Drone Fleet Deployment Strategy for Large Scale Agriculture and Forestry Surveying

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***Abstract*—Agriculture drones offer clear advantages over other monitoring methods including satellite imaging, manned scouting, and manned aircraft. However, for large scale areas, such as large forestry and agriculture mapping problems, the single drone is hard to accomplish its mission of mapping in a relatively short time period of 30 to 45 minutes. In addition, in large forestry mapping, camera, communication, and payload settings may further reduce the maximum endurance of drones in the air. With a single drone, the total required mission time to cover all the area is prolonged, not only producing a high cost for a drone service provider but also having more uncertainty. While with multiple drones, or a fleet of drones, it is possible to identify a globally optimized solution to reduce the total required mission time. In this paper, we mainly discuss the strategy of drone fleet deployment for large scale area surveying. Three key parts are analyzed, including a fleet of drones, cooperative coverage path planning, communication and data processing. The associated state-of-the-art solutions are listed and reviewed. In addition, in this paper, the key operational constraints for large scale agriculture and forestry surveying are analyzed. It should be pointed out that, from a comprehensive point of view, a drone fleet deployment for large scale surveying could attract more attention from the commercial drone industry.**

***Key words*—Drone fleet management, Agriculture and forestry surveying, cooperative path planning**

I. Introduction

Unmanned Aerial Vehicles (UAV) or drones have gained popularity in many industries due to their vast potential applications, such as survey, search and rescue, agriculture, and forestry. In a 2016 report, Goldman Sachs estimated that drone technology will reach a total market size of \$100 billion between 2016 and 2020 [1]. Commercial drones currently only represent 6% of the market in term of units, but their price tags of approximation of \$100,000 are projected to representing 60% of the industrial revenue. According to PWC, the most promising industry seems to be infrastructure, with a global potential valued at \$45 billion, followed by agriculture, at \$32 billion and transportation at \$13 billion [2].

Agriculture drones offer more compelling advantages over other monitoring methods. Satellite imaging, manned scouting and manned aircraft, for example: 1) Cheaper imaging: for fields less than 50 hectares in size, drones are considerably less expensive than satellites or manned aircraft surveillance. 2) Greater precision: drone cameras take centimeter-level images. 3) Earlier detection of problems: because drones survey more frequently, abnormalities are detected earlier [3].

In previous research, significant effort has been applied on studying the single drone mission flight within line-of-sight. However, for large scale area, such as large forestry and agriculture mapping problems, single drones are hard to accomplish its mission of mapping in a relatively short amount of time, 30 to 45 minutes and within line-of-sight range. With multiple drone, it is capable of accomplishing tasks which single drone cannot. In addition, large forestry mapping and assessment, camera, communication, and payload settings determine the maximum available flying time. With single drone, the possible mapping time is restrained, while multiple drones, it is possible to identify the global optimized solution. Thus, in this paper, we aims to discuss drone fleet deployment strategy on large scale land surveying, which is beneficial in reducing the cost efficiency of commercial drone service providers.

II. State-of-the-art

A. Coverage planning with single drone

In operational reality, many of the latest agriculture drones come with flight planning software that lets the users to draw a box around the field they want to survey on Google Earth map. Otherwise, an automated flight plan to be created for the user. Some even automatically plan the camera shots for them. Then, the users would upload the flight path onto their drone and get ready to fly. If the users are using a home-built platform or a ground control station, then they may need to manually code or set for each points to turn [3].

B. Coverage planning with multiple drones

In the sight of academic research field, researchers spot their attention closely on the swarm behavior of drones. They aim to use networked swarm model for drone operations. For example, Swarm Robotics for Agricultural Applications (SAGA). Multi-rotor drones are deployed to collectively monitor a sugar beet field and cooperatively map the presence of volunteer potatoes. The major threat is that they spread diseases (e.g., late blight) and facilitate harmful soil nematodes [4]. Swarm robotics, in particular, is considered extremely relevant for precision farming and large-scale agricultural applications. However, swarm robotics research is yet confined,only a few application in the field is currently available [4]. SAGA demonstrated for the first time the application of swarm robotics principles to the agricultural domain. Specifically, SAGA targets a decentralized monitoring/mapping scenario, and implements the use case for the detection and mapping of weeds in field by a group of small drones.

In terms of industrial usage, most of the popular drone fleet management models are designed simply. It models with a number of independent missions. There is no communication between drones, but there maybe a conflict alert service for remote pilots. However, one start-up company SkyX is special, they are in the field of Precision Agriculture Spraying Swarm (PASS). It enables the modular swarm of autonomous rotor drones for spraying. SkyX is developing a proprietary communications and computing hardware that will be installed on each drones to allow for real-time planning and swarming. Unfortunately, there is no application of fixed-wing swarm drones found available for precision agriculture.

