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Control algorithms and capabilities of universal UAV

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Control algorithms and capabilities of universal UAV

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Abstract. The area of unmanned aerial vehicles (UAV) has been studied for a long time. They are actively used for military purposes. Nowadays, their application in everyday life to solve the problems of ordinary people has become relevant. There are many UAV designs, but the issue of an effective universal UAV design has not been fully addressed. In this paper, it is proposed to consider a variant of the universal UAV design, which differs from existing solutions and requires the development of its own rules for generating a PWM signal, control and stabilization algorithms, and the assessment of technical characteristics and application possibilities. The paper provides a brief description of the main differences of the proposed universal design from other solutions. It is proposed to consider the necessary control algorithms for UAVs of universal design, which were tested on the developed mathematical model of the UAV flight process of universal design. The basic equations of motion of this UAV are presented. The optimal technical characteristics and examples of using the electric version of the UAV of universal design to solve the problem of processing the field when powered by rechargeable batteries or an electric cable are considered.

As a result of studying the designs of unmanned aerial vehicles (UAVs) [1, 2], the problems of the existing universal UAV designs were identified and an improved universal UAV design [3] was proposed, which can effectively solve the widest range of tasks and have maximum stability and controllability.

The proposed universal design is similar in structure to the Boeing's Phantom Swift X-Plane, but with 6 motors (instead of 4) located on two axles. On one axis there are two pairs of coaxial screws (4 motors), and on the other axis there are two rotary, rotating screws (2 motors). The proposed design has greater stability and controllability due to the maximum symmetry of the structure, the location of the center of mass in the middle of the structure, the same distance of the motors from the middle of the structure. The proposed UAV does not require the use of wings and provides parallelism of the UAV platform when moving in space in any combination, which also increases its stability and controllability, resistance to wind and wind gusts.

The control algorithm of the proposed universal UAV design is different from existing algorithms. Therefore, it is necessary to determine the basic equations of motion, the rules for generating a PWM signal for brushless motors, control and stabilization algorithms, technical characteristics and capabilities for the proposed design.

The stabilization and motion control of the UAV occurs with the help of 6 brushless motors. Work with motors is carried out using a PWM signal. Each motor has its own PWM signal (K_1 , K_2 – rotating motors; C_{11} , C_{12} and C_{21} , C_{22} – coaxial motors). Formulas (1)-(6) show the rules for regulating the PWM signal necessary for the operation of a UAV of universal design.



Parameters PWM_{max} and PWM_{min} denote the maximum and minimum value that the ESC can transmit to the brushless motor (these values are always in the range from 0 to 1). Rotating motors without additional parameters always start with a maximum PWM signal value equal to PWM_{max} , and coaxial motors with a minimum value PWM_{min} .

$$PWM_{K_1} = (PWM_{max} - PWM_{ksryb}^{max}) + \left(-\frac{PWM_{ks}^{max}}{2} + PWM_{ks}\right) \quad (1)$$

$$PWM_{K_2} = (PWM_{max} - PWM_{ksryb}^{max}) + \left(-\frac{PWM_{ks}^{max}}{2} - PWM_{ks}\right) \quad (2)$$

$$PWM_{C_{11}} = (PWM_{min} + PWM_H) + \left(\frac{PWM_k^{max}}{2} + PWM_k\right) + \left(\frac{PWM_s^{max}}{2} + PWM_s\right) \quad (3)$$

$$PWM_{C_{12}} = (PWM_{min} + PWM_H) + \left(\frac{PWM_k^{max}}{2} - PWM_k\right) + \left(\frac{PWM_s^{max}}{2} + PWM_s\right) \quad (4)$$

$$PWM_{C_{21}} = (PWM_{min} + PWM_H) + \left(\frac{PWM_k^{max}}{2} - PWM_k\right) + \left(\frac{PWM_s^{max}}{2} - PWM_s\right) \quad (5)$$

$$PWM_{C_{22}} = (PWM_{min} + PWM_H) + \left(\frac{PWM_k^{max}}{2} + PWM_k\right) + \left(\frac{PWM_s^{max}}{2} - PWM_s\right) \quad (6)$$

The maximum setpoint value of the PWM signal is necessary for rotating motors, because their thrust is used not only to lift the UAV, but also for high-speed forward movement, in connection with this, the maximum value makes the control circuit effective, allowing one to adjust the speed only by rotating the motor housing to the required angle without the need for speed control, which could significantly affect the thrust of the UAV upwards when trying to return the motors to their original state. Similarly, if there is a lack of torque for the rotating motors to stabilize the y axis during the set speed, the motors can be rotated back to a vertical position until the stabilization angle is not less than the specified critical deflection angle.

