UAVs Team and Its Application in Agriculture: A Simulation Environment

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Abstract: The work proposes a simulation environment for UAVs management in the agriculture domain. In these last years, new technologies can effectively support farmer to face issues and threats such as parasites and sudden climatic changes that can severely degrade the crop or the quality of the cultivated products. However, to properly manage a UAVs team, equipped with multiple sensors and actuators, it is necessary to test these technologies in order to plan specific strategies and coordination techniques able to efficiently support farmers and achieve the targets. At this purpose, this contribution proposes a simulator suitable for the agriculture domain, where it is possible to set many parameters of this domain of interest.

1 INTRODUCTION

In this paper, it is supposed to use UAVs (also called drones) in the agriculture domain in a situation where it is necessary to monitor plants or products in a land. Often, farmers need to face many issue such as parasites or sudden climate changes that can severely affect the agricultural products quality. At this purpose, new technologies such as drones equipped with specific sensors, cameras and fertilizers can support farmers to face the threats and, in the specific case, to kill parasites that can destroy plants in the cultivated field (Zhang and Kovacs, 2012).

Let us suppose to have a cultivated area where a certain number of plants such as trees are distributed. In this area, it is possible that some parasites, in any part of the area, can generate and attack the nearly plants and to reproduce themselves and finally destroy the plants in the area. In this case, a UAVs team can be very useful in overseeing the overall area in order to localize through cameras the attacked plants or to see parasites moving among plants.

In order to propose coordination techniques of drones for precision agriculture domain, it is necessary to have a simulator where it is possible to set the main parameters of the domain of interest and test the proposed strategies and protocols for coordinating the drones in the area.
There is no simulator till now, at the best of our knowledge, that provide these modules and this testifies the novelty of the research area although an increasing interest has been shown on the industry and research field.

The paper is organized in the following way: in Section 2 the related work about the coordination techniques of swarm of drones is presented; the proposed simulator and its parameters are presented in Section 3. Section 4 shows the simulation environment with results and finally the conclusions are summarized in Section 5.

2 RELATED WORK

Recent works have been proposed regarding the use of drones or micro-drones in precision agriculture domain, showing as the applications of drones for precision agriculture can be interesting and very useful for farmers especially if the technology can reduce the cost of control systems (see (Costa and et.al, 2012); (Primicerio and et al., 2012); (Zhang and Kovacs, 2012)). Moreover, through the introduction of spectrometry or cameras on drones, it is possible to evaluate the height of the crops or soil moisture that can be useful to understand how the crop is raising such as shown in (Anthony and et.al, 2014); (Colomina and Molina, 2014); (Hassan-Esfahani and et.al, 2014).

UAVs applications in agriculture are described in (Pederi and Cheporniuk, 2015). The authors list some fields of applications of UAV spraying different protection chemical like insecticide, fungicides and herbicides. Crops spraying UAVs are suited for these tasks because many fields need of ultra low application volume of pesticides per hectare and only on some specific zones of a field and only at a specific

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time. In (Devraj and et.al, 2015) authors propose a web-based system that facilitate farmers/extension workers to diagnose insects/pests of major pulse crops suggesting the suitable treatments.

In (Ye and et al., 2013) four architectures of Precision Agricultural Management Systems (PAMS) are proposed. These architectures are: the spatial information infrastructure platform, the IoT infrastructure platform, the agriculture management platform and the mobile client.

In order to support the study of drones, microdrones or UAV applied to precision agriculture, it is necessary to design a simulator able to support in a modular and flexible way the different actors playing in the domain. All these issues are focused at an early stage in this work, showing as it is possible to model each single module such as mobility module for parasites, mobility module for drones, resistance characteristics of plants, and communication technologies (De Rango et al., 2008), (Fotino et al., 2007) of drones useful to implement a coordination strategy among drones (Palmieri et al., 2017).

