



Conference Paper

Swarm robotics as a solution to crops inspection for precision agriculture

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Abstract

This paper summarizes the concept of swarm robotics and its applicability to crop inspections. To increase the agricultural yield it is essential to monitor the crop health. Hence, precision agriculture is becoming a common practice for farmers providing a system that can inspect the state of the plants (Khosla and others, 2010). One of the rising technologies used for agricultural inspections is the use of unmanned air vehicles (UAVs) which are used to take aerial pictures of the farms so that the images could be processed to extract data about the state of the crops (Das et al., 2015). For this process both fixed wings and quadrotors UAVs are used with a preference over the quadrotor since it's easier to operate and has a milder learning curve compared to fixed wings (Kolodny, 2017). UAVs require battery replacement especially when the environmental conditions result in longer inspection times ("Agriculture - Maximize Yields with Aerial Imaging," n.d., "Matrice 100 - DJI Wiki," n.d.). As a result, inspection systems for crops using commercial quadrotors are limited by the quadrotor's maximum flight speed, maximum flight height, quadrotor's battery time, crops area, wind conditions, etc. ("Mission Estimates," n.d.).

Keywords: Swarm Robotics, Precision Agriculture, Unmanned Air Vehicle, Quadrotor, inspection.

1. Introduction

In nature, species like ants, birds and fish constantly develop entities, higher and more powerful when they work together. Examples of those collective behaviors in nature include: flying patterns of birds to fly more efficiently, colonies build by ants, travel patterns of fish for safer travel, etc. (Beni, 2005). The collective behaviour of organisms has inspired researches that were focused in applying the same behavioural pattern to robotics. (Bayındır, 2016). Swarm robotics is the technological concept that allows a decentralized control system with multiple robots, in other words it allows every robot

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Received: 15 November 2017
Accepted: 5 January 2018
Published: 4 February 2018

Publishing services provided
by Knowledge E

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Selection and Peer-review under the responsibility of the ESTEC Conference Committee.



to take actions based on the behavior of the other robots without receiving commands from a central computer (de Vries and Subbarao, 2011).

Swarm robotics is a powerful technology since it allows high-scale creation of collective robotic entities (Tan and Zheng, 2013; Weng et al., 2014). This makes swarm robotics an attractive option for automated crops inspection. Agriculture is one of the main application of quadrotors UAVs (Kolodny, 2017) and swarm robotics using these robots provides an opportunity to inspect agricultural data for large areas and it allows to highly enhance the tasks required in precision agriculture. This paper is divided in 3 sections, the first section explains swarm robotics features and some inspections solutions, the second division explains the agriculture precision concept and the inspection tasks procedures, the third section discusses how Robotics Swarm can be applied to the inspection procedures using quadrotors and what advantages are expected as a result.

2. Swarm robotics

Swarm robotics create collective entities using smaller single entities (Navarro and Matía, 2013). The single entities present among swarms are called agents. During a swarm interaction, every agent acts according to the other agents behavior, thus agents need communicate with each other (Kumar et al., 2017). The method of communication could include cameras, microphones, wireless transmissions, etc. The communication method needs to be consistent with the information receiving capability of the agent and the design of the swarm will be based on the capabilities of the agents (Garcia and Keshmiri, 2016).

Table 1 summarizes a comparison of the multiple multi-robot systems including feature performances. Swarm robotics is known for its high scalability due the decentralized control system, allowing the swarm to maintain high amounts on robots to work simultaneously. The decentralized control system feature a low bandwidth transmission from any source swarm, due to the absence of a central computer updating information in every robot. (Tan and Zheng, 2013).

Swarm robotics is inspired by nature behavior like most species that can synchronize when working together without any higher entity controlling the swarm (Weng et al., 2014). It is clear that animals and insects are very efficient at fulfilling their day by day specific task which inspires the curiosity of many researchers (Kennedy et al., 2001).

TABLE 1: Multi robot control systems.(Tan and Zheng, 2013).