Height adjustment takes place only with coaxial screws. To do this, use the parameter $PWM_H = PWM_{max} - PWM_{min} - PWM_k^{max} - PWM_s^{max}$. There may be situations when it is necessary to temporarily reduce the maximum value of rotating motors, for example, when a heavy cargo from a UAV is dropped, for this a variable parameter is provided PWM_{ksryb}^{max} .

Parameters PWM_{ks}^{max} and PWM_s^{max} determine the maximum number of PWM signal steps allocated for UAV stabilization for the axis of rotating motors (y axis) and for the axis of coaxial motors (x axis). Axial stabilization occurs by creating a differential in the thrust of the motors located on the same UAV axis using the parameter PWM_{ks} or PWM_s . The last two parameters cannot be greater than $PWM_{ks}^{max}/2$ or $PWM_s^{max}/2$. In this case, it will be possible to assuredly subtract and add the required number of PWM signal steps from the average value of the range PWM_{ks}^{max} or PWM_s^{max} , but not more than the value $PWM_{ks}^{max}/2$ or $PWM_s^{max}/2$, which is enough to create a stabilizing differential.

To ensure rotation of the UAV (yawing), a similar method of creating the differential mentioned above is used. UAV rotation is carried out only using the torque differential of the coaxial screws; therefore, the term $PWM_k^{max}/2$ is added to the calculation formulas of the PWM of the coaxial screws. The value PWM_k is added to one of the two motors located on one side of the x axis of the UAV, and is subtracted from the second and vice versa when rotating in the opposite direction. The same occurs on the opposite side of the x axis with another pair of coaxial motors.

UAV stabilization and control is carried out using 5 algorithms: the axis stabilization algorithm of coaxial motors, the axis stabilization algorithm of rotating motors, the algorithm for maintaining a given height, the algorithm for holding a given course, and the algorithm for holding a given speed. With the exception of some details, these algorithms are similar to each other in the way they adjust the retention rate of set values (speed, height, angles). Some of them differ in the rules for the distribution of the PWM signal. These rules were mentioned earlier in the description of formulas (1)-(6). Therefore, only one of the 5 algorithms will be considered in detail: the algorithm for maintaining a given course (figure 1).

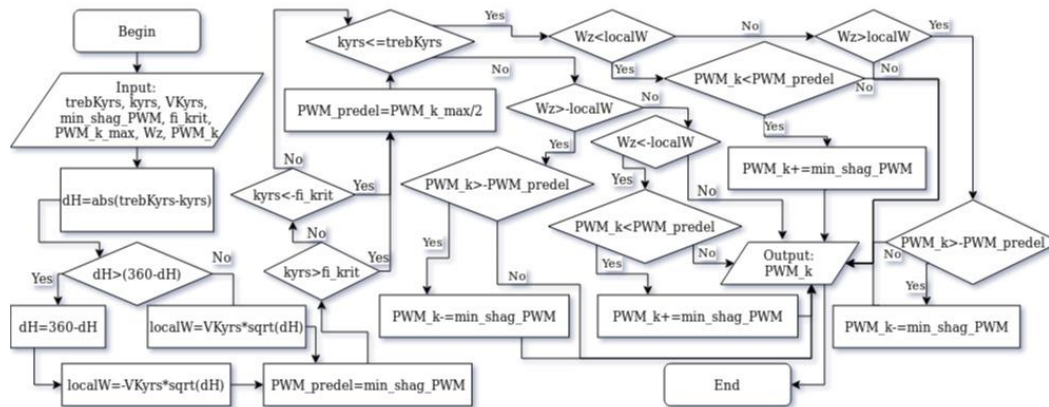


Figure 1. The algorithm for maintaining a given UAV course.