C. Contributions

Note that line-of-sight drone flying rule makes swarm drones for large scale agriculture application concept operationally less achievable to be implemented in reality. However, it should be emphasized that restriction for drones has its publicity support by the Beyond Visual Line Of Sight (BVLOS) missions in nowadays. In case of resulting in injury to person due to unmanned aircraft crash that is below a certain severity threshold, it may permit to do a BVLOS mission with small drones [5]. Facing the near future with BVLOS drones in the national airspace and the great revenue of drone services in agriculture, new drone fleet management system is needed for accident avoidance, such as life-threatening collision. Efficiently planning paths with multiple BVLOS drones, requires collaboratively communicating among drones, etc. In this paper, we will address the problem of BVLOS drone fleets deployment for large scale agriculture and forestry surveying from a strategic point of view. Three topics are: fleets of drone, coverage path planning, the communication and data processing.

III. Strategy of Drone Fleet Deployment for Large Scale Area

A. Fleet of drones

Fixed-wing drones are the best choice to cover a large scale of area. Fixed-wing agriculture drones can cover up to 10 times of the acreage then a typical quadcopter can cover in a single flight [3]. The most popular ready-to-fly agriculture drone systems in the world with fixed-wing and battery powered are listed in Table I. Most of the agriculture drones are powered by electric batteries, when in need for heavy duty, or heavy payload, drones with gas powered are available. Gas powered agriculture drones could fly much longer than the battery powered drones, also more stable in windy weather for aerial photography purpose. However, operating cost of gas powered drones is more expensive and more pollute to the air. Hybrid drones merge the benefits of fixed-wing drones with the ability to hover, Vertical Take-Off and Landing (VTOL) same as rotor drones and cruise ability as fixed-wing drones. These three kinds of fixed-wing agriculture drones are shown in Fig.3. In this paper, battery powered fixed- wing agriculture drones are selected as the study case for drone fleets deployment.

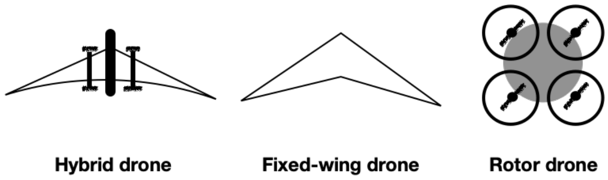

Fig. 1. Type of agriculture drones

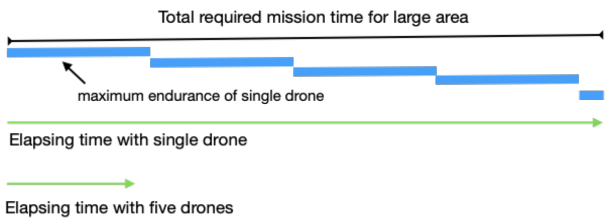

Fig. 2. Elapsing time with single drone or multiple drones for large area

B. Coverage path planning

1) Coverage decomposition: The shape of the area could be convex polygon, irregular polygon, or irregular line etc. For a large area, a single drone with generally maximum of 60 minutes flying endurance can only cover some part of the large survey area. The solution could be numbers of separated missions with individual drone at different time, or using multiple drones to cover the entire area at the same time, see

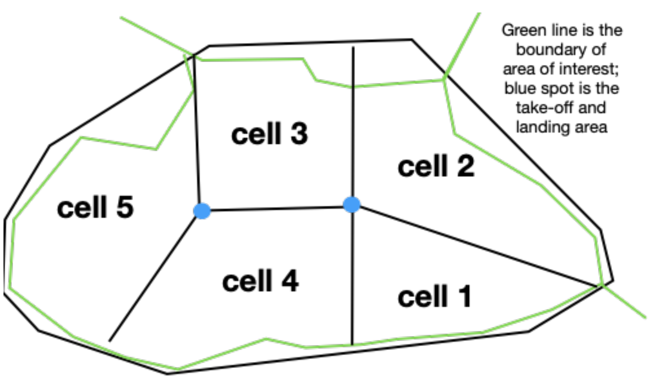

Fig. 3. Coverage decomposition wit cells

TABLE I
AGRICULTURE DRONES SPECIFICATIONS

Type of drone	Weight [lb]	Max. Time [min]	Max. Cov. [acres/flight]	Cruise speed[m/s]	Wind resis. [m/s]
eBee SQ	2.4	55	500	11-31	12
Birdseyeview Firefly6 Pro	9.9	59	600	15-18	null
AgDrone	4.75	55	600	13-23	9
AgEagle RX60	7	60	400	13.8-29.9	19
Delair UX11	3.1	59	600	15	12.5

