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SEMI-AUTONOMOUS DRONE FOR AGRICULTURE ON THE TRACTOR BASE

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This paper deals with the prospects of using a drone for spraying the gardens and vineyards. Relevance of this process is substantiated with the help of statistical data on the industry in Ukraine. To increase the efficiency of drones during the plant treatment, the concept of a semi-autonomous drone is proposed with connection to a communication line with a tractor – a "tractor-drone" complex. A spraying solution and commands for the drone are transmitted via the communication line. Basic physical formulas for appropriate selection of technical means for the lifting of sprayer frame are presented. Environmental parameters for the flight control system were estimated: temperature fluctuation at 20 K requires screw speed increase by 1.5%; an increase in atmospheric pressure by 5% allows reduction of screw speed by 2%. Tasks of the control system for the concept of semi-autonomous drones are defined in the paper.

Keywords: unmanned aerial system; drone; semi-autonomous; tractor; sprayer; garden

The most important roles in realizing the state sustainable development tasks are placed on agriculture and food security. The State Statistics Service of Ukraine shows reduction in the fruit, berries and wine-hail consumption from 56.3 kg per person (State Statistics Service of Ukraine, 2017a) to 52.8 kg per person (State Statistics Service of Ukraine, 2017a). At the same time, there is a scarcity in production of certain crops (Table 1) (State Statistics Service of Ukraine, 2017b). Solution of the problem must be based on the productivity intensification and re-equipment of agriculture. Considering these goals, the primary tasks are to reduce the cost of fuel and lubricants and increase the efficiency of agricultural machinery.

This paper observes the solution of the aforementioned tasks for open-ground farming and industrial gardening – more exactly, for the process of spraying. It is possible due to the fact that material costs represent 55.4% of the overall costs for the crop production; they include inorganic fertilizers – 17.8% and oil products – 9.6% (State Statistics Service of Ukraine, 2017c). Crop spraying process performed in accordance with the requirements allows preservation of the crop commercial quality. The fact that producers are aware of this is evident from the development of quantity of crop protection machinery during period from 2014 to 2017 – there was an increase by 13.68% (State Statistics Service of Ukraine, 2014, 2017d).

Potential method for enhancing the efficiency of machinery use in the crop protection and treatment results in the increasing of tractor engine power due to:

increase in traction of the tractor and aggregation of broad-grab agricultural machines;

increase in operation speed accompanied by an increase in the specific cost of fuel.

These issues are especially relevant for the treatment of gardens, vineyards, maize and sunflower crops, for which the Federal Aviation Administration (USA) approved small aviation means (Gillespie, 2015), carrying rotary sprayers and rod sprayers with high location.

In order to achieve the given goals, it is advisable to consider the construction of a boom sprayer, small aircraft devices and flying drones. This could improve the efficiency of crop treatment by reduction of processing costs (higher operational speed, lower aerosol dispersion requirements, improving of equipment reliability) and enhance the quality of processing by increasing the penetration depth of the aerosol and reduction of the aerosol volatility.

There are multiple publications and patents related to usage of aviation equipment (Horodian, 2004; Perederii, 2013; Zhang et al., 2017) and drones (Xiongkui et al., 2017) for crop spraying. Considering the tasks given, implementation of these ideas is especially relevant for gardens, maize and sunflower fields. For the treatment of the mentioned crop fields, the width necessary to cover naturally exceeds the working width of a small aircraft or unmanned aerial vehicle (Siera et al., 2014). Furthermore, this type of equipment does not ensure the appropriate penetration of nutrient solutions into the crown or along the stem.

Research objective is to observe the issues of usage of flying drones in agriculture and propose the methods for solving them. Research aim is to increase the efficiency of drone usage for technological processes including plant spraying.

To achieve this goal, it is necessary to solve the following tasks:

– to study the problems of drone usage in agriculture;

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Table 1 Foreign trade with the selected types of goods in 2017

Product	Export		Import	
	quantity (t)	value (thousand US dollars)	quantity (t)	value (thousand US dollars)
Total, including	–	9,216,388.3	–	1,368,027.2
Grapes, fresh or dried	104.56	105.3	47,040	34,358.8
Apples, pears and quinoa, fresh:	23,731.6	6,894.0	42,346.8	15,634.4
– apples	2,299.6	6,627.1	40,316.7	13,431.3
– pears	735.5	266.9	1,974.6	2,154.9
– quinoa	–	–	55.4	48.2
Apricots, cherries and sweet cherries, peaches, plums and thistles, fresh:	11,723	9,561.6	38,117.5	28,805.1
– apricots	8.6	3.3	3,119.6	2,629.2
– cherry acid (Prunuscerasus)	79.8	63.5	13.0	12.8
– others	3,612.0	3,264.4	42.3	49.4
– peaches, nectarines	27.1	9.2	33,949.8	25,208.5
– plums and thorns	7,995.3	6,221.3	992.8	905.3

- to develop the concept of a semi-autonomous drone for spraying;
- to determine the technique for selection of technical means for vertical movement of the sprayer frame;
- to define the tasks for control system.

