Simulation of multiple unmanned aerial vehicles for compensatory pollination in facility agriculture

Hao FAN\(^1\), Minsheng YANG\(^2\), Ruyi WANG\(^3\), Xiujuan WANG\(^4\), Xun YUE\(^5^*\)

\(^1\)College of Information Sciences and Engineering, Shandong Agricultural University, Tai’an, Shandong, China
\(^2\)Smart Hospital Construction Office, Taian City Central Hospital, Tai’an, Shandong, China
\(^3\)College of Information Sciences and Engineering, Shandong Agricultural University, Tai’an, Shandong, China
\(^4\)College of Information Sciences and Engineering, Shandong Agricultural University, Tai’an, Shandong, China
\(^5\)College of Information Sciences and Engineering, Shandong Agricultural University, Tai’an, Shandong, China

*yuexun@sdau.edu.cn

Abstract. In order to enhance the economic benefits of fruit and vegetable cash crop facilities for agriculture, precise stereotactic of compensatory pollination technology in effective pollination period, is the effectively improve the fruit setting rate and the economic benefits of crop. The effects of honeybee pollination on the flowering can provide theoretical support for crop yield and ecological security. However, manual spraying of compensatory pollination technology is high, the working efficiency is low, and the control strategies based on single multiple UAV faces great challenges, which are the effects of flight heights on the droplet deposition and distribution. In this paper, firstly, flow chart of multiple unmanned aerial vehicles in facility agriculture for precise stereotactic of compensatory pollination method is given. Then, the thermogenesis and precise detection of the flower tissues is studied. Last, simulation of 16 UAVs and the effectiveness of the theoretical results is given in Matlab environment. Time varying formation control, formation tracking control of UAVs in facility agriculture, which based on precise stereotactic of compensatory pollination technology, provides a feasible solution scheme for ecological unmanned farm.

1. Introduction

Multi-rotor UAVs (Multiple Unmanned Aerial Vehicles) are supported by a single platform and an information collaborative interaction system. According to the external loading task requirements and the perception environment, they independently carry out formation (aggregation) and cooperative task assignment (disintegration) \([1-3]\). In recent years, with the in-depth integration of emerging digital information technologies (smart chips, internet of things, big data, cloud computing, artificial intelligence, etc.), platform technologies, sensor technologies, command and control technologies related to UAV equipment have made great progress, and advances in various new structural designs and power storage technology have greatly improved the efficiency of UAVs \([4-6]\). In order to achieve...
green, efficient, and sustainable development of agriculture, drones, intelligent robots, and big data
technologies have been applied to agricultural ecological fields such as plant care, environmental
monitoring of farmland IOT, and remote sensing analysis of farmland [7-9].

Modern facility agriculture is a modern agricultural efficient production method integrating
biotechnology, engineering technology, environmental technology and information technology, in
which the pollination rate during the effective period of crop pollination is the key gateway and a must
for determining high and stable yields. As the plastic film or glass of facility agriculture isolates
pollinating insects and wind from the natural world, the pollination techniques used in facility
agriculture for fruits and vegetables are mainly based on pollination by wall bees, supplemented by
artificially assisted pollination (dipping flowers) and hormone spraying. However, these pollination
techniques have drawbacks that are difficult to overcome. For example, the lack of pollinating insect
sources due to perennial application; manual flower dipping is not only labor intensive and time-
consuming, but also has a low fruit set rate and a high rate of malformed fruit, but the pollination effect
is not ideal and requires daily operation, which can easily cause plant stem scars and disease infections;
the hormone treatment is ideal for increasing yields, but the fruit quality is poor and the rate of
 malformed fruit is high, and more importantly, it also causes hormonal pollution, which directly affects
the health of consumers. The current fruit setting rates of fruits and vegetables in facilities are 14.3% for
natural pollination, 68.8% for artificial pollination and 66.5% for wall bee pollination [10]. In order
to meet the economic needs of the facility agriculture industry chain of major high-end fruit and
vegetable cash crops, there is an urgent need to develop new ways and methods of pollination of facility
crops with independent intellectual property rights. A multi-rotor UAV-based liquid pollination
technology was proposed in China. A DJI T20 multi-rotor plant protection UAV was used to compare
the particle size and coverage results of droplets deposited in the canopy of pear trees when sprayed by
UAVs and backpack sprayers at different spray volumes. The results show that the single multi-rotor
UAV with low or ultra-low volume spraying has uneven particle size and coverage of the droplets
deposited in the canopy of pear trees, and that the inflorescence and flower fruit set rates are still low[11,
12]. From the perspective of precision pollination production practices, there is an urgent need for more "grounded" multi-rotor UAV clustering strategies for facility agriculture.