3 UAVS SIMULATOR

We consider a team of UAVs/drones, that performs a mission of monitoring a land for destroying parasites in the plants. Once the parasites are detected by a UAV, it tries to destroy them through a certain quantity of pesticide that the UAVs carry. However, the pesticide resources of each drones are limited in quantity. Once a drone (called leader) notices parasites in a region, it has to form a coalition based on its current resource level such as pesticide and energy resources and it broadcasts some information (i.e, its location, type and number of its capabilities) to the other UAVs. The other drones, that have the required resources, will evaluate their availability to reach the leader or not. It should be noticed that the coalitions formed are temporary by nature; once the detected parasites are destroyed, the coalition members can perform other tasks.

Drones movement is modeled through the use of a local map that is stored on-board. This map collects info about already visited fields, if there are plants in the near field (cell) and if some plants are infected or not. Each of these info last for a time on the basis of the time set by the simulator. This temporal dependence of plants and insects reflect the real situation where an insect can attach again the plant or a plant can be planted again on the field.

The map is implemented by a cells square matrix and each cell represents a portion of field. The drone is assumed to be in the middle of the cell. The info related to the cell can be the presence or not of the plant, the presence of parasites and consequently if the plant can be infected or not. Moreover, the info in the cell can also express if a plant is under care or if the cell has not been explored yet. Drone updates its map after any movement removing the old info on the map and replacing them with more updated info. This local map helps the drone about the next field (cell) to visit. It selects one of the unexplored cells performs the field selection. The cell selection probability is uniformly distributed among all unexplored cells. However, after visiting some cells, the selection probability can be distributed again among the remaining cells.

When all cells in the local map cannot be visited because they have been already visited from a few time or because these cells are occupied by a health plant, the cell selection probability can be changed.

Each drone can exchange its map with all neighbor drones (drones within the drones transmission range). This possibility can assure that a drone can know the situation of neighbor cells also without going to explore them and this speed up the convergence of the overall field exploration.

Moreover, we consider many plants disseminated on the field that can attract the parasites. It is assumed that each parasite does not communicate with other parasites to perform a strategy but it moves on the basis of its local scope. It is oriented towards a single direction and it is limited by its local scope that is assumed in our case to be its three cells in front. During the movement the parasite can go in one of the adjacent and visible cells.

4 SIMULATION ENVIRONMENT

4.1 Simulator Indicators in the GUI

Each drone is equipped with a battery providing the energy to fly and move in the interested area. It is also equipped with a pesticide tank to spray on the parasite to kill them and a wireless module to communicate with neighbor drones. The communication range of each UAV is assumed to be limited. However, a UAV can reach another UAV by a sequence of communication links. The fuel tank is considered in milliliters (ml) whereas the battery power in Watts (W). All these parameters are selected before assessing the simulation through a GUI in the front-end of the simulator.

The battery power can be dissipated in three ways: drone movements, pesticide spraying and communi-

Figure 1: Example of UAVs level.

cation, which is due to radiation, signal processing as well as other circuitry. It is assumed that to eliminate a parasite is necessary a fixed amount of pesticide.

It is also assumed that drones can move at a constant speed from a cell to another one or they can stop to spray the pesticide on the tree attached by parasites. This assumption could be removed extending the mobility model and without affecting the validity of the overall proposed simulator model.

Moreover, when the fuel tank is below a minimum level the drone needs to come back at its base station or when the drone terminated its pesticide. In order to provide a friendly graphical interface, all drones are represented with some indicators that can change the color on the basis of the quantity of remaining pesticide or the battery level such as shown in Fig.1.

In the Fig.1 it is shown the circle colored in the most internal part to indicate the residual pesticide quantity of each drone i (S_i) using colors listed in Table 1. The residual battery levels of each drone i (P_i), instead, is represented with colors indicated in Table 2.

Indicators are also related to the tree health in order to represent the resistance level to the parasites attack (Table 3). More specifically, when a tree has been attached to parasites, its health decreases on the basis of number of parasites attaching the three and the time of the parasites remain into the three. We refers to H_i as the current health state of each tree and H as the initial state.

Table 1: Indicator of pesticide remaining quantity.

