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An Autonomous UAV for Spraying Pesticides

Aamer Sohail[1], G Satyanarayana[2], K Durga[3],

ABSTRACT

The use of pesticides in agriculture is essential to maintain the quality of largescale production. The spraying of these products by using aircraft speeds up the process and prevents compacting of the soil. However, adverse weather conditions (e.g., the speed and direction of the wind) can impair the effectiveness of the spraying of pesticides in a target crop field. Thus, there is a risk that the pesticide can drift to neighbouring crop fields. It is believed that a large amount of all the pesticide used in the world drifts outside of the target crop field and only a small amount is effective in controlling pests. However, with increased precision in the spraying, it is possible to reduce the amount of pesticide used and improve the quality of agricultural products as well as mitigate the risk of environmental damage. In the past several years, UAV has been extensively used in agriculture. However, the efficiency is still not as high as desired and the phenomenon of pesticide pollution is still existing. This is mainly because of the following two problems: 1) the autonomy of most existing UAV system is still very limited. Actually, most of them are still operated through remotecontrolling. 2) the UAV's operating precision is not high enough due to the low accuracy flight control near the plants. The paper presents combination of new approaches and technologies in modern-day agriculture. Perspectives and benefits of usage of Unmanned Aerial Vehicles in different spheres of agriculture considered on the base of spraying drone project called "Aero Drone"

KEYWORDS: UAV (Unmanned Aerial Vehicle); Aero Drone; Pesticides.

INTRODUCTION

Pesticides, also known as agrochemicals, are generally applied in agricultural crop fields to increase productivity, improve quality and reduce production costs. However, prolonged contact (either directly or indirectly) with these products can cause various diseases to humans such as several types of cancers, complications in the respiratory system and neurological diseases. It is estimated that about 2.5 million tons of pesticides are used each year throughout the world and this amount is growing. Much of the pesticides are wasted during the spraying process due to the type of employed technologies.

[1]Assistant Professor and Head, Assistant Professor[2,3]

[1,2,3]Dept. of Mechanical Engineering,

[1,2,3]Global Institute of Engineering and Technology, Moinabad, Hyderabad

There are evidences that show that the drift of pesticides is generally found at a distance of 48 m and 800 m from the target crop field, the deviation can reach a distance of 5 km to 32 km, downwind. The use of UAVs to carry out the task of spraying pesticides can be beneficial to many reasons, including (I) to reduce human contact with the chemicals, which helps to preserve human health; and (ii) to improve the performance of the spraying operation, avoiding the presence of chemicals outside designed areas, which helps to preserve neighbourhood fields, that can be other crops, preserved nature areas or water sources. Sets of control rules, to be employed in an autonomous UAV, are very hard to develop and harder to fine-tune to each environment characteristics. Thus, a fine-tuning phase must involve the parameters of the algorithm, due to the mechanical characteristics of each UAV and also must take into account the type of crop being handled and the type of pesticide to be used. In this paper we present an evolutionary

Fig 1. UAV used for pesticides spraying

algorithm to fine-tune sets of control rules, to be employed in a simulated autonomous UAV. We describe the proposed architecture and investigations about changing in the evolutionary parameters. The proposed architecture employs an UAV, which has a system of coupled spray, and it is able to communicate with the Wireless Sensor Network, which is organized in a matrix-like disposition on the crop field. This WSN aims to send feedback on the weather conditions and how spraying actually are falling in the target crop field. Based on the information received, the UAV appropriately applies a policy to correct its route. Hence, the main contributions of this research are as follows: (I) investigate an

evolutionary methodology capable of minimize human contact with pesticides, (ii) evaluate an evolutionary approach able to minimize the error in spraying pesticides in areas of growing vegetables and fruits, (iii) investigate techniques able to maximize quality in agricultural production, and (iv) contribute to increase the autonomy of the architecture proposed by, in which the policy parameters were set empirically and applied independent of weather conditions. The autonomy level of existing UAV system used for agriculture can be separated into several levels: execution level, coordination level and organization level. The execution level is the lowest level, which is a basic condition of UAV as long as it can fly. The coordination level provides the appropriate sequence of control and identification algorithm to the execution level, such as [9, 11]. The organization level is a highest level with environment awareness system, mission management etc., for example, [12, 13] introduces an autonomous cargo transportation system with high efficiency. This work presents a fully autonomous UAV research platform for indoor and outdoor search and rescue.

METHODS OVERVIEW

A. Precision Agriculture and It's Tasks

For last couple of years, the term precision agriculture has often been used in UAV industry. This can be explained by the fact that farmers worldwide are making their decisions more often depending on the data that were collected by the drones. That is why it is possible to say that precision agriculture is the understanding of the complex interactions between crop growth and decision-making. Many methods and chemicals serve to protect crops and improve their final output. Mostly, chemicals are applied over entire farm or a field. With the help of precision agriculture, it is possible to identify problematic areas and apply chemicals only to those areas. This will allow for significant savings. Unmanned Aerial Vehicles have several applications and purposes in precision agriculture. They can perform such tasks: Normalized Difference Vegetation Index (NDVI) Monitoring. Plants Pathology Monitoring Crop Water Stress Index (CWSI) Monitoring Spraying of Liquid Fertilizers, Pesticides and Spraying of Entomological Material (Trichogrammatid) Aerial Mapping.

B. Detailed Description of Precision Agriculture Methods B.1. Plant Health Monitoring

Normalized Difference Vegetation Index concept is based on evaluating the amount of incident light absorbed and reflected at different wavelengths and has been utilized in the development of several ratios, known as indices, which are sensitive to different environmental and physiological conditions. NDVI only uses measurements from two sensors: optical and infrared. Normalized Difference Vegetation Index may be used to identify areas of poor soil fertility. Currently, NDVI is calculated from satellite images. It takes big amount of time and causes poor management decisions because of old data. That is why it is reasonable to use UAVs for such operations. Advantages of using a drone equipped with optical and Near Infrared (NIR) sensors are that UAVs are significantly cheaper to use, there is relatively little time delay and the resolution of images is better.

In case that average farmer uses fertilizer on his entire farm uniformly, the main task of UAV is to save on cost and quickly supply decision-making data. Assuming that average farm in Ukraine is 200 hectares and that fertilizer costs 800 horn per hectare, the cost to apply it to the entire farm is about 160,000 horns. Expecting modest 30 % savings the total savings for the farmer will be 48,000 horns. Such calculation concerns just NDVI monitoring method for fertility. Other methods can save significantly much money. Plant pathology is the science of plant disease by pathogens. The categories for plant pathogens are viruses, bacteria, fungi, nematodes and parasitic higher plants. In this paragraph, we will focus on the leaf rust detection. Leaf rust is a fungus that affects wheat, rye and grains. Losses from it over large areas can range from 1 to 20 %. Nowadays, leaf rust monitoring is done visually. Farmers observe the fields with Hyperspectral Imaging (HSI) to detect deceased areas. HSI provides high potential as a non-invasive method. Afterwards, it is possible to mount Hyperspectral Sensor as a payload for UAV

Another serious plant decease is called Hangdogging (HLB). It infect and devastate hundred thousand of hectares of citrus crops around the world. Both NIR and thermal IR can detect the presence of HLB. These sensors can detect disease before the visible changings in leaves or fruits occur, while it has its own spectral characteristic. Crop Water Stress Index Monitoring Method concern the demand of particular crops in irrigation water. It is possible to calculate CWSI using the difference between the plant temperature and air temperature and comparing it to the dryness of surrounded air (Vapor Pressure Deficit). Vapor Pressure Deficit can be calculated from the relative humidity. CWSI could be used to schedule irrigation. When the CWSI number gets i.e., 0.6 it means that crops demand irrigation. Using a thermal sensor on an UAV and a measurement of relative humidity will allow to develop a thermal image for CWSI calculation and analysis.

B.2. Crop protection Crops

spraying is very perspective and important branch of precision agriculture. Frequently, such task is common for ground-based sprayers and agricultural aviation. However, today it is possible to use UAVs for this task, i.e., Japanese farmers using unmanned helicopters and 40% of all rice fields in Japan are sprayed with the help of drones. Mentioned above method is much cheaper as regular agricultural aviation because of lower fuel consumption and costs. Both unmanned helicopters and fixed wing UAVs may be used for crops spraying. However, their application is different. Helicopters are useful for small farms, farms with difficult terrain and wineries. Fixed wing vehicles may perform the same work as normal fixed wing tractor aircraft. Usage of UAVs as liquid fertilizer sprayers is ineffective. Ordinary field needs 5–7 litters of fertilizer per hectare. Payload for most UAV Sprayers does not exceed 50 kg. Only some UAVs that correlated to the size of present agricultural aircrafts may perform such task effectively. Although, UAVs can spray different types of plant protection chemicals. There are a lot of plant protection products exist today. Main pesticides that used in precision agriculture are:

SOLUTION OVERVIEW

Great amounts of unmanned aerial platforms for agriculture exist around the globe. Most of them are small drones, equipped with different types of special cameras and sensors for agricultural fields monitoring. Exceptions are small UAVs and multicopper systems that are used for entomological material (Trichogrammatid) “dusting” and only sometimes for classical dusting designations. Ukraine based start-up “Aero Drone” develops a unique project that has no analogues worldwide. As far as it is known, this project is the first working prototype of fixedwing spraying UAV. It has many advantages, comparing with traditional crop protection methods, realized by means of big aircrafts and ground tractors. Main of them are:

- low fuel consumption;
- high productivity;
- ultra-low volumes spraying methods (1...3 hectare), avoids waste of water and ground contamination;
- low noise pollution;
- no chemical contamination risks for operator;
- no risk for operator because low working altitu
- multifunctional frame;
- crop dusting costs are much lower

Disadvantages:

- productivity fall with the strong causes drift of crop protection c
- small cropping areas and those high obstacles may not be able t
- large cropping areas may need coverage.

Based on this, it is possible to say th spraying despite of disadvantages i safer and cheaper than traditional s specification of PAM-20:

- wingspan – 1.5 m.
- max takeoff weight – 10 kg.
- payload weight – 15 kg.
- power of engine – 5 hp.
- cruising/working speed –30km
- max flight time – 30 minutes.
- max range – 100 km.
- max altitude – 5 km.
- working altitude – 10...15 m.

“Aero Drone” is presented in Fig. 2. It is equipped with 5 litters fuel tank, 2×10 litters suspended tanks for chemicals, has fuel consumption 0.2 litters per hectare and gives an ability to spray up to 10 hectares per one flight. It also has an alternative mode, when suspended tanks are replaced by fuel tanks that prolonging flight time and range and giving an ability to mount special video unit with cameras and sensors. Such mode make it possible to use this UAV for all types of monitoring, of course primarily for precision agriculture needs. “Aero Drone” has suspended portable control unit that includes autopilot, modems, measuring devices, sensors and other electronics. Such control unit may be installed on other UAVs, but with other settings file, which should be uploaded by the operator before the flight. Autopilot provides fullautomated missions (take off, flight, and landing) and supports up to 1000 GPS-points for mission routing.

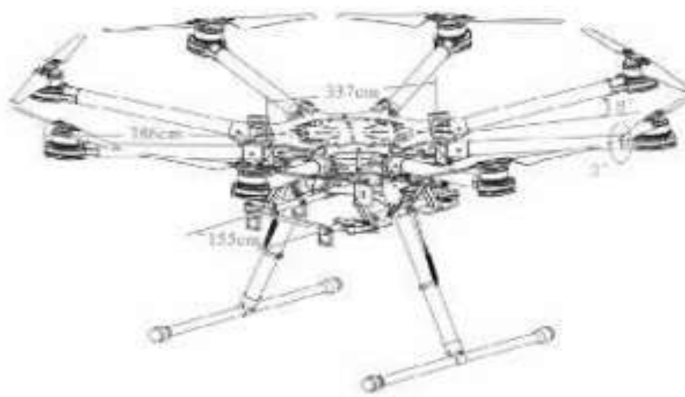

Fig. 2. UAV Aero Drone.

SIMULATION PLATFORM ESTABLISHMENT AND RESULTS ANALYSIS A. Simulation Platform Establishment

In order to verify the reasonability and correctness of the optimal mission assignment scheme, a simulation platform is established using MATLAB and a series of simulations are carried out. This simulation platform mainly includes four modules: parameter initialization, mission assignment, quadcopter control and plotting. Fig.2 is a block diagram showing how this simulation platform works. As shown in Fig.2, the values of m, r h, war and w0 are entered by the user, but other parameters such as the base, the current point, the current velocity, the destination point, the last point, the way point, the current way point, the maximum electric quantity, the charging rate, the consuming rate, the control parameter, the control precision, the control model and the quadcopter states are initialized by the parameter initialization module. The mission assignment module implements the optimal mission assignment scheme, the way point generation and the path planning on the basis of known parameters. The quadcopter control module implements the cooperative control of the quadcopters, the quadcopter attitude control and the quadcopter state determination. The plotting module implements moving path plotting in the "Mission display" area in Fig.3 based on the mission assignment scheme and the generated way point from the mission assignment module.

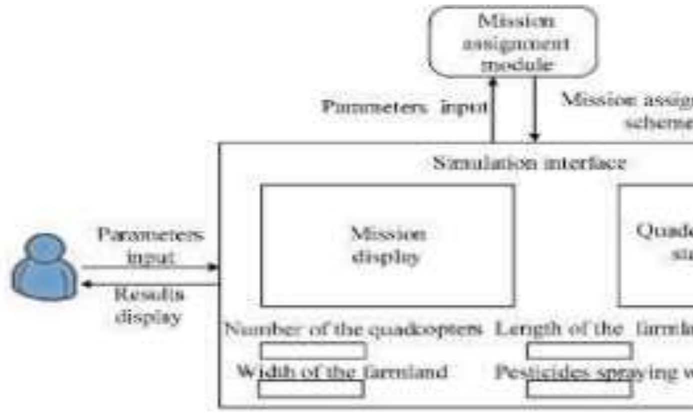

Fig. 3 A block diagram of the simulation platform

Results Analysis

The values of m, r h, war and w0 are given as 3, 60 meters, 300 meters and 10 meters, respectively, and so n is 30. In order to verify the reasonability and correctness of the optimal mission assignment scheme, two kinds of simulations have been carried out. One is to divide all tasks equally without optimization, and the other is to use the optimal mission assignment scheme to assign the tasks. Then, the time for each quadcopter to complete its mission is recorded. Fig.4 is the path diagrams showing the time for the first quadcopter to complete its mission when the tasks are divided equally without optimization, and Fig.5 is the path diagrams showing the time for the first quadcopter to complete its mission when use the optimal mission assignment scheme to assign the tasks.

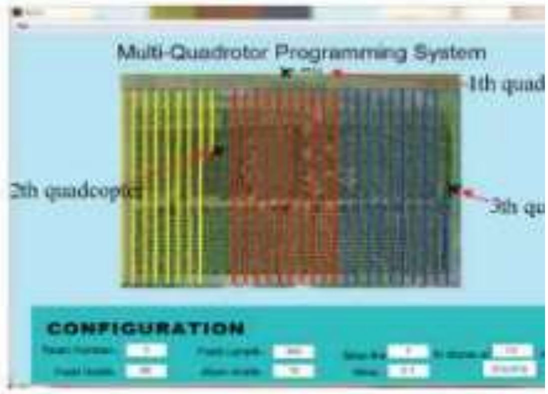

Fig. 4 The time for the first quadcopter to complete its mission when the tasks are divided equally