Fig. 2. No matter which approach, the problem of decomposition method is important. It is found that this decomposition problem is immensely similar to the airspace sectorization optimization problem in Air Traffic Management (ATM). ATM is a collaborative way to ensure that safety and efficient of aircraft operation in the sky. The entire airspace is divided into several sectors by considerating the traffic complexity and controller's workload. The objective of sectorization is to find the best solution with minimum number of sectors and relatively balanced workload for controller. In addition, the airspace sectorization optimization include both static and dynamic airspace management [6], [7]. As shown, the related algorithms in ATM airspace management could give some experience in developing a suitable model for large scale survey with multiple drones. Here, for large area of agriculture or forestry surveying with drones, the coverage decomposition is to divide the area of interest into several smaller cells, as shown in Fig.3. Some operational constraints in coverage decomposition are discussed as following:

- The available number of drones in a fleet. Different drone service providers have different number of drones available for a specific mission in large area agriculture or forestry surveying.
- The required mission time constraint. Due to the uncertainty of weather in local or tropical area,day-time drone operational rules, and priority levels of mission, the possible mission time for drone fleet varies. Especially, most of the agriculture drones have low resistance to water, available mission time could be a tremendous constraint during the optimization process.
- Take-off and land site. Fixed-wing drones need to take off at a specific site, the space of this site has to be wide enough, especially in forestry mapping where the density of the trees is high, it is challenging to locate suitable taking-off sites. Constraint in the optimization is: at least one available site is available for one drone for each small sector after coverage decomposition.
- Endurance. Battery volume is fixed, and it is impossible to recharge battery while airborne in today's technology. Moreover, the endurance of battery is sensitive to the weather condition. In the optimization problem, the shortest endurance and the longest endurance should be transferred into a maximum coverage area in consideration of the ground speed of drones. Meanwhile, the data solution with camera and sensor system consume high level of energy, contributing to the endurance. Last but not least, it is important that emergency procedure is available for drone return to safe place with its maximum endurance.
- Radio frequency. To manage a fleet of drones, decentralized and centralized architecture are feasible. In a centralized approach, radio communication between drone and ground station about commands and control links must be emphasized. The remote pilot, who is on the ground, can control the aircraft using commands and control links, receiving real-time information about the drone on-board system. The radio communication signal range and the availability of radio frequencies are constraints for drone fleet deployment. Once signal is lost, disconnection between drones and ground station occurs. In this case, it is dangerous. Thus, in the optimization problem, a constraint was considered, that is: the signal should 100% cover all the sectors after coverage decomposition.
- The controlling capacity of remote pilot. Most of the remote pilot only control one drone. In order to control a fleet of drones, decision making supporting tools should be developed to help remote pilot to handle more drones at a time. For example, conflict detection and warning, conflict resolution manoeuvring advice, multiple flight trajectory management system etc. If remote pilot could handle two drones at a time, the mission time could be reduced to half of the mission time completed by a drone, which is beneficial to drone service providers.

2) Shape of mission area and cooperative path planning: For conventional agriculture surveying and mapping problem, geometric approach is popularly. As shown in Fig.4, in convex polygon and concave polygon case, a conventional back-and-forth path planning is designed to cover all of the surveying area, and with different cooperative path planning with multiple drones, the strategy is different.In the case of polygon with no-fly zone, firstly we decompose the entire irregular polygon shape into several small polygon area by the blue cutting line, then a conventional rectangular back-and-forth pattern to be applied to do the survey on each smaller cell. The path planning consists of several nodes and legs, either straight legs or curved legs. For curved legs, it requires drones to have a better manoeuvrability.