For the course maintaining algorithm to work input parameters are needed, there are 8 of them. The first of them "trebKysrs" is set by the user and indicates the required degree of rotation of the UAV. The parameter "kyrs" indicates the current degree of rotation of the UAV; in reality a gyro sensor is used to obtain it. "VKysrs" is defined by the user and indicates the intensity of the rotation speed; if this parameter is too large, that is, the risk of slipping through the desired degree and entering the oscillation process, if it is too low, the rotation will be slow. The parameter "Wz" indicates the current speed of rotation of the UAV; in a real situation it is calculated from the readings of the gyro sensor. The critical angle value "fi_krit" is set by the user and serves to reduce the oscillation of the UAV rolling with slight deviation angles.

The parameters of the minimum pitch of the PWM signal ("min_shag_PWM"), the calculated current additional heading control value for each coaxial motor ("PWM_k") and the maximum additional heading control value for each coaxial motor ("PWM_k_max") were considered earlier.

The parameter "dH" is calculated in the algorithm and shows the difference between the current rotation and the required one. The "localW" parameter determines the local UAV rotation speed so that by the time the desired angle is reached, the UAV rotation speed is zero and it does not slip this position (the correct operation depends on the user-specified value "VKysrs").

The UAV moves along three axes. Each axis of the UAV corresponds to the acceleration of translational motion a_x, a_y, a_z . In the proposed universal design of the UAV, the movement along the y axis will not be carried out, so there is no need to calculate the change a_y from the motors.

When two pairs of coaxial screws are located on the same UAV axis, their total thrust will be determined as $F_{TC11} + F_{TC12}$ for one pair and $F_{TC21} + F_{TC22}$ for the second and $(F_{TC11} + F_{TC12}) + (F_{TC21} + F_{TC22})$ for two pairs of coaxial screws. Having two rotating motors on the other axis of the UAV, we get their total thrust $(F_{TK1} \cos \alpha + F_{TK2} \cos \alpha)$. As a result, taking into account the angles, we obtain the formulas for the dependence of the UAV translational motion on the traction force (7), (8).

$$a_z = \frac{1}{m} ((F_{TC11} + F_{TC12}) + (F_{TC21} + F_{TC22}) + (F_{TK1} \sin \alpha + F_{TK2} \sin \alpha)) \quad (7)$$

$$a_x = \frac{1}{m} (F_{TK1} \cos \alpha + F_{TK2} \cos \alpha) \quad (8)$$

In formulas (7), (8) m – the mass of the UAV, and the angle α indicates the rotation of rotating engines. The UAV is subject to torque, depending on the propeller thrust. Therefore, the angular accelerations $\varepsilon_x, \varepsilon_y, \varepsilon_z$ relative to the UAV axes will be calculated by formulas (9)-(11).

$$\varepsilon_x = \frac{r_c}{I_x} [(F_{TK1} \sin \alpha - F_{TK2} \sin \alpha) + \frac{1}{d_B} (M_{BK1} \cos \alpha - M_{BK2} \cos \alpha)] \quad (9)$$

$$\varepsilon_y = \frac{r_c}{I_y} [(F_{TC11} + F_{TC12}) - (F_{TC21} + F_{TC22})] \quad (10)$$

$$\varepsilon_z = \frac{r_c}{I_z} \{ (F_{TK1} \cos \alpha - F_{TK2} \cos \alpha) + \frac{1}{d_b} [((M_{BC11} - M_{BC12}) - (M_{BC21} - M_{BC22})) + (M_{BK1} \sin \alpha - M_{BK2} \sin \alpha)] \} \quad (11)$$

In formulas (9)-(11): M_b – screw motor torque, r_c – distance from the center of mass to the motor (the same for all motors), d_b – motor shaft diameter, I_k – UAV case inertia moment.

For the proposed universal design based on the studied literature [4-7], a mathematical model of the UAV flight process has been developed, which allows real-time prediction of the mode of motion and based on this to determine the optimal parameters, motors, replaceable batteries and operating modes of the stabilization and control algorithms depending on operating conditions, functions and tasks solved by UAVs.