Material and methods

Nowadays, there are some technical and organizational solutions for the use of drones related to the tasks of observation in ecology (James et al., 2016; Beloev, 2016) and monitoring of microclimate parameters (Roldán et al., 2016), assessment of crops (López-Granados et al., 2016; Ming et al., 2009) and ultra-small volume spraying (Xiongkui et al., 2017). Methods for determining the control parameters for ensuring stable motion along a given trajectory are described quite well (Kanatnikov and Akopyan, 2015).

On the basis of a review of theoretical information on the use of modern civil unmanned aerial vehicles (drone) (Hristov et al., 2016), we have analysed drone usage in agriculture (Table 2).

Considering the garden spraying, the main constraining factors are the indicators of cost and carrying capacity. We propose the solution for mentioned shortcomings by simplifying the technology of Copters – wire communication – and raising only the hydraulic armature (the tank with the working solution is transported separately and leading), which would reduce the number of degrees of freedom of the Copter (Fig. 1). This design would also minimize the impact of threats and reduce the costs for practical implementation. This approach is implementable in order to monitor the parameters in the greenhouse (Roldán, 2016) and it has proven its efficiency.

For theoretical substantiation of the technical solutions and determining the parameters of the sprayer frame (weight, geometry, length), propellers, engines and the control system, it is necessary to describe the basic physical processes and create the mathematical models to support the operation of multi-rotor autonomous drones.

Table 2 SWOT analysis of the drone usage in open field conditions

Advantages – environmentally friendly treatment – non-combustible fuel usage – adaptation to precision farming systems – collection of field state data – does not affect the ground – the all-day round work can be organized.	**Disadvantages** – low load capacity – high costs for materials and equipment – high-speed engine, screws, sprayer frame made of light materials – high costs for software for control and positioning – capacity and weight of the batteries reduce the overall payload – ecological hazards for finely dispersed spraying – aerosol is blown away by wind
Opportunities – better use of equipment – it is possible to use in the side wind – modernization of software – adaptation to precision farming systems – multipurpose use – spraying, monitoring of plantations, protection	**Threats** – drone can be damaged by birds, tree branches and vandals – water and dust can damage electrical equipment of the drone – the flight course deviation due to gusts

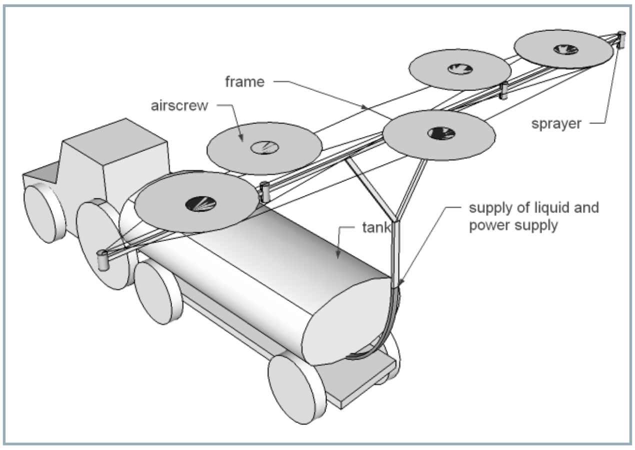

Fig. 1 Overview and technological elements of sprayer device

Calculation of the drone elements is dependent on the flight mass (Arzamastsev and Kryuchkov, 2014). In general, the sprayer will consist of a multi-rotor machine of mass *M* (kg) with the number of screws *k*, with the radius of each screw *r* (m) and step *h* (m). The speed of each propeller (motor) is *n* (s^{-1}). Consequently, air flow velocity from the apparatus downwards will be as follows:

$$V_{dn} = h \times n \tag{1}$$

The mass of air flow directed down from several propellers will be:

$$M_{dn} = \pi \times \rho \times r^2 \times V_{dn} \times k \tag{2}$$

where:
ρ – air density, $kg \cdot m^{-3}$

Air density can be determined from the reference data or Mendeleev-Clapeyron formula that allows taking into account the environmental parameters:

$$\rho = \frac{P \times \mu}{R \times T} \tag{3}$$

where:
P – air pressure, 1.01×10^5 Pa
R – universal gas constant, 8.31446 $J \times mol^{-1} \times K^{-1}$
T – absolute air temperature, K
μ – averaged molecular mass of air, 28.98×10^{-3} $kg \times mol^{-1}$

By substituting the Eq. 3 to Eq. 2, we obtain the equation for calculation of the mass of air directed by screws of the apparatus downwards (Arzamastsev and Kryuchkov, 2014):

$$M_{dn} = \pi \frac{P \times \mu \times r^2 \times V_{dn} \times k}{R \times T} \tag{4}$$