There is another strategy to do the cooperative path planning on the irregular area with no-fly zone. A grid based approach is introduced by [8]. Firstly, the area of interest is divided into several regular grids. Each cell represents

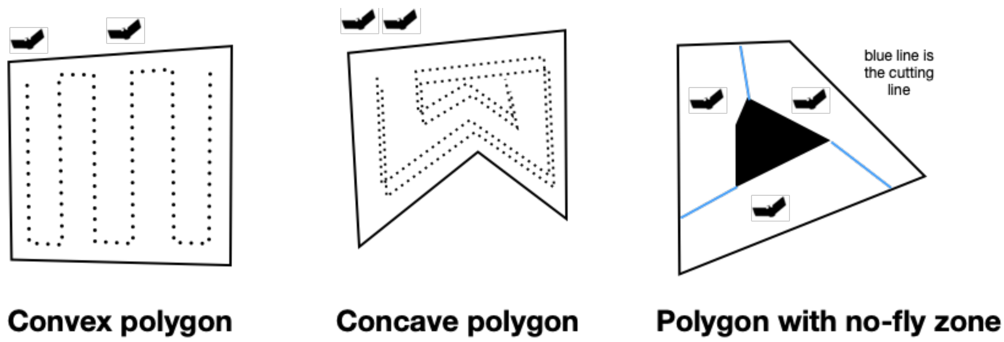

Fig. 4. Shape of mission area and cooperative path planning

a way-point of the path and its size, depending on the picture dimensions of the on-board camera. Then a heuristic algorithm is applied to invedtigate the links between different nodes. As shown in Fig.5, the solution with single drone and the solution with multiple drones are totally different. With multiple drones, it is possible to cover all the area of interest in a short time, and these drones could share the same take-off and landing area. This kind of cooperative strategy with a fleet of drones requires networked based deployment. This problem is also similar to Open Vehicle Routing Problem (OVRP). OVRP is a version of the well known Capacitated Vehicle Routing Problem (CVRP), in which each route ends with the last serviced user. More precisely, a vehicle does not return to the depot after servicing the last user as is the case of classical CVRP. There are another cooperative path planning with multiple drones, such as spiral, line formation, and decentralized technique based strategy [9]. They significantly contributing to the reduction of mission time in single drones.

3) Weather effect: Besides seamless routing constraints on the coverage path planning problem, rising expectations to the new outdoor applications are aspect to be considered, such as the weather forecast and energy consumption.

The capability and application of new drones require high demand of power which triggers the need of developing strategies to promote efficient energy usage. Exploiting wind-energy is one of the most important ways to extend flight duration for drones. To support functions of all sensor system on board to the best usage, wind is of foremost awareness. The importance to affect migrating birds' optimal flying speed and altitude, and their optimal migratory routes. With the same concept, we could develop an optimal coverage path planning algorithm in consideration of multiple objectives: energy saving, good quality of sensor data collection and bigger coverage area etc. With the benefit of wind, the ground speed of fixed wing drone could satisfy the requirement of surveying speed without consuming excess energy on board. Thus, searching for a feasible and optimal path, planning solution with the precise wind field prediction could definitely benefit a lower cost on large scale aerial survey. [10] proposes a novel method based on meta-heuristics produce an optimized flight time trajectory to survey a non-convex polygon area in wind with a fixed-wing drone and curved path. While offering better results than the previous approach, this algorithm is proved to greatly reduce execution time. Thus, it can be used for online re-planning tasks where the plan goals are deduced from a vision-based simultaneous localization and mapping (SLAM), which exhibits areas where additional data must be gathered. This work is developed and validated within a realistic simulation framework.

Rain, another weather condition that affect large area surveying missions. Especially in tropical area, due to the higher uncertainty of precipitation prediction, some on-the-job mission has to be stopped, and it may cause damage to drones. Thus, 1-3 hours' weather forecast data should be provided to remote pilot for a better path planning.

C. Communication and data processing

Pre-flight path planning is important. Due to the complexity of weather and other uncertainty factors, an online planning decision making is required to dynamically adapt to the environmental conditions which drones operate. Meanwhile, agriculture and forestry surveying need to use cameras to extract high quality photos. All this operations require power. However, the amount of energy that battery carries on drone is constrained.

Firstly, drones are aircraft flown in absence of physically present humans on board and can either be operated remotely or with pre-programmed script to execute planned missions on given data. The challenge is to find a smart and intelligent approach to efficiently execute the mission with smart online communication and data processing. To process image data, one solution is to use drone equipped Odroid-X motherboard 1, which consumes a high amount of energy for processing images than other boards, such Rapsberry PI. Another alternative is the possibility of integrating them with Cloud processing. Depending on the kind of processing required by the drone, Cloud offloading is possible, that is transfer the processing of some images from the drone to the Cloud, so that it can be processed properly, without overloading the drone. This entails the drone sending the images to Cloud by 3G network service and being given the result of the processing afterwards. The outcome from image processing by Cloud can be sent back to the drone

