Group Control of Heterogeneous Robots and Unmanned Aerial Vehicles in Agriculture Tasks

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Abstract. The tasks of monitoring agricultural lands using multicopters, which have higher video capture speed, higher resolution, invariance to clouds and other advantages, are considered. The aim of the research is to develop formal model and algorithms for group control of heterogeneous robotic complexes, including unmanned aerial vehicles in solving agrarian problems. Based on the analysis of existing robotic solutions in the agricultural sector, the classification of the operations is given. A formal statement of the task of controlling a group of heterogeneous agricultural robots in a certain agricultural space is formulated. We have considered the parameters of a set of cultivated lands; the number of processing agricultural objects; a set of objects of basing and storage of robotic means; a set of cultivated crops; sets of heterogeneous robots; possible options for the approach of robots from the basing area to the cultivated territory, as well as a set of resource constraints.

Keywords: Agricultural robots · Precision farming · Unmanned aerial vehicles · Multicopters · Heterogeneous robots

1 Introduction

With the development of science and technology, unmanned aerial vehicles (UAV) are increasingly being used in various sectors of the national economy. In the conduct of environmental research, UAVs provide: environmental monitoring and research; weather forecast and meteorological data collection; protection of wild animals from poaching; control over the animal population; search and rescue of people and animals; creation of maps, especially 3D-maps [1]. In agriculture, UAVs solve the problem of applying fertilizers, pesticides, etc. [2].

Agriculture accounts for the consumption of most (70%) of the world's water resources and 45% of the world's food reserves, which is produced on irrigated land, covering only 18% of the acreage [3]. Given that other national economic sectors are gradually increasing water consumption, as well as considering the current climate change projections that indicate an increase in the frequency and intensity of drought

A. Ronzhin et al. (Eds.): ICR 2017, LNAI 10459, pp. 260–267, 2017.
DOI: 10.1007/978-3-319-66471-2_28

periods in the Mediterranean and semi-arid regions, the problem of monitoring water resources and their economical use in irrigation is crucial [4].

In addition, the projected global food demand by 2050 indicates that crop production should be doubled [5]. The field of plant growing was substantially developed after the Second World War as a result of the "green revolution" of the 60 s. According to the main criterion of the "blue revolution", which focuses on preserving the environment, in agriculture water management is being currently optimized to obtain the desired volume of yield per unit of water.

Within the framework of the European research program "Horizon 2020", exact agriculture is one of the priority interdisciplinary scientific directions. The American National Research Council has identified this type of agriculture as the most promising in terms of the use of information technology and robotic complexes for monitoring, obtaining data and managing crop growth, taking into account the landscape heterogeneity and variability of borders [6].

Traditional approaches of remote sensing with the placement of remote sensors on towers over fields of crops (thermal imaging, multi and hyperspectral cameras, fluorimeters, etc.) have a limited range due to the fixed position near which data are collected. Another traditional method of remote sensing is based on the use of aircraft or satellites, but temporal and spatial resolution significantly limits their effectiveness for agricultural assessments, given the very dynamic changes in vegetation with respect to the environment [7]. Also, the quality of images obtained from satellites or manned vehicles is often affected by weather conditions, so additional temporary and financial resources are expended for re-visiting at the time appropriate for shooting.

In recent years, remote sensing, based on aerial photography using UAVs, has been actively used due to technical progress, reducing costs and dimensions of sensors, the development of a global positioning system, intelligent programming systems and flight control. Improved parameters of spatial and temporal resolution of aerial photography using UAVs make it possible to extract more data on the state of the leaf cover of the crops.

The urgency of the introduction of robotic complexes in the agricultural sector is also due to social causes. The agricultural sector is characterized by heavy physical labor, monotony, heavy dependence on climatic conditions, dynamic seasonal work and other factors that negatively affect the employment of labor in the agrarian sector of the economy. In some countries of Southeast Asia, rice is one of the most important crops and the staple food. However, labor in agriculture is constantly shrinking due to the fact that the younger generation is more interested in working in offices, factories and industrial zones than in agriculture. Therefore, the activity of the agricultural sector is also declining. The most promising approach to solving this socio-economic problem is the automation of production and the use of mobile robotic complexes for agriculture.

Compared to radio-controlled aircraft, multicopters have a low cost and a low flight altitude, which ensures high resolution of images when using standard on-board cameras. In addition, due to the low flight altitude, more accurate delivery and distribution of fertilizers on agricultural land are achieved.