Comparison of swarm robotics and other systems				
	Swarm Robotics	System of multiple robots	Sensor network	Multi-agent system
Population Size	Variation in great range	Small	Fixed	In a small range
Control	Decentralized and autonomous	Centralized or remote	Centralized or remote	Centralized or hierarchical or network
Homogeneity	Homogenous	Usually heterogeneous	Homogenous	Homogenous or heterogeneous
Flexibility	High	Low	Low	Medium
Scalability	High	Low	Medium	Medium
Environment	Unknown	Known or unknown	Known	Known
Motion	Yes	Yes	No	Rare
Typical applications	Post-disaster relief Military application Dangerous application	Transportation Sensing Robot football	Surveillance Medical care Environmental protection	Net resources management Distributed control

Researchers started providing innovative ways of applying Robotics Swarm for common tasks that could be used for human tasks.(Bayındır, 2016). According to.(Bayındır, 2016), the swarm tasks can be mainly divided in:

- Aggregation: agents gather in an common area.
- Flocking: agents travel together to the same location.
- Foraging: agents pick up and bring back objectives to a common location.
- Object Clustering and Sorting: agents pick objectives and bring them to clusters of objectives of the same type.
- Navigation: agent with limited capabilities travels with more capable agents in order to reach objective.
- Path Formation: agents create a path formation trying to minimize the distance between each agent
- Deployment: agents scatter mantaining a desired distance between each other.
- Collaborative Manipulation: agents change the state or position of a common objective.

- Task Allocation: agents change task based on environment conditions and other agents behavior

For the purpose of this paper it is necessary to consider a combination of the tasks mentioned in order to obtain a swarm behavior for crops inspection, thus a task allocation will be used.

3. Precision agriculture

Precision agriculture (PA) is the application of geospatial techniques and sensors (e.g., geographic information systems, remote sensing, GPS) to identify variations in the field and to deal with them using alternative strategies. In particular, high-resolution satellite imagery is now more commonly used to study these variations for crop and soil conditions. Precision agriculture is optimizing application of geospatial analysis techniques and sensors to detect variations in the field by managing the available resources (Leonard, 2016; Zhang and Kovacs, 2012). To optimize the resource handling it is necessary to gather all the information about the resources available. This procedure varies according to the resource and the type of data to be extracted. One of the automated technology is to analyze the state of the crops through various inspection by taking pictures of the plants with multiple types of cameras. The images are submitted to imagery algorithms that extract the data related to the state of the plants (Das et al., 2015).

Satellites can be used to take pictures of the crops, high resolution imagery has been used in some fields (Zhang and Kovacs, 2012) but even then the satellite images cannot provide the resolution required for the detailed analysis that is needed for some application in precision agriculture. As a solution, quadrotors has been used with measurement sensors mounted on them for detailed analysis of crops (Das et al., 2015). These devices sensors include RGB stereo cameras, multi-spectral cameras, a thermal imaging camera, a laser range scanner (LIDAR), and navigational sensors illustrated on Figure 1.

The type of the inspections for precision agriculture varies based on the analysis that is required for the field inspection. Four different crucial data extractions methods are explained on Table 2 based on (Das et al., 2015). It can be seen that all the inspection procedures could be done by quadrotors aerial picture taking, and accordingly to the precision required, and the distribution and size of the plants in the farm the height of flight may vary.

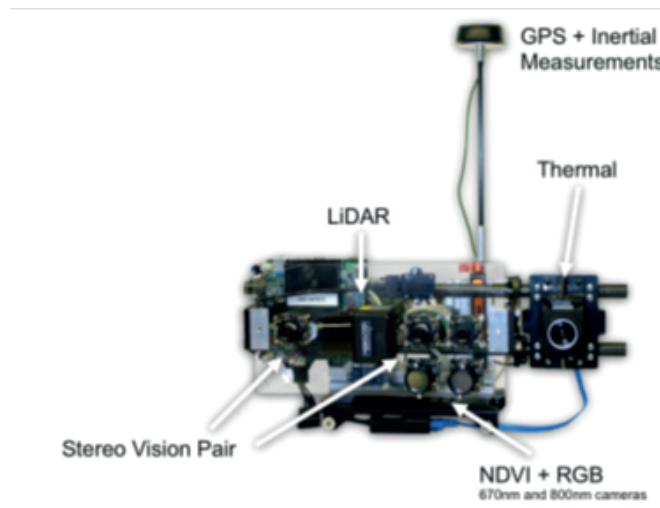


Figure 1: Sensor suite designed for crop inspections (Das et al., 2015).

TABLE 2: Crucial data extractions for precision agriculture (Das et al., 2015).