The calculation of the main characteristics for a UAV of universal design when operating from 6 motors and a rechargeable battery based on the developed mathematical model is given in table 1. A payload of 10 kg and 5 kg with a total mass of UAV 23.656 kg can be reset during the flight, which will not affect the controllability quality of UAVs of universal design (the parameter value PWM_{ksryb}^{max} should be set as 0.36 after dropping 10 kg and 0.18 after dropping 5 kg).

The technical characteristics and capabilities are considered on the example of using a UAV of universal design in an autonomous mode during cultivation of plants in the fields in order to reduce yield losses and improve its quality. A stand-alone version of the use of UAVs involves receiving electricity directly from replaceable batteries without a direct connection to the mains.

To solve the problems of diagnosing the state of plants during the growing season or determining the presence of pests and parasites, UAVs of a universal design can be used (figure 2a). To increase the duration of the flight, it is possible to use a helium ball (“Airship” operating mode).

One of the possible complex options for using a UAV of universal design can be the processing of a hectare of field. To process the field with a substance or to diagnose the soil, it is necessary to use UAVs without additional accessories (figure 2b). With a payload of 10 kg it is possible to spray 36 g per hour or 0.864 kg per day of substance per square meter of hectare. Processing is carried out by UAV flying at a maximum speed of a strip 100 m long and 3 m wide using two nozzles (Figure 2b) fixed at a distance of 1.5 m. The entire cycle of flying around a strip together with refueling with a substance can take about 100 s (figure 2c). Refueling takes place by gravity by immersing the tank in a container with the substance (the UAV is capable of completely immersing in water, like the “Bathyscaphe”). For an hour, a single processing of 36 such strips is possible. For the day of operation of the universal UAV, it is necessary to carry out 30 charges/replacements of batteries with a capacity of 2 817Wh for a special charging station (figure 2d).

Table 1. Specifications for UAVs with 6 motors powered by batteries.

The ESC controller accepts from 18 V to 25.2 V at the input; it operates at a PWM duty cycle of more than 55%. All engines are T-Motor MN7005-KV230.			
	The total weight of the UAV, g	25 656 (3 656)	20 656 (3 656)
	Payload weight, g	10 000	5 000
	Battery weight, g		12 000
Li-ion, 21.6 V, 4.26 g/Wh	Battery operation until full discharge, Wh		2 817
	Flight duration	48 min	56 min
	Maximum speed, km/h	90	255
	Acceleration to 54 km/h, s	57	6
	Current output		Over 100A

When calculating the characteristics of a 100-meter flight cycle, three specific sections of the track are identified. In the first case, a UAV with a fully charged substance must be dropped as fast and uniformly as possible onto a 100m long strip with an area of 300m². To do this, it flies in a straight line with maximum speed gain and begins to slow down immediately after a 100m span of the field strip. At the same time, the total length of the site, taking into account the braking distance, will be about 204 m. The UAV will fly by and stop at the end of this strip in 31 seconds.

To calculate other parts of the flight cycle, a strip was chosen on one of the two hectare halves 25m away from the container with the substance, because it is an average value, which will allow for more accurate values when calculating the general indicators. The second section of the path involves flying to the container with the substance when UAV is lightweight without a payload. This section of a 206m UAV overcomes in 29 seconds and stops above the container with the substance. Further, the UAV tank is replenished within 20 seconds, which is accompanied by the lowering of the UAV from a working height of 3 m and lifting back, after filling the UAV tank with substance. The third section of the path has an average value of 25 m, since it gradually changes from 50 m to 0 m as the strip approaches or moves away from the tank with the substance. To overcome the site in a 25m UAV with a tank filled with a substance, you need to spend 20 seconds. After that, the UAV is ready to restart the flight cycle and processing the material strip 100m.