Considering the urgency of using UAVs for the development of the agricultural sector, in Sect. 2 we analyze the existing technical solutions with the classification of the problems being solved, and in Sect. 3 we give a formal statement of the task of managing a group of heterogeneous agricultural robots, which is the main goal of this study.

2 Review of Existing Robotic Solutions in Agriculture

Since 2000, UAVs have been increasingly used in the civil sphere and in particular for accurate farming. Initially, two types of UAVs were used for agricultural purposes: helicopters and fixed-wing aircraft. Both airplanes have a number of advantages and limitations. In the NASA projects, the Pathfinder-Plus UAV (with a wingspan of 36,3 m and weight of 318 kg, a flight time of several hours, equipped with visible and multispectral cameras to obtain images of 0,5 and 1 m per pixel respectively) was used to detect flooding and control Fertilization during the ripening of cereals in agricultural fields of coffee plantations in Hawaii in flight at an altitude of 6400 m above sea level [8]. Another development of NASA is the RCATS / APV-3 fixed wing UAV, which was used to study vineyards in California [9].

Unmanned helicopters have more sophisticated flight control systems, but provide a lower flight altitude. They are able to move in any direction and hang, maintaining a stable position in flight. These helicopters do not require special areas for take-off and landing, which is critical for standard agricultural fields. One of the latest Pheno-copter helicopter-type UAVs with a payload of 1,5 kg can fly for 30 min and perform remote measurements of the area under investigation [10].

Fixed wing aircraft use less sophisticated flight control systems and, due to a longer flight time, are able to cover a large area, but their shortcomings are a large flight altitude (as a consequence, a lower resolution of images), impossibility of hanging, and a need for a special runway [11].

The multicopter flying platform has flight characteristics similar to the helicopter, but it has more stability, maneuverability and does not require a runway. Typically, multicopters are designed from lightweight materials (carbon fiber, aluminum, fiberglass, Kevlar, etc.) with 4, 6 or 8 engines, depending on the requirements for the payload mass. Due to low cost and convenience of application, multicopters are widely used for professional and non-professional purposes. Farmers use multicopters to obtain real-time data, diagnose the state of the crop and analyze the sites that require irrigation.

Figure 1 presents a classification of the main monitoring tasks, solved with the help of UAVs on various agricultural lands. Next, consider a number of works describing the specific implementation of UAVs in solving the problems of agrarian robotics.

In [2] it is proposed to use UAVs to determine the fertility of rice using image analysis. The developed multicopter platform allows determining the fertility of rice and the required amount of fertilizers by processing images obtained from a camera installed in a multicopter.

The color chart of the leaves is used to determine the fertility of rice in the analyzed field by comparing the color of the leaves of rice plants with a list of five available green levels. The described prototype of the Quad-X multicopter platform has the following main parameters: weight 750 g, flight time 12 min, hang time 15 min,

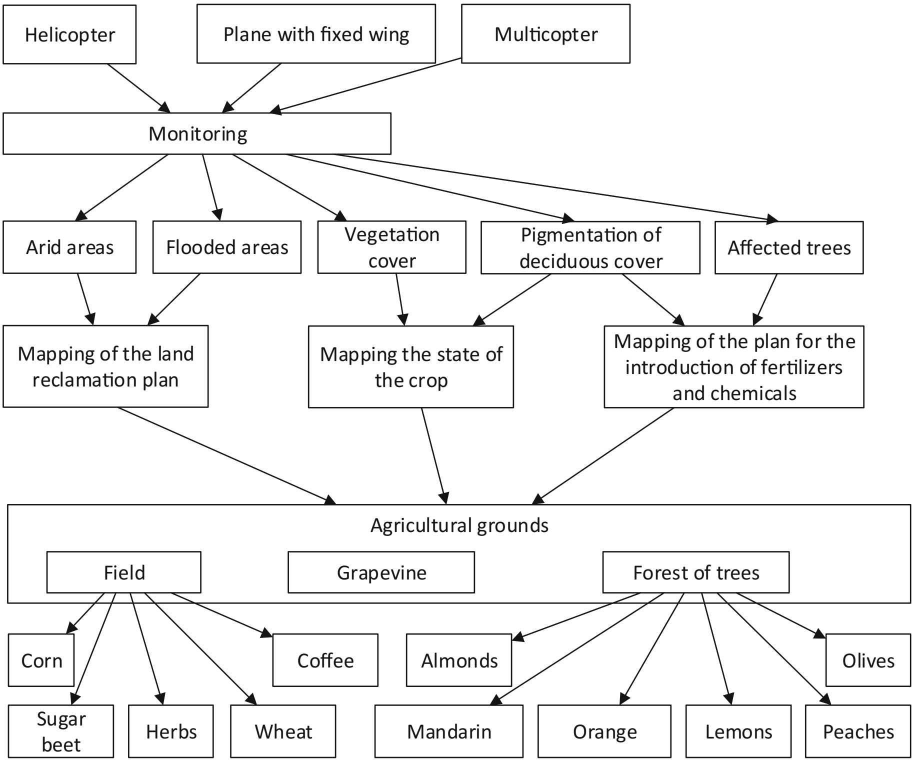

Fig. 1. Classification of tasks of agrarian robotics solved by UAVs

maximum speed 40 km/h, maximum radio distance 1000 m, price 499 euro. According to the results of the experimental check, it is revealed that the choice of the following parameters influences the efficiency of the application of the multicopter: monitoring time, flight altitude and resolution of the on-board video camera. In particular, the optimum height of the video camera was chosen – 17,37 m above the ground, and the capture time of aerial photographs – from 07.00 to 08.00 in the morning with the best light intensity for image processing. The use of multicopters for aerial photography of fields allowed farmers to reduce the amount of fertilizers by 27,1%.

In the paper [12], the use of UAVs is proposed to assess drought-prone soil and water resources needed for sustainable agricultural development. This study uses a multicopter with various non-contact sensors for remote sensing of plant conditions. The applied remote sensing technology is mainly based on the estimation of the color of leaves and other parts of plants along the wavelength and the reflection coefficient in the visible spectral range (RGB, red, green and blue) and invisible in infrared (IR) thermal radiation. As secondary indicators of plant status, the following was used: normalized vegetation difference index (NDVI); chlorophyll uptake index (TCARI); photochemical reflection index (PRI); optimized vegetative soil index (OSAVI). The NDVI index is related to the volume of plant mass and can correlate with the quality of crops, while biomass proportionately increases in parallel with photosynthesis. The photochemical reflection index (PRI) provides valuable information on the physiological state of plants when measuring the fluorescence of leaf chlorophyll from UAVs. A great advantage of UAVs in comparison with the satellite measurement of the fluorescence of leaf chlorophyll is a decrease in the altitude of their flight, which significantly increases the resolution of the image. Precise farming requires increasing the scale of captured images to extract information about the state of the plant to the level of leaves by improving the spatial and temporal resolution of remote sensing. The basis of remote sensing technology for assessing the availability of water resources of the plant is to estimate the difference between the temperatures of leaf cover, air and stomatal conductance of leaves using thermal normalized indices. The stomatal conductance of the leaves and the water potential of the leaf are useful indicators of a possible drought, and thermal normalized indices are used to analyze the variability of environmental parameters that affect the relationship between soil moisture and plant temperature.

A review of the existing UAVs, used in the agricultural sector, made it possible to identify a list of the most important operations to be performed, and also to formulate a problem statement for managing a group of heterogeneous agricultural robots while servicing some agricultural space.

3 Formal Task Statement of Control of a Group of Heterogeneous Agricultural Robots

To systematize the tasks of agrarian robotics with reference to the domain parameters that are characterized by high dynamics of processes and the limited resources available, let us next consider the task of managing a group of heterogeneous robots when servicing the workspace.

Let there be a working agricultural space S, characterized by a cortege of parameters $\langle H, P, G, C \rangle$, where $H = \{H_1, \ldots H_{i^H}\}$, $i^H \in \{1, \ldots, N\}$ is the set of cultivated lands, $P = \{P_1, \ldots P_{i^P}\}$, $i^P \in \{1, \ldots, N\}$ is the set of agricultural objects, $G = \{G_1, \ldots G_{i^G}\}$, $i^G \in \{1, \ldots, N\}$ is the set of objects of basing and storage of robotic means, $C = \{C_1, \ldots C_{i^C}\}$, $i^C \in \{1, \ldots, N\}$ is the set of cultivated crops. There is also a set $W = \{W_1, \ldots W_{i^W}\}$, $i^W \in \{1, \ldots, N\}$, which describes possible options for approach of robotic equipment from the basing area to the cultivated territory.

There are many heterogeneous robots $R = \{R_1, \ldots R_{i^R}\}$, $i^R \in \{2, \ldots, N\}$, used in this area. It is necessary to solve the problem of developing methods and algorithms for managing a group of heterogeneous robots R for servicing the workspace S in the presence of a set of resource constraints L.

Next, consider each of the parameters in more detail. Figure 1 shows an example of the layout of objects involved in the planning of agricultural robotics.