Applying the law of conservation of momentum in the scalar form $F = m \times v$ and taking into account the fact that $M_{dn} = m \times t$; and $v = V_{dn}$, we get:

$$F = M \times g = \pi \frac{P \times \mu \times r^2 \times V_{dn}^2 \times k}{R \times T} \tag{5}$$

Then, the total mass of the retained apparatus can be determined from the following expression:

$$M = \pi \frac{P \times \mu \times r^2 \times V_{dn}^2 \times k}{R \times T \times g} \tag{6}$$

Taking into account the peculiarities of the design of multi-rotor aircraft, it is necessary to introduce an additional dimensionless coefficient $0 \leq \eta \leq 1$ in the resulting Eq. 6, which characterizes the area of the frame parts that cover the area of the propeller grip. Obtained Eq. 6 allows substantiating the mode of propeller operation for a given design of the sprayer frame, hydraulic armature and a specified mass of engines for propeller rotation. Disadvantage of the method lies in a need for several iterations when changing the parameters of the frame, selecting hydraulic equipment and engines. These parameters affect the weight of the drone.

Results and discussion

For instance, considering the construction of a frame constructed of the most common materials in Ukraine – a metal profile UD75 × 40 (1.1 $kg \cdot m^{-1}$) – we shall assume that weight of 4 engines is 2 kg and hydraulic equipment weights 25 kg. Subsequently, with the length of the sprayer frame of 22 m, the device will be able to cover 4 rows of garden (46° 51′ 51.00″ N/35° 23′ 2.00″ E). Total weight of the sprayer bar is 100 kg. Propeller used in experiment is DLE110CC: *r* = 0.343 m, *h* = 0.04 m. According to the manufacturer's data, at *n* = 6,350 *rpm* = 665 s^{-1}, thrust will be 27.5 kg.

With the obtained value of the sprayer bar mass, the airflow velocity at temperature 20 °C was determined by Eq. 6:

$$V_{dn} = \sqrt{\frac{M \times R \times T \times g}{\pi \times P \times \mu \times r^2 \times k}} =$$

$$\sqrt{\frac{100 \times 8.83446 \times 293 \times 9.81}{3.14 \times 1.01 \times 10^5 \times 28.98 \times 10^{-3} \times 0.343^2 \times 4}} = 24.23$$

By means of Eq. 1, the number of screw revolutions was determined:

$$n = \frac{V_{dn}}{h} = \frac{24.23}{0.04} = 605\left[\frac{1}{s}\right] = 5{,}780\left[rpm\right]$$

Results provided by manufacturer differ by 9%, which can be explained by a higher total thrust of 4 screws (110 kg) in comparison to the calculated mass of the sprayer bar with a frame with *M* of 100 kg. It should be noted that at a temperature of *T* = 303 K, the necessary speed will increase by 1.5%, and an increase in atmospheric pressure by 5% will allow speed reduction by 2%. Obtained results of the screw rotational speed represent minimal values necessary for ensuring the separation of the sprayer rod from support surface.

As a result, a "tractor-drone" complex was obtained; with the "tractor" element being a master and the element "drone" being a slave. It is assumed that the drone is connected to the tractor through a cable and a hydraulic armature for supplying spray solutions. For practical application, tasks of the control system should be:

- stable horizontal movement behind the tractor (tractor provides the supply of electric power and movement of the storage tank with a solution for plant treatment);
- protection against the fall of the drone, engine failure, safety engineering;
- stabilization of the horizontal motion under the disturbing influences (side wind, change of the drone mass due to spraying regime);
- stabilization of the horizontal movement in the sprayer asymmetrical operation (spraying the extreme rows);
- synchronization of the turns of the tractor-drone system.

In order to ensure the controllability of the sprayer frame, it is necessary to describe the control system for this and consider the equations describing the drone operation that allow the compensation of the external environmental disturbances and the inertia of movement from the tractor. For this purpose, it is possible to use the results presented by Kanatnikov and Akopyan (2015) and Hristov et al. (2016).

Conclusion

Innovative technology allows improvement of the useful weight of the drone, working time and processing efficiency by increasing the working width, processing speed and penetration of working solutions into the plants. This will reduce the costs for fuels and lubricants, improve the quality and speed of treatments and allow performing of treatments in windy weather. A semi-autonomous drone can be used for spraying of gardens, vineyards, maize and sunflower fields.

Proposed functional dependencies allow justification of the selection of technical means for vertical displacement of the sprayer frame. Environmental parameters should be taken into account, since at temperature fluctuation of 20 K, the required screw speed will increase by 1.5%, and at increase in atmospheric pressure by 5%, the required screw speed will decrease by 2%.

Results presented in this paper can be used for gardens lacking protective shelter in various climatic conditions.

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