	$S_i > \frac{1}{2}\, S$ (tank capacity)
	$\frac{1}{4}\, S < S_i \leq \frac{1}{2}\, S$ (tank capacity)
	$0 < S_i \leq \frac{1}{4}\, S$ (tank capacity)

Table 2: Indicator of battery remaining quantity.

	$P_i > \frac{1}{2}\, P$ (Initial battery capacity)
	$\frac{1}{4}\, S < P_i \leq \frac{1}{2}\, P$ (Initial battery capacity)
	$0 < P_i \leq \frac{1}{4}\, P$ (Initial battery capacity)

Table 3: Tree health indicators.

	$H_i > \frac{1}{2}\, H$
	$\frac{1}{4}\, H < H_i \leq \frac{1}{2}\, H$
	$0 < H_i \leq \frac{1}{4}\, H$
	$H_i = 0$ (Three completely damaged)

4.2 Simulator Front-end

In Fig.2 it is shown an example of the graphical interface of the designed simulator. Fig. 3 shows the GUI to set all simulation parameters. More specifically, the parameters adopted in the simulation are listed in the following:

- Pesticide tank: it indicates the capacity of the pesticide tank (ml);
- Maximum battery level: it indicates the maximum battery level when the battery is charged;
- Minimum battery level: it indicates the minimum battery level to be preserved to reach the base station;
- Percentage of trees in the field: it represents the tree percentage to distribute on the considered field;
- Tree lifetime: it is the initial health state of all trees; it is represented by a number that can be decreased if a parasite attaches the tree;
- Base station number: it represents the number of base station from which drones can leave or can come back to recharge the batteries;
- Energy spent in unit of pesticide spray: it indicates how much energy is dissipated in spray 1 ml of pesticide;
- Movement energy: it represents the energy dissipated to move by 1 m in the considered area;
- Tree damage due to parasites (for each time unit): it indicates the damage attributed to the tree by the parasite for each time unit that parasite attaches the plant; it is important because reduces the tree health state and it can reduce the number of trees on the field;
- Minimum pesticide amount to kill a parasite: it indicates the minimum amount of pesticide (in ml) to kill a single parasite;
- Communication link bandwidth : it is the bandwidth related to the communication link; it is important because it affects the transmission delay of all info that a drone sends to other drones (for example the local map distribution among neighbor drones);

- Simulation number: it is the number of independent simulations before elaborating statistics; it is important to present simulations results in the confidence interval of 95 % ; this parameter can be selected at the beginning of the simulation and it can change on the basis of the simulation parameters adopted;
- Communication distance: it is the transmission range among drones expressed in meter;
- Pesticide spraying delay : it represents the time necessary to perform 1 ml spray of pesticide;
- Recharge time: it indicates the minimum amount of time to recharge the battery and refill the pesticide tank at the base station;
- Parasite movement delay : it is the time necessary to the parasite to move by 1m;
- Map update time: it is the periodic time that drones exchange their local map with other neighbor drones; it is important because it can affect the convergence time of the link state routing and it can affect also the topological info of the drones network
- Map lifetime: it is the time till MAP information is considered valid by drone; it assured that info needs to be updated otherwise they will be removed because obsoleted; this assures also that a drone can visit again a cell if it does not receive any more info of other drones about the cell status; this assured that if some parasites move from one cell to another cell already visited, they can be detected again and killed;
- TTL for help request: it represents the maximum number of hops that a help request can propagate in the network; it is useful also to avoid loop or help request diffusion without time limit;
- Time-out help request: it represents the waiting time of a drone requesting a help by other drones; after this time a drone can recall the best drones among all drones answering to help request on the basis of selection criteria.

In the front-end interface it is possible to select the data diffusion strategy. In particular, map info can be disseminated in a restricted flooding with different maximum-hop. For example a local map distribution inside the local range of each drone can be considered a particular case of a restricted flooding with number of hops equal to 1. If the number of hop increases, the restricted flooding can become the classical flooding where all drones are involved in the communication and can receive the local map of each drone updating in a fast way the overall network topology.