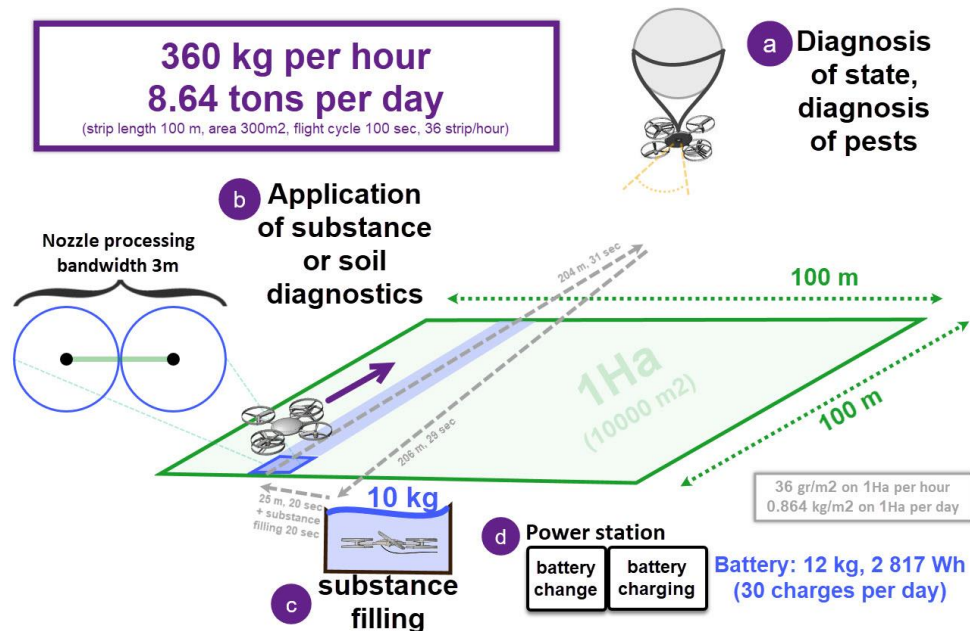


Figure 2. Examples of UAV use in field processing.

Thus, in the course of the calculations it was found that one UAV of universal design is able to spray about 360 kg of substance per hour or 8.64 tons per day over a field of 1 hectare. If processing of larger fields is required, then the autonomous version will be effective for spot processing of the field when it is not necessary to process the entire field, but only problem areas on it, for example, localization of pests or diseases, mowing and sowing of dead crop areas, watering arid areas, fertilizer problem areas, etc. [8]

In the case of autonomous use of UAVs, the issue of quickly recharging the battery becomes relevant, because a simple battery charge may take several hours, and the process should not be interrupted. In this case, it is preferable to use an inductive wireless charging station, finalizing this option, for example, adding a battery extraction and replacement system to the UAV.

In addition to autonomous use with batteries, UAVs of a unique design can be used in a wired version. In this case, the batteries are removed from the UAV, and the power is connected directly from the wires.

A UAV of universal design is capable of pulling a cable that provides it with DC power, which is confirmed by mathematical modeling. This cable has a certain mass and a slack, which will require a cable of greater length than the required range of the UAV. The cable can be located on a pole or on a movable platform (figure 3).

Moving around the field, the UAV pulls a movable platform. Electricity to the UAV comes through two tensioned cables, through the places of their junction with a movable platform. Thus, not only electricity can be supplied to the UAV, but also water with reagents using an exhaust hose. In order to increase the controllability, thrust and radius of the UAV flying around, a helium ball can be attached to it, but at the same time it will become less mobile and maneuverable.

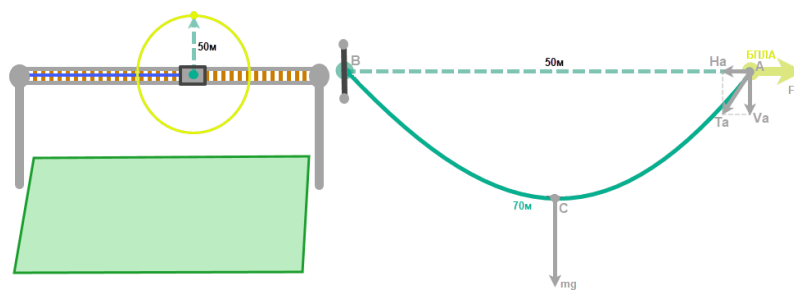


Figure 3. The concept of using a UAV in a wired version.

The calculations were carried out on a mass of 1 meter of aluminum wire equal to 0.0864 kg, consisting of two cores isolated between each other. The thickness of the calculated cable corresponds to the current consumption for the UAV under consideration. To determine the effect of the cable on the UAV, its behavior will be considered similar to the physics of the chain line [9].

