Unmanned systems and experience of their application in agriculture

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Abstract: The use of unmanned aerial vehicles (UAVs) is booming in almost every sector of the economy, especially in the agricultural industry. According to some reports, the agricultural UAV market is expected to increase from USD 2.6 billion in 2020 to USD9.5 billion in 2030. In this paper a brief overview devoted to the use of UAVs in the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy (RSAU-MTAA), including the results of studying the equipment use effectiveness for automatic driving of tractor equipment when sowing grain crops and planting potatoes. In the course of studying the equipment use effectiveness for automatic driving of tractor equipment, the deviations of the guess row spacing from the standard row spacing provided for by the seeder design were established; in the case of sowing barley using a marker, it was up to 4.3 cm, and in the case of winter wheat it was up to 5 cm. When using the autopilot system, these values were no more than 1.5 and 2.3 cm, respectively, which indicates the high accuracy and efficiency of the automatic driving systems. The autopilot system use provided a deviation of adjacent rows from the straightness when planting potatoes from 2.8 to 3.0 cm. The paper concludes that the use of unmanned robotic systems in agriculture, in conjunction with modern means of receiving and processing information, opens up new opportunities for increasing agriculture efficiency.

Keywords: agriculture, automatic driving, automatic sampler, precision farming, robotic systems, unmanned aerial vehicle (UAV)

INTRODUCTION

The growing population of our planet creates a situation characterized by a shortage of agricultural products. Previous studies emphasized that by 2050, the world's population will reach 9.6 bln people [Molajou *et al.* 2021a, b]; therefore, there will be a need for a significant increase in the production of agricultural enterprises to provide it food supply [Afshar *et al.* 2021; Kim *et al.* 2019].

The main factors influencing the agriculture productivity growth may include the production organisation methods, the level of mechanisation, automation, and the innovative technologies implementation degree [El Bilali, Allahyari 2018; Chao *et al.* 2007; Gusev *et al.* 2019; Ozdogan *et al.* 2017; Zhao *et al.*

2018]. These goals were achieved throughout the 20th century using classical tools: energy-intensive agricultural machines, highly productive varieties of agricultural crops, effective care methods (fertilisers, growth regulators), and optimal agricultural techniques. Today, these tools are still relevant, but their potential has almost reached the limit possible with the current level of agricultural development. Currently, new tools have appeared, in particular satellite and computer technologies, which have become generally available [Keicher, Seufert 2000; Ren *et al.* 2020]. Their development and introduction into agriculture led to the creation of precision farming [Aubert *et al.* 2012; El Bilali, Allahyari 2018; Zeyliger *et al.* 2019].

Further development of precision farming tools and technologies has led to the emergence of a new type of

agricultural activity based on the introduction of digital technologies, automatic unmanned and robotic machines, and system [AKHMEDYAROV 2019; FUNG et al. 2020]. Accurate management, together with the use of advanced technologies and solutions to increase productivity, made it possible to maximise yields and minimise losses by collecting and analysing data in real-time, as well as optimising the control mechanism for agricultural machines for various purposes [GUSEV et al. 2019; MALOKU et al. 2020].

Currently, one of the key tasks for the development of the Russian economy is a significant increase in the share of industries and production facilities operating within the framework of the fifth technological mode (informational). The fifth mode is based on achievements in the field of microelectronics, robotisation, informatics, biotechnology, genetic engineering, new types of energy, materