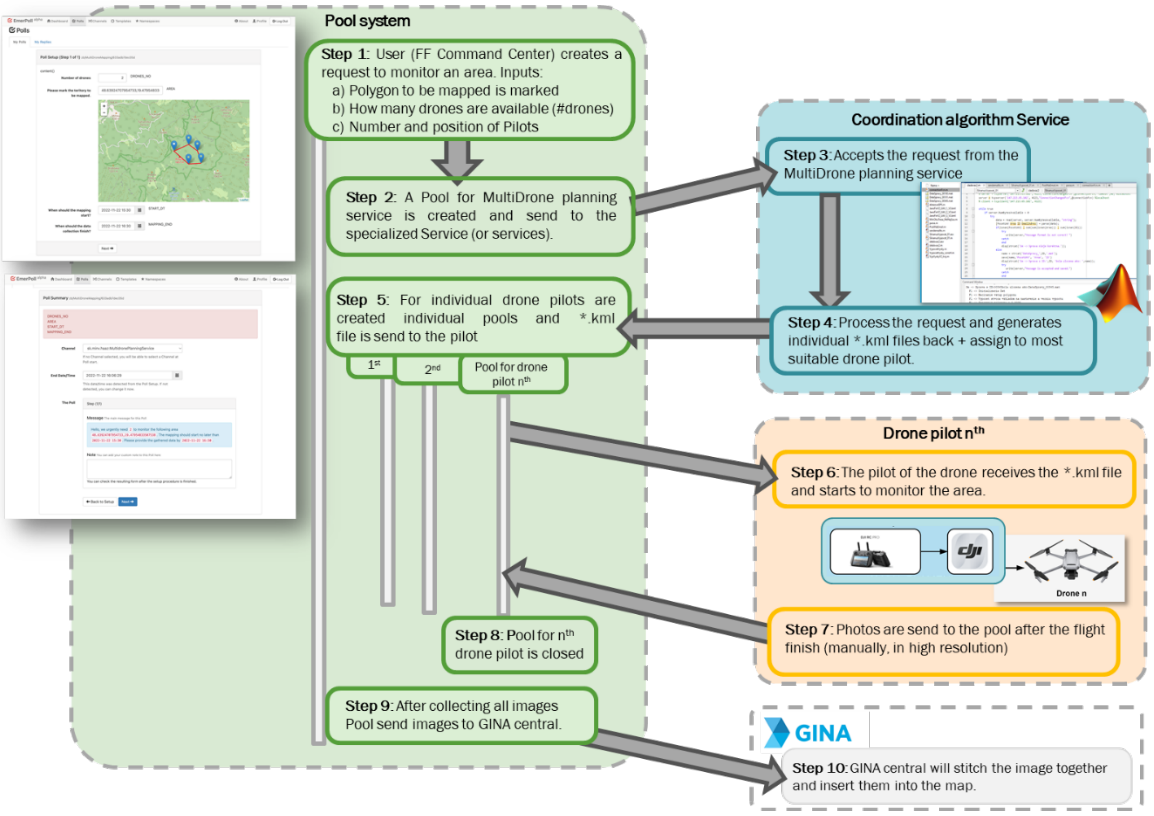

Figure 3. Structured flow diagram for the Slovak Pilot.

[3] https://www.ogc.org/standard/kml

COORDINATION ALGORITHM SERVICE

To ensure optimal results is necessary to know the following inputs of the algorithm:

- a number of available drones and their features (resolution of camera, focal distance of lens, number of pixels on camera chip *NoPCC*);
- an ability to import *.kml file;
- wind directions;
- an area of interest (a polygon);
- a required resolution of mapping *RoM* or approved flight height.

Based on the selected area of interest, the specified properties of the drone camera and the required mapping accuracy, the flight height is calculated. This calculated height also determines the spacing of the points at which the pictures are taken. In case the flight height is specified by a higher aviation authority the flight height is not calculated and is considered as input parameter. The flight level *h* [cm] can be calculated by the following equations:

$$va = \frac{alfa * \sqrt{\frac{NoPCC}{alfa * beta}}}{RoM} \quad (1)$$

$$h = \cos\left(\frac{beta}{2}\right) * \frac{va}{2 * \tan\left(\frac{alfa}{2}\right)} \quad (2)$$