Taking into account the previously determined mass of 1 meter cable (0.0864 kg), an optimal cable length parameter of 12 m was obtained, at which the UAV is capable of operating at a height of 3 m with a column height of 10 m. The maximum radius of departure from such a pillar is 10m. At the same time, UAVs moving within a given circle with a radius of 10 m will never come into contact with the cable to the ground (figure 4).

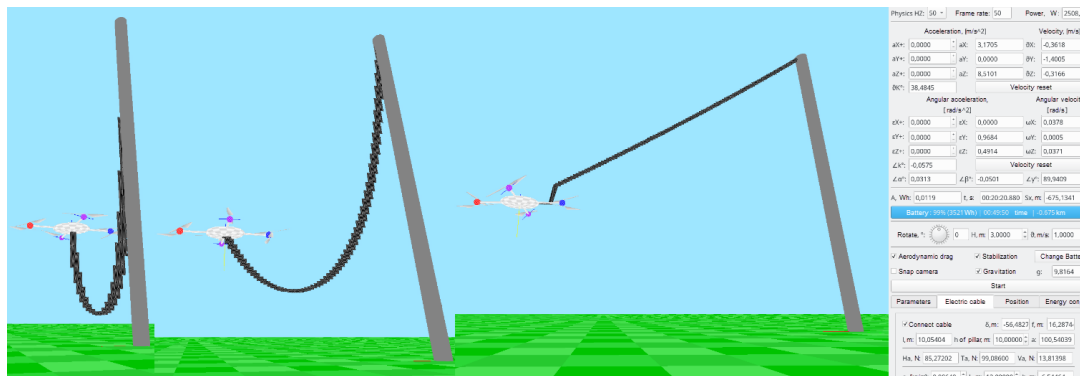


Figure 4. An example of cable parameters with no contact with the ground.

The proposed cable length of 12m allows the UAV to maintain a 20m wide strip without contacting the cable with the ground, if the cable is not mounted on a pole, but on a movable platform, as shown in Figure 3. For example, 10 poles are needed for 1 ha. On one side of the field are 5 columns, similarly on the other. They will form 5 strips 20m wide and 100m long. Thanks to the movable platform, one

UAV will be able to efficiently serve the entire field with a resettable load capacity of about 10 kg, powered by an electric cable without the need for a battery.

Efficient operation of the UAV in a wired version on a larger field is also possible. For example, for an area of 100 km², you need to fly around 500 lanes with a width of 20 m and a length of 10 km. In this case, to effectively maintain the field, it will be necessary to use at least 10 UAVs with an increased drop-off load capacity of up to 100 kg or 1 t. The task of increasing the load capacity of the power plant of electric motors is easier than in the stand-alone version, because the UAV is powered through an electric cable.

In addition, a universal design UAV is capable of pulling to the side and lifting up electric and other types of cables, which allows it to be used when laying electrical networks and other types of communications. For example, an UAV with a drop-off carrying capacity of 10 kg is capable of stretching laterally by 80 m and lifting fully up a cable 85 meters long with a mass of 1 meter 0.0864 kg (Figure 5). Theoretically, the UAV is able to connect and disconnect the power cable from itself, so a hybrid version of its use in wired and autonomous versions is possible.

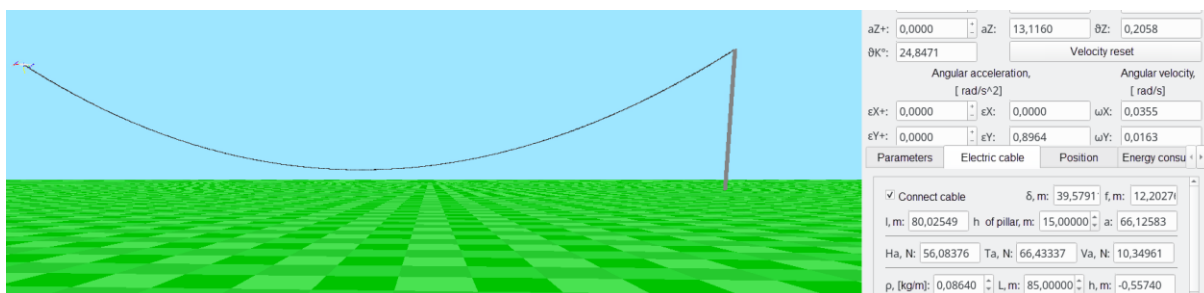


Figure 5. An example of the maximum cable length entirely raised of a UAV.