In order to enhance the economic benefits of fruit and vegetable cash crop facilities for agriculture,
on the basis of ensuring insect pollination as the primary pollination supporting technology, the paper
proposes a multi-rotor UAVs control strategy based on compensatory precision pollination technology
for facility agriculture, which can assisted multiple fertilization stimulation of facility fruit and vegetable
crops, facilitate settling fruit, and vigorous, not easy to cause abortive fruit and increase the fruit setting
rate, enhancing the economic benefits of fruit and vegetable cash crop facilities for agriculture. Based
on the technologies of compensatory precision pollination, the clustering of multi-rotor UAVs for
facility agriculture, such as target location assignment, path planning, collision avoidance requirements
and attitude trajectory tracking control [13], the virtual simulation of multi-rotor UAVs for compensatory pollination for facility agriculture was implemented in Matlab.
2. Description of the Method of precise stereotactic of compensatory pollination in facility agriculture

2.1. Flow chart of multiple unmanned aerial vehicles in facility agriculture for precise stereotactic of compensatory pollination

![Flow chart of method](image)

2.2. Technical feasibility analysis

Key technologies to achieve a cluster of multi-rotor UAVs for compensatory precision pollination in facility agriculture are as follows:

1) The geographical area of agricultural UAV operation is limited by energy cells, which is one of the bottlenecks limiting the development of agricultural UAVs at present. However, for smaller areas of facility agriculture cash crops and for the demand of flying in low-altitude airspace (within 10 meters), multi-rotor UAV for facility agriculture have obvious advantages in real-time, quantitative and optimal configuration.

2) With the potential of combining UAVs with 5G wireless networks, the technology for the formation control of multi-rotor UAV clusters in facility agriculture is integrated with the new generation of 5G mobile communication technology. The communication between the clusters of UAVs is achieved by the airborne UAVs accessing the ground infrastructure of the 5G wireless network. The ideal state of continuous exchange of information within the limited communication channel bandwidth can be guaranteed in terms of signal strength and coverage.

3) For the whole industry chain of facility agriculture (mainly vegetable greenhouse base in Shouguang, Shandong Province, supplemented by green fruit and vegetable agricultural products with regional advantages), which has been formed on a scale in Shandong Province, based on pollination of facility crops by wall bees. A cluster of multi-rotor UAVs for compensatory precise pollination of facility agriculture, where the pistil stigma is stimulated by multiple fertilization, enhance and improve the fruit setting rate.

4) Based on DJI's release of the P4M aerial survey UAV equipped with an integrated multispectral imaging system. The auxiliary identification and positioning technology of the object of the UAV's precise directional pollination operation is, firstly, in accordance with the obvious difference
characteristics between pollinated and un-pollinated (the female style is light green after pollination and the green gradually disappears the next day), marked by photoelectric digitalization of modern facility agriculture; secondly, through the monitoring data analysis of the monitoring sensors and network system of modern facility agriculture; thirdly, the development of precise positioning and dynamic monitoring based on spectral imaging technology Intelligent identification technology.

5) Compensatory precision pollination of multi-rotor UAV for facility agriculture, where pollinating parents have a high demand for anthers and where pollen quality is a favorable factor in improving fruiting rates.

6) The single UAV pollination technique suffers from uneven particle size and coverage of the deposited droplets within the layers, and the pollinated inflorescences and flowers still have low fruit setting rates. This paper proposes a multi-rotor UAVs cluster for compensatory precision pollination in facility agriculture.

3. Compensatory precision pollination in a multi-rotor UAVs virtual simulation experiment for facility agriculture

3.1. Global evolutionary cycle of the formation control and dynamic task assignment for leader–following multiple unmanned aerial vehicles

Stage 1: Cluster formation (aggregation) of multi-rotor UAVs for facility agriculture

- Initial state of the cluster: A certain size, loosely defined individual facility agriculture multi-rotor UAV exists in a controlled range of bounded time and space.
- Positive path information begins to gain, no inverse path information: the central node in a dominant position, through the individual sense of the operating environment and the external mission payload command and control platform, the use of data chain-based information sharing global information interaction, began to gradually, in batches "top-down" overall constraint, drive the lower level of the facility agriculture multi-rotor UAV, the beginning of the cluster hierarchy leading the dynamic configuration of topological interaction structure of the aggregation.
- Normal path information grows to a very large number, no inverse path information: The "bottom-up" normal path information of the cluster control grows to an extreme value, and the multi-rotor UAVs aggregation process follows a certain hierarchy of leading topological interactions to form a two-dimensional / three-dimensional spatially specific arrangement of cluster system formations.

Stage 2: Optimization of cluster formation of multi-rotor UAVs for facility agriculture (adjustment optimization)

- Normal path information remains very large, and inverse path information starts to gain from very small values: The lower level multi-rotor UAVs with multi-modal sensing capabilities sense changes in the surrounding environment, and the "top-down" inverse path information transfer feedback from the cluster control within the cluster system starts to increase.
- Inverse path information is balanced with normal path information: The cluster control "bottom-up" normal path information flow pattern begins to diminish. The formation of the cluster system is dynamically adjusted to the formation. The "top-down" normal and "bottom-up" inverse path information flow within the cluster is balanced, maintaining a relatively stable balance in the cluster system formation.