On the other hand, it is possible in the GUI to select also a link-state routing as map distribution protocol in order to build a map and drones topology in the overall network with the possibility to compute the minimum cost paths from each drone towards all drones in the network. The shortest paths are considering changing the classical minimum-hop count metric with the residual pesticide of drones. This means that the modified link-state routing allows to select drones with higher amount of pesticide guaranteeing that the infected area can be cured after the arriving of the involved drones.

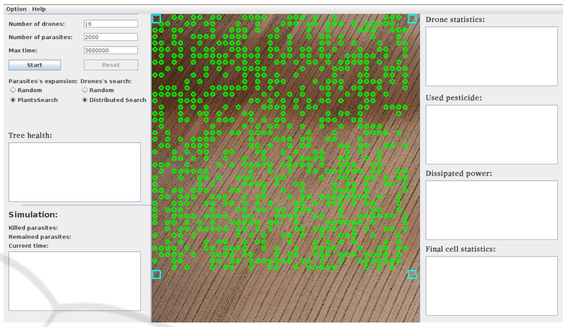

Figure 2: Graphical Interface.

4.3 Simulation Results

In the following some simulation results related to consumed energy, killed parasites and pesticide consumption are shown. It is worth pointing out that the hand designed simulator is a discrete event simulator.

In Fig. 4 it is shown the consumed energy for flooding with restriction to 1 hop until 5 hops and link-state routing. LS and restricted flooding to 3, 4 hops perform better than restricted flooding to 1 hop. Thus is due to the map exchange that is not exploited when the flooding is too restrictive. On the other hand, extending the flooding to more hops, the advantage of the map distribution allow more drones to reduce their movement in already explored areas. In Fig. 5 it is shown the number of killed parasites for restricted flooding and LS. Also in this case it is perceived a dependence flooding by the number of hops. For this performance metric the best results are achieved for restricted flooding with 2-3 hops. LS is a good compromise between number of killed parasites and consumed energy. Concerning the last graphic in Fig. 6, the used pesticide is shown for restricted flooding and LS. In this case, LS is able to perform better than flooding because the distributed protocol is able to better consider the residual pesticide among drones involving in the spraying action drone with more pesticide capacity.