A hybrid option may be preferable when it is necessary to simplify the system of filling a substance in a wired version, make it more centralized, reduce battery maintenance costs, extend the life of a movable platform and reduce the number of electrical communications.

The technology of electric UAVs in comparison with other technologies has the following advantages: accuracy and locality, mobility and universality, simple repair and maintenance, environmental friendliness. One UAV is capable of analyzing the state of the soil and the external state of vegetation, to form problem areas on the field and the task for their elimination, flight route, refueling; able to independently carry out the pilot task he has formed (figure 6).

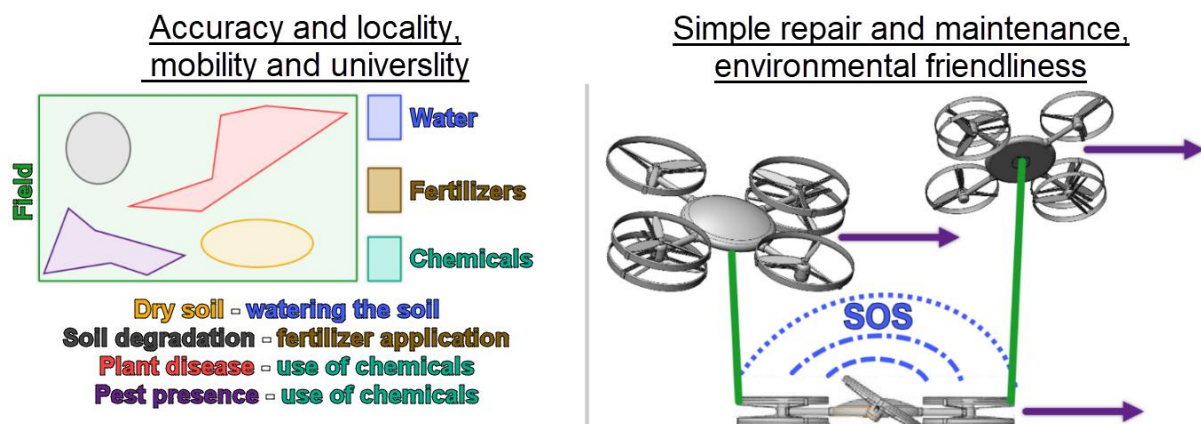


Figure 6. The advantages of UAV technology.

Precision farming using UAVs can reduce the use of harmful chemicals (fungicides, herbicides, insecticides, bactericides, etc.) through the use of more expensive and high-quality products with their application only to those areas where they are needed.

References

- [1] Austin R 2010 *Unmanned Aircraft Systems. UAVS Design, Development and Deployment* ed I Moir *et al.* (West Sussex: John Wiley & Sons Ltd)
- [2] Hayward K 2013 *Unmanned Aerial Vehicles: a New Industrial System?* (London: Royal aeronautical society)
- [3] Mitrashchuk V V 2016 Development of UAV as quadcopter type with the provision of movement parallel to the ground surface of the platform with removable equipment modules *Actual Problems of Aciation and Astronautics* (Krasnoyarsk: SibSAU) **1** pp 299-301
- [4] Beard R W and McLain T W 2015 *Small Unmanned Aircraft: Theory and Practice* (Moscow: Technosphere)
- [5] Bresciani T 2008 *Modelling, Identification and Control of a Quadrotor Helicopter* (Lund: Department of Automatic Control Lund University)
- [6] Michini B 2009 *Modeling and Adaptive Control of Indoor Unmanned Aerial Vehicles* (Cambridge: Massachusetts Institute of Technology)
- [7] Shapovalov I, Soloviev V, Finaev V, BeloglazovD, Zargaryan J and Kosenko E 2014 Influence of internal and external factors on a controlled quadrotor flight *International Journal of Mathematical Models and Methods in Applied Sciences* (Houston: North Atlantic University Union) **8** 498-504
- [8] Krishna K R 2017 *Agricultural Drones* (Waretown: Apple Academic Press)
- [9] Merkin D R 1980 *Introduction to Flexible Thread Mechanics* ed A B Elagin and N V Kosheleva (Moscow: Nauka)



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