Stage 3: Disintegration of multi-rotor UAV cluster formations for facility agriculture (task allocation)

- Positive path information is maintained, negative path information is gradually gained: The "bottom-up" negative path transfer feedback information flow method within the cluster is dominant.
- Normal path information fades to very small values, inverse path information gradually gains to great values: Cluster formations are grouped and assigned based on multiple targets, multi-rotor UAVs are led from the bottom up in a cluster layer led topological interaction structure, starting with layer-by-layer disintegration, and task assignment each (layer) multi-rotor UAV has its own task or sub-target.
3.2. Compensatory precision pollination in a multi-rotor UAVs virtual simulation experiment for facility agriculture

On the premise of first considering multiple technical issues such as cluster formation target location assignment, path planning, collision avoidance requirements and attitude trajectory tracking control, and assuming the ideal state of continuous information exchange within the communication channel bandwidth, a cluster formation control simulation of a multi-rotor UAV for facility agriculture with compensatory precision pollination is designed to assist compensatory pollination with stationary fixed multi-objective matching candidate queue optimization algorithms and regional path planning for cluster queues, taking a 16-cell cluster system as an example, to give an intuitive and reliable comprehensive virtual simulation experiment in the Matlab environment.

**Step1.** It is assumed that the multi-rotor UAV units completing the previous task (e.g. pesticide spraying) are randomly distributed in position within the environmental interval of growing cash crops in facility agriculture. In order to compensate for accurate pollination, the control is controlled by a leading cluster formation control mechanism, where the randomly distributed multi-rotor UAV units need to be transformed into a leading cluster formation of 16 multi-rotor UAV units for battery energy replenishment and pollination of the parent anthers. This is shown in Figure 2(a-b).

![Figure 2](image)
Step2. The identification and localization of pollination targets is aided by the human distinction between pollinated and un-pollinated features, which are digitally marked with specific photo-electricity. In the virtual simulation, the long colored blocks represent the objects that require compensatory precision pollination.

Step3. In the virtual simulation experiments, for the three compensatory precision pollination operation objects, the one-long serpentine formation of the 16 multi-rotor UAV units leading cluster formation was dynamically adjusted to three small formations as shown in Figure 3.

Step4. After the three compensatory precision pollination missions were completed, the 16 multi-rotor UAV units were again returned to a leading cluster formation in a single line formation for battery energy replenishment and pollination of the parent anthers in preparation for the next formation mission.

4. Timing analysis of simulation algorithm and Conclusion
In order to verify the timeliness of the leading compensatory precision pollination multi-rotor UAV cluster formation simulation algorithm, the rationality and stability of the proposed model is verified mainly from the perspective of the size of the cluster formation and the range of the initial target position allocation of the cluster formation, under the premise of determining the relevant parameters (operating speed, etc.) of the virtual simulation experiment.
timeliness, shown in Figure 4. It indicates that the timeliness of the algorithm in this paper meets the planning requirements for compensatory precision pollination multi-rotor UAVs. However, the simulation results show that the larger the initial target location assignment range is the longer the corresponding algorithm convergence time. The number of compensatory precision pollination multi-rotor UAVs has a large impact on the timeliness of the model algorithm, and therefore a reasonable solution needs to be selected.

The current high-end fruit and vegetable cash crop industry chain in modern facility agriculture has problems with artificially assisted pollination based on the mainstream technology of ensuring insect pollination, such as high labor intensity and low operational efficiency, as well as uneven particle size and coverage of the deposited droplets within the layer of a single UAV pollination. In order to improve the fruiting rate of conventional insect pollination of fruit and vegetable cash crops, this paper proposes a multi-rotor UAV clustering strategy for compensatory precision pollination in facility agriculture, and designs a stationary fixed multi-objective matching candidate optimization algorithm for compensatory pollination and cluster queue area path planning based on the realization of UAV cluster formation target position assignment, path planning, collision avoidance requirements, attitude trajectory tracking control and other technologies. Finally, a 16-unit virtual simulation of a multi-rotor UAV cluster for facility agriculture with directional compensatory pollination is implemented in the Matlab environment, as well as a cluster simulation algorithm timeliness analysis.

The next steps are as follows:

1) Crop germplasm resources harbor their own specific plant life information at various stages of reproductive development. This electromagnetic spectral information, which is not visible to the human eye, together with subsequent analyses, can provide crucial support for technical feasibility. Using the biological phenomenon of the effective and optimal pollination period of plants, the intelligent core algorithms, theories and methods of the new digital technology of plant life information perception are developed using a combination of various monitoring sensors and network road systems in modern facility agriculture.

2) Fully 5G mobile network and multi-dimensional agricultural sensors, using agricultural engineering system means to establish "real-time sensing, intelligent control, precise operation, intelligent service" of modern agricultural facilities agricultural UAV cluster system, to provide specialized, standardized service mode and comprehensive agricultural system solutions for precision planting of ecological unmanned farms.

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