	Plant Morphology	Plant vigor	Leaf area estimation	Automated fruit counting
Data extracted	Canopy volume characteristics, and plant and fruit types	Normalized Difference Vegetative Index (NDVI)	Total leaf area of plants	Fruit amount by types
Resource handling to be optimized	Plants and fruits classification and distribution	Fertilization and mitigation	Fertilization, pruning and spraying	Storage of fruits
Sensors used	RGB Stereo camera, Laser range scanner, thermal camera	Multi spectral, camera	RGB Stereo camera, Laser range scanner, thermal camera	RGB Stereo camera, Laser range scanner, thermal camera
Inspection procedure	Image taking from the side of the plants	Image taking from above	Image taking from above	Image taking from the side of the plants

4. Swarm robotics in quadrotors for crop inspections

Precision agriculture is becoming the most used application for quadrotors (Kolodny, 2017). Additionally, measurements have illustrated that with communication protocols can increase the overall battery lifetime of the sensors (Srbínovska et al., 2015). Thus this paper discusses a way to enhance the inspection procedures made by quadrotors in precision agriculture. Swarm robotics seeks to augment the capability of the quadrotors that work together to create more capable entity that will represent the overall inspection system. By having multiple quadrotors working cooperatively the control system is able to reduce the time of inspection and adding more quadrotors

to the swarm decreases the time required for the analysis to be performed.(Tan and Zheng, 2013). Hence swarm robotics is an attractive technological solution to overcome the limitations that crops inspections face with current quadrotors.

Swarm robotics for quadrotors would require a swarm algorithm and a trajectory generator. The swarm algorithm is the criteria that the quadrotors follow to decide which objective to go, and the trajectory generator will provide the quadrotors with the ability to fly safely within the swarm to their chosen objective (Bayındır, 2016; Garcia and Keshmiri, 2016). In crop inspection, the mentioned criteria must be taken into account including as many environmental conditions as possible in order to create a robust and accurate inspection control system.(Bayındır, 2016). Experimental design practices of previous studies must be taken into consideration during studies and testing for the following features:

- Accurate dynamic model for the control system: Mathematical model that represents the way that forces are applied in the rigid body of the quadrotor so the processing of the feedback variables in the control system is accurate (Kumar et al., 2017).
- Sensor interference: Since feedback variables must be gathered from measurement sensors and these will never be fully accurate and precise, then error models for these must be taken into account (Meyer et al., 2012).
- Robust control system for the quadrotor: Control system that will receive commands from the algorithm and the trajectory generation and will output the propulsion of the propellers (Mulgaonkar et al., 2015).
- Quadrotors count: Different amounts of quadrotors will test the effectiveness of the algorithm in the swarm (Rutishauser et al., 2009).
- Quadrotor communication range: If the size of the crop is too big, quadrotors might fly out of communication range of each other and won't be able to share information ("Matrice 100 - DJI Wiki," n.d.).
- Quadrotor speed limit: Maximum speed will limit the capability of the quadrotor swarm according to their amount ("Matrice 100 - DJI Wiki," n.d.; Rutishauser et al., 2009).
- Altitude: The altitude of the quadrotors will change the area of coverage during flight, thus the inspection time will vary (Das et al., 2015; "Mission Estimates," n.d.).

- Air density: At very high altitudes the quadrotors will have to spend more energy in order to fly, thus the time of flight will vary and battery replacement could come more often.
- Wind speed: Wind forces can make the quadrotor lose accuracy in flight and spend more energy (Meyer et al., 2012).
- Battery replacement operations: In the algorithm the quadrotors will have to return to base to change batteries when they start running out of energy ("Matrice 100 - DJI Wiki," n.d., "Mission Estimates," n.d.).
- Crop area size: If the crop is big and the quadrotor count is low, the battery replacement operations must be taken into account ("Matrice 100 - DJI Wiki," n.d., "Mission Estimates," n.d.; Rutishauser et al., 2009).
- Crop area geometry: If the geometry of the crop is very irregular, the distribution of area per quadrotor could get complex and the swarm inspection algorithm must take this into account (Torres et al., 2016).