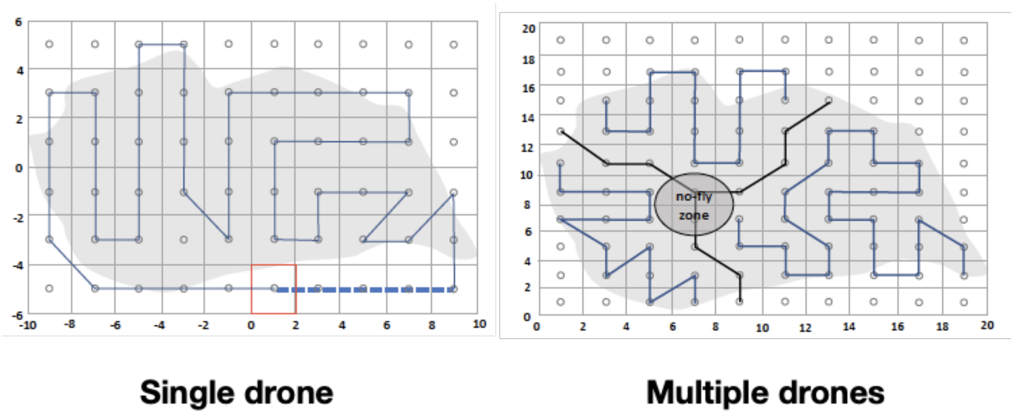

Fig. 5. Grid based approach to cover the irregular area (Note: figures from [9])

or be forwarded directly to a base station. This solution needs an embedded intelligence in the drone so that it can make decisions while taking images and deciding whether it should process images locally or convey it to a Cloud. In addition, compared with expert image data processing and local self-processing methods, cloud-based automated processing normally is at low cost, fast turnaround time, and high reliability, but the accuracy may be relatively low.

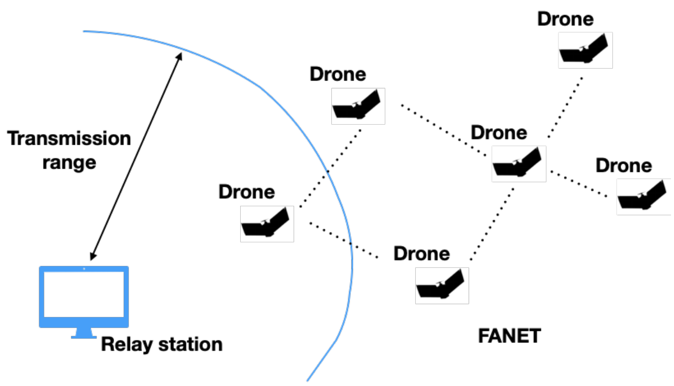

Fig. 6. FANET concept

Secondly, as each drone has limited coverage and computational capabilities, for large scale surveying mission with a fleet of drones, it is necessary to consider how to keep effective communication between drones and a relay station. A relay station is a broadcasting system that uses communications signals to direct drones. Relay stations can be a satellite, command vehicle, or ground station. In [11], Flying Ad-hoc NETwork (FANET) concept is proposed to bolster the performance and range of small drones, see Fig.6. FANET is based on the Vehicular Ad-Hoc Network (VANET) wireless communication system created to help self-driving cars position themselves in relation to other self-driving cars in the area. In FANET, multiple drones are part of a cooperative system, which contains a sensor unit, a communication unit, and an information-processing unit. The range and efficiency of a FANET is enhanced by the coordination and collaboration of its drones, which allows the network to cover more ground. When the communication session between a single drone and its relay station is interrupted, the drone becomes isolated. With FANETs, the communication between drones and relay station will remain more resilient due to the support of wireless communication gateways through select drones, which disseminate information throughout the network. The gateway selection is a critical component of FANET. To optimize gateway selection, [11] has also developed a dynamic gateway-selection algorithm for ensuring that the gateway function in the network is sustained. If a gateway drone goes down, another gateway drone in the cluster will take over relaying the information. The simulations demonstrated that the proposed dynamic gateway clustering was capable of significantly increasing the average gateway-retention probability.

IV. Conclusion

With multiple drones, it is possible to largely reduce the mission time, which gives great benefits for drone service providers. In this paper, the strategy of drone fleet deployment for large scale agriculture and forestry surveying problem was mainly analyzed. Firstly, a short review about state-of-the-art coverage path planning is done. Then, several key aspects in drone fleet deployment was explained in details, including fleet of drones, coverage decomposition, cooperative path planning for regular and irregular area, weather effect, communication and data processing. In future works, we are going to build up a mathematical optimization model to solve a real surveying problem and get the numerical results.

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