where *alfa* and *beta* are horizontal and vertical angle of view, *va* represents an aliquot part of the chip area for the *alpha* angle and the required resolution of mapping *RoM* and a number of pixels on the camera chip *NoPCC*. We are using a mathematical method, based on triangulation, to calculate the coordinates of individual points. It is designed in a way that ensure a sufficient pictures overlap. The points are calculated in the way that they will be placed in a triangular grid oriented in the direction of the wind. Points are generated sequentially from the starting point, so each point has assigned a serial number of the point creation process. This fact enables the simplest planning of the flight path. In the process of flight planning all you need to do is to follow the sequence of serial numbers of the individual points. The next step of the service is to divide the area of interest into sub-areas for individual drones. This equal distribution is ensured by using the K- nearest neighborhood (KNN) algorithm. The parameter number of clusters is set equal to the number of drones. The result of this setting is

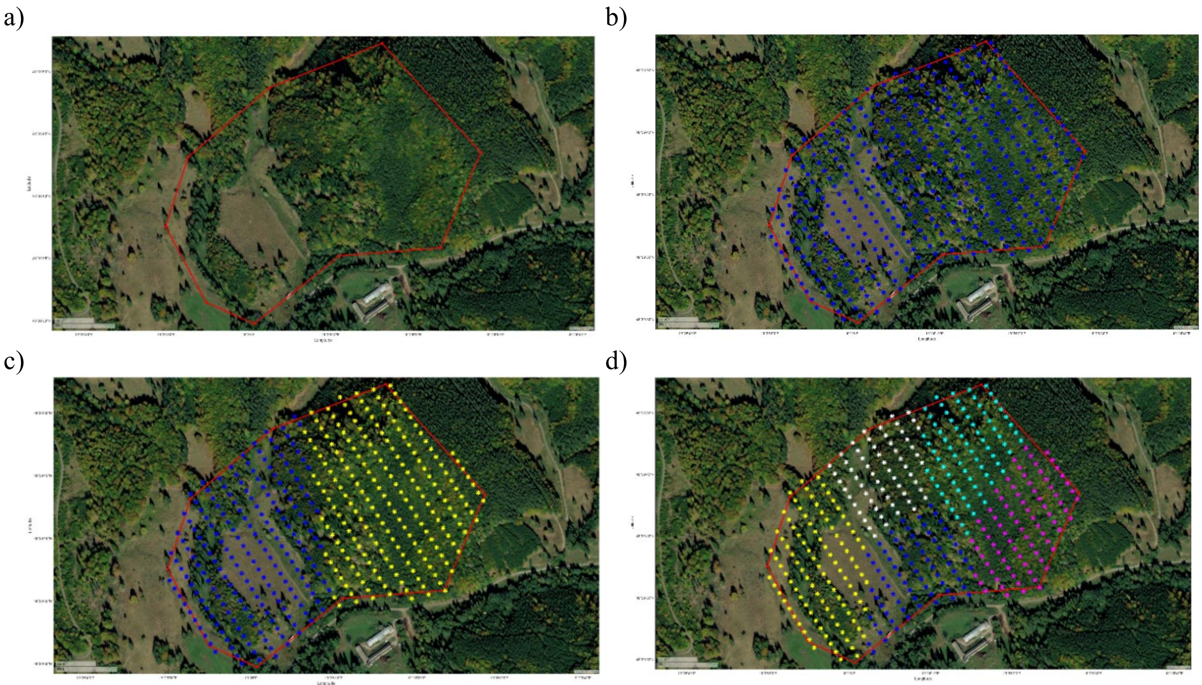

Figure 4. Input polygon of the area of interest a), calculated the points to take a photo b), divided area by the K-mean to two c) or five d) sub-areas.

an evenly divided area. An illustration of the distribution of the points of interest and the division of the surveillance area into sub-areas for 2 or 5 UAVs can be seen in the Figure 4. The next step is to create a *.kml file that can be transferred into the drones. The klm file can be generated in two ways:

- a trajectory route planning (an exactly defined path, illustrated on Figure 5a, b);
- a polygon (path will be planning by drone app based on received polygon, illustrated on Figure 5c, d).