Each of the cultivated lands H_{i^H} is described by a tuple of parameters $\langle H^E_{i^H}, H^D_{i^H}, H^A_{i^H}, H^M_{i^H} \rangle$, where is $H^E_{i^H}$ is the set of coordinates of the vertices of the polygon that encompasses the boundaries of the given site; $H^D_{i^H}$ – the set of coordinates of the points of the planned regular crop plantation, grounded in its vegetative parameters;

$H^A_{i^H}$ – the cartogram of the agricultural contours [13], differing in the heterogeneous soil cover heterogeneity, its fertility; $H^M_{i^H}$ – the set of coordinates of the points that determine the trajectory of motion/flight of robotic means in the performance of agricultural tasks on the site.

As objects of basing and storage of robotics we consider only open areas for the access of ground equipment and vertical landing of UAVs. For remote sensing we are able to use external satellite and large UAVs that require a runway, but are not located on a multitude of objects of basing and storage G [14]. In this case, the object G_{i^G} can be described by the set of coordinates of the vertices of the polygon enclosing the boundaries of the object. If you need to use several objects, you should consider their compact location and requirements for entrance/approaching.

The parameters of the cultivated crop C_{i^C} can be represented in the form of a tuple of parameters $\langle C^D_{i^C}, C^O_{i^C} \rangle$, where $C^D_{i^C}$ – the description of the crop, including the parameters of planting the crop, harvesting, soil characteristics, etc. [15]; $C^O_{i^C} = \left\{ C^{O^1}_{i^C}, \ldots C^{O^{i^O}}_{i^C} \right\}$, $i^O \in \{1, \ldots, N\}$ – a set of operations planned in the process of cultivation. In turn, each operation $C^{O^{i^O}}_{i^C}$ is described by a tuple of parameters $\langle O^C_{i^O}, O^S_{i^O}, O^D_{i^O}, O^R_{i^O}, O^P_{i^O}, O^E_{i^O} \rangle$, where O_{i^O} – the conditions for the beginning of the operation; $O^S_{i^O}$ – the planned time of the beginning of the operation; $O^D_{i^O}$ – the planned duration of the operation; $O^R_{i^O}$ – the resources necessary for the operation; $O^P_{i^O}$ – the set of processing agricultural objects necessary for the operation; $O^E_{i^O}$ – the set of criteria for assessing the degree of performance of an operation.

Each robot R_i is characterized by a tuple of parameters $\langle R^B_{i^R}, R^F_{i^R}, R^T_{i^R}, R^E_{i^R} \rangle$, where $R^B_{i^R}$ – the type of basing of the robot (water, land, air, space, etc.); $R^F_{i^R}$ – agricultural functions performed by the robot; $R^T_{i^R}$ – a plan of tasks set for the implementation of the robot; $R^E_{i^R}$ – a multi-criteria evaluation of the degree of implementation of the task plan.

The developed formalization for managing a group of heterogeneous robots R when servicing the workspace S must also take into account resource limitations L, including the time of operations; the available amount of equipment, including robotic, mineral and water resources; loading of processing objects, and other factors.

4 Conclusion

The urgency of the introduction of robotic complexes in the agrarian sector is caused by socio-economic reasons due to heavy manual labor and a reduction in the world's freshwater resources. Robotic means become especially popular in small-scale agriculture. Unmanned aerial vehicles are now actively being used to monitor land, map the yields of land and plan fertilization zones.

Multicopters, not requiring a runway, have high resolution and therefore high prospects for widespread use. In addition to the onboard camera, the multicopters can also be equipped with other sensory means, such as thermal imager, thermometer, gas sensors, sonar, wind speed sensors, pressure sensors, infrared and other sensors.

A distinctive feature of agrarian robotics is the relatively stable regularity of the topology of planting of cultivated crops, in contrast to other areas of application of robots, where the objects served do not have known coordinates and can move in space [16–18]. This factor somewhat simplifies the algorithmization of the trajectory of the movement of robotics in the process of performing agro-industrial operations. However, this simplification, which is characteristic of accurate farming, can be used in tasks of monitoring and cultivating land, but not when harvesting (e.g. fruit or berry crops).

The proposed formal description for solving the task of managing a group of heterogeneous agricultural robots in a certain agricultural space includes the following parameters: a set of cultivated land; a set of agricultural processing facilities; a set of basing and storage facilities for robotics; a set of cultivated crops; a set of heterogeneous robots; possible options for the entrance/approach of robotic means from the basing area to the cultivated territory, as well as a set of resource constraints.

Acknowledgments. This work is partially supported by the Russian Foundation for Basic Research (grant № 16–08–00696).

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