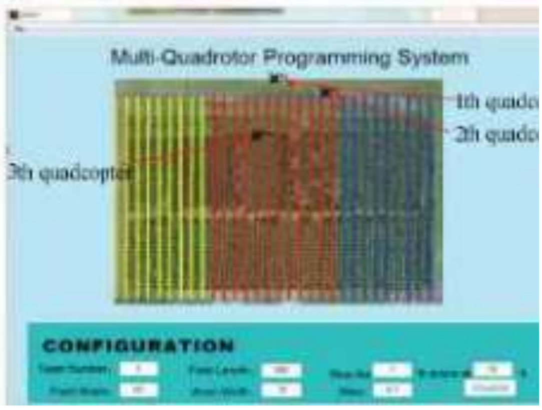

Fig. 5 The time for the first quadcopter to complete its mission when the optimal mission assignment method is used to assign the tasks

By comparing the above simulation path diagrams, it is known that the total time to complete the spraying task is different. When the sub tasks are divided equally, the number of sub tasks assigned to each quadcopter is 10 and the time for three quadcopters to complete its mission are 787.6, 956.6 and 985 simulation time intervals, respectively. When use the optimal mission assignment scheme is used to assign the tasks, the number of sub tasks assigned to three quadcopters are 9, 12 and 9, and the time for three quadcopters to complete its mission are 844.5, 855.6 and 872.6 simulation time intervals, respectively. From the above comparison results, we can know that the mission execution will be more efficient and the mission time of each quadcopter will be close to each other by using the optimal mission assignment scheme. In order to make the simulation results more persuasive, more simulations are carried out, including 1) the same number of the quadcopters with the different size of the farmland, and 2) the different number of the quadcopters with the different size of the farmland. The results of the simulations are shown in TABLEs Ċ & ċ. The parameter 1s is the average allocation scheme; 2 s is the optimal mission assignment scheme; 1 t is the completion time of the average allocation scheme; 2t is the completion time of the optimal mission assignment scheme; At is the time saving by the optimal mission assignment scheme. The simulation time interval is used as the unit of 1 t, 2t and At

TABLE I. RESULTS OF THE DIFFERENT NUMBER OF THE QUADCOPTERS WITH THE DIFFERENT SIZE OF THE FARMLAND

m	n	s_1	s_2	t_1	t_2
3	30	10:10:10	9:12:9	985	872.6
4	40	10:10:10:10	8:12:8	786.5	592.4
5	50	10:10:10:10:10	7:11:14:11:7	658.9	598.6
6	60	10:10:10:10:10:10	6:11:13:13:11:6	723.5	689.2

TABLE II. RESULTS OF THE SAME NUMBER OF THE QUADCOPTERS WITH THE DIFFERENT SIZE OF THE FARMLAND

m	n	s_1	s_2	t_1	t_2
3	30	10:10:10	9:12:9	985	872.6
3	40	14:13:13	11:18:11	1136.9	1040.9
3	50	17:17:16	15:20:15	1110.7	971.9

As can be observed from TABLEs I & II the effect of saving time by using the optimal mission assignment scheme is significant whether when the number of the quadcopters is the same but the size of the farmland is different or when the number of the quadcopters is the different and the size of the farmland is different.

CONCLUSION

This paper proposes a new mission assignment scheme aimed at the farmland spraying problem. A simulation platform is established and a series of simulations are carried out to verify the reasonability and correctness of this scheme. This scheme mainly solves the mission assignment problem when use the plant-protection-quadcopters to spray pesticides on a rectangular field, and its purpose is to minimize the time to complete the spraying mission. The results of this paper prove that, by using the optimal mission assignment scheme, the mission execution will be more efficient and the mission time of each quadcopter will be close to each other. Although this scheme has some ideal simulation results in this paper, there are still some aspects need to be improved. Firstly, most of the actual farmland is not rectangular and this scheme only suitable for the rectangular farmland. Thus, this scheme needs to be improved to apply to the irregular farmland. Secondly, a quadcopter may suddenly be damaged and unable to work in practice. Thus, this scheme should also consider quadcopter failures in future research.

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