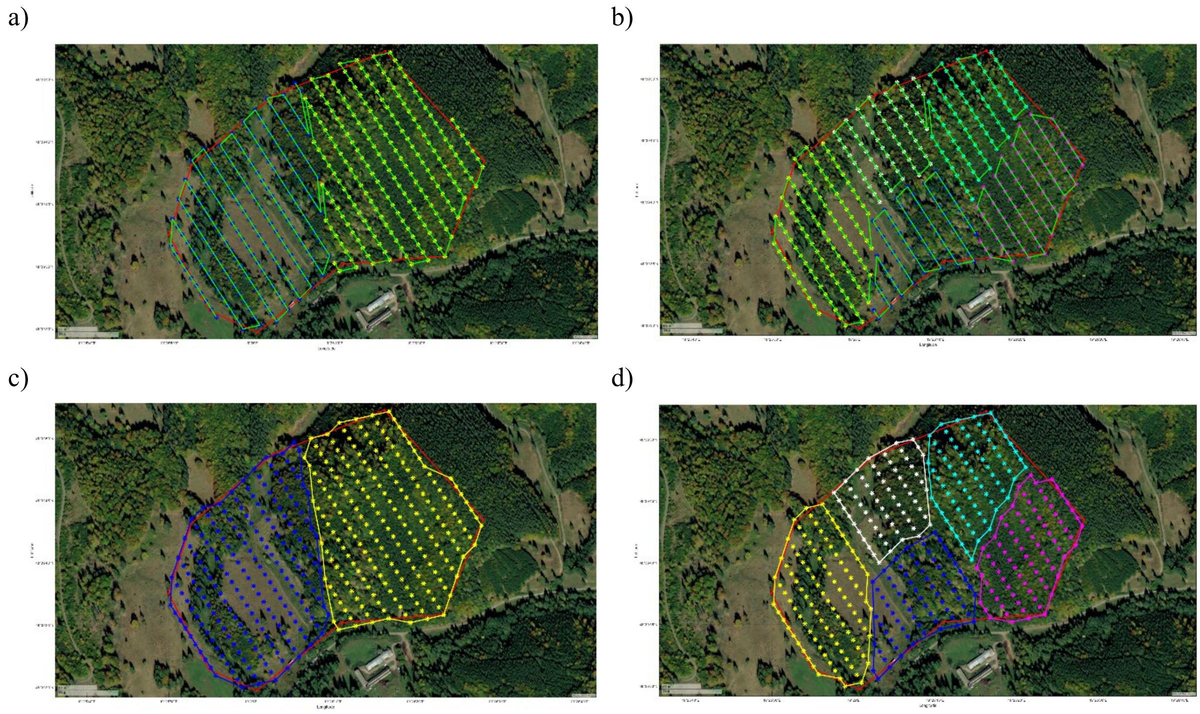

Figure 5. Trajectory route planning output for two a) and five b) sub-areas, polygons output for two c) and five d) sub-areas with marked individual points of interest.

A coordination algorithm service creates a kml files and sends a message back to the EmerPoll system. The Slovak pilot is considering the use of commercial DJi drones. The presented solution is designed with regard to the current Slovak legislation and the technical specifications of the drones that will be used.

CONCLUSION

The results achieved in the simulations proved the functionality of the proposed concept. The EmerPoll provides comprehensive coordination and aggregation of data from individual drones in the swarming the proposed demonstration scenario. The drone management algorithm theoretically allows coordinating tasks for any number of drones for any vast area. Based on simulation experiments we verified the proposed method as robust enougth to enable further expansion. The algorithm divides the target area into separate smaller areas (partial missions) based on the number of available drones and pilots while ensuring that the paths of individual drones do not collide, which is important for the overall safety of the mission.

The future work will focus on a real-world testing and validation during a live in-field exercise planned in Slovakia for the end of April 2023. This will be a critical phase since it will validate the viability of the proposed solution in real operational settings. Moreover, it will be necessary to harmonize all the legal and security requirements of the Slovak legislation together with the technical requirements for the proposed solution testing. Additional complexity will be introduced by the fact that the use of firefighting helicopters is planned to be demonstrated during the exercise as well – where helicopters and drones must not operate in the same area at the same time. Since Slovakia is a geographically diverse country it will be important to carry out tests in mountain areas as well as in lowlands. Therefore, testing is planned to be performed in environments with varying topographies and under different conditions (with respect to the parameters of the used hardware). As further future work we plan to expand the algorithm to respect dynamically computed fire danger indexes for target areas. This would enable a more precise distribution of drones respecting the higher risk areas. Also, two or more Algorithm Coordination Services are planned to be integrated to provide alternative path plannings for the multi-drone route planning. Another challenge will be dynamical real-time replanning of partial missions for drones in a case if one drone malfunctions or gets destroyed. The report about the enacted field exercises as well as lessons learned will be summarized in the relevant deliverable of the SILVANUS project and at relevant conferences.

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