A real life operation would take into account additional variables like operational costs, safety policies, airspace regulations, but this paper considers the ones mentioned above as the most significant ones for the research development of a swarm algorithm and a swarm trajectory generation (de Vries and Subbarao, 2011; Zhu et al., 2015). By taking these factors into account a swarm algorithm and a swarm trajectory generation could be developed that will create a robust quadrotor swarm inspection system that will greatly enhance the automated inspection system required for precision agriculture.

Previous studies using swarm robots for inspections presents results of great performance in which the time of inspections are considerably reduced. Figure 2a shows an inspection arena of miniature robots inspecting 16 turbine blades. Figure 2b shows the time inspections for teams with different amounts of robots, the yellow bars show experimental results for teams of 5, 10, 16 and 20 robots, and the black thin bars show expected results calculated with a predictive model for teams from 1 to 20 robots. It can be seen that the time reduction is greatly reduced by adding a few robots but eventually the number of robots doesn't improve considerably the time reduction. This means that every mission conditions has a limit on how many robots may be worth adding (Correll and Martinoli, 2006).

As mentioned earlier, also the operational costs constraint will have to be considered at some point. Swarm robotics is a very promising technological solution to reduce the time of multiple types of operations. However, maintenance for the robots and

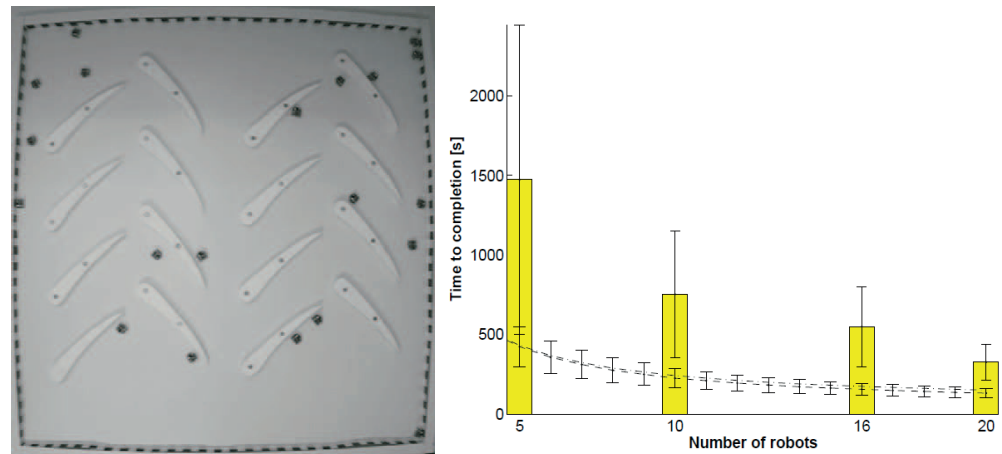


Figure 2: a) Arena emulating a simplified turbine inspection scenario. b) Inspection time vs number of robots for inspection of 16 turbine blades (Correll and Martinoli, 2006).

any other hardware or operational cost involved in the inspection operations could represent a crucial constraint on how many quadrotors or robots could be economically optimal to handle at a given time (Couceiro, 2014; Navarro and Matía, 2013). The number of economically optimal robots could be lower than the limit of robots that considerably improve the performance of the swarm (Correll and Martinoli, 2006; Couceiro, 2014).

5. Conclusions

Precision agriculture is one of the main application for quadrotors, and swarm robotics is one of the main application in multi-UAV systems, therefore future studies about quadrotors in agriculture should be highly encouraged to take swarm robotics into account as a possible solution during preliminary studies for automated farming research. Precision agriculture could significantly enhance the production on farms and this represents the possibility of vegetative friendly technologies. Similarly, swarm robotics provides a powerful concept of multi robots automated system, as the amount of robots increases while the robot size decreases, the capabilities of the swarm entity increases, this could lead to solutions that would be nearly imposible to be achieved with a single robot. Quadrotors are becoming increasingly popular for agricultural applications because of their movement capability, those capabilities could also be exploited in many human tasks while swarm robotics is applied. As a result, there are many possibilities of multi-quadrotor automated system applications precision agriculture being one of the leading ones. However, as stated in the last section, every mission will have constraints on how many robots increase considerably the

performance of the swarm, therefore this optimal number should be in the concerns of any swarm research. Also this number could be affected by the operational cost of the swarm, there could be a point where the cost for adding a robot is higher than revenue by the improvement in performance.

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