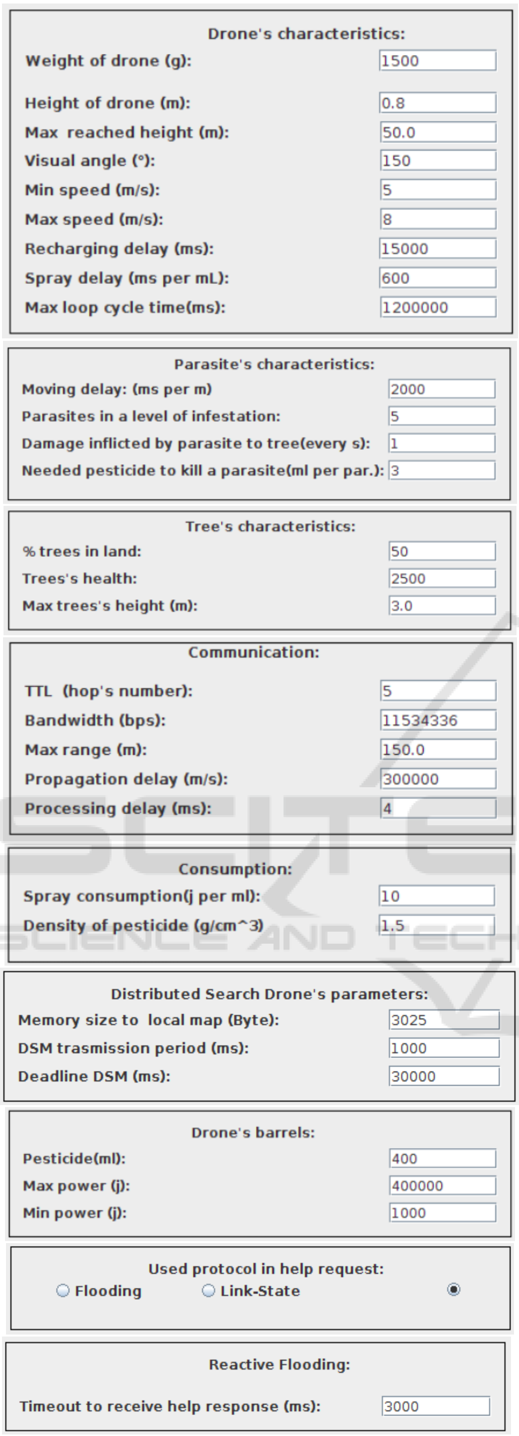

Figure 3: GUI to set the simulation parameters.

5 CONCLUSIONS

In this paper a novel simulator working in the agriculture domain is proposed. It allows to instantiate the agriculture field, drones with related communication module and sensor/actuators, parasites with their local movement and scope and plants with some resistance characteristics. Moreover, two coordination strategy have been proposed and studied: the first one is based on a local field map distribution in order to let neighbor drones about the presence of parasites or already visited pieces of land; the second one is based on the extension of a link-state routing protocol to the agriculture application domain to distribute all topology info among all drones. It is shown as the distributed link-state distribution is more suitable since it allows to reduce the energy consumption and to increase te number of killed parasites. More-

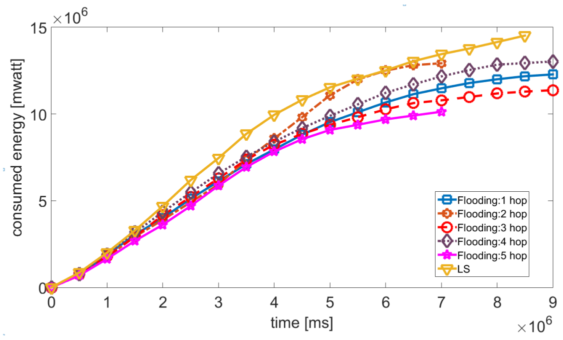

Figure 4: Consumed energy vs topology update time for flooding and link-state routing with pesticide quantity as metric.

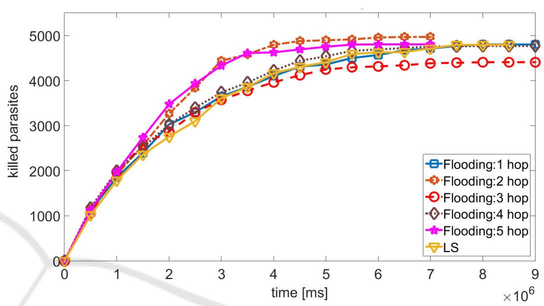

Figure 5: Killed parasites vs topology update time for flooding and link-state routing with pesticide quantity as metric.

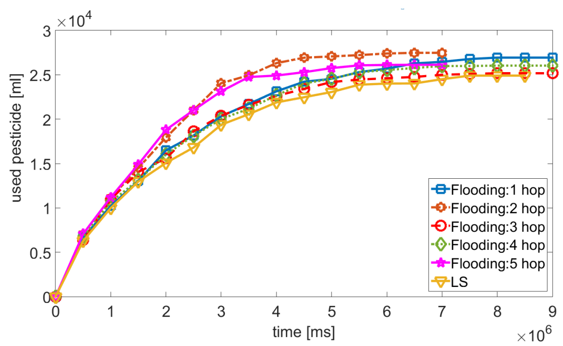

Figure 6: Used pesticide vs topology update time for flooding and link-state routing with pesticide quantity as metric.

over, the distribution of pieces of already visited maps among all drones allow to speed up the algorithm convergence reducing the number of cells visited more times. The link-state routing has been modified to account more metrics such as remaining pesticide quantity and already visited cells. Future work includes the introduction of others parameters, coordination techniques, and many constraints related to the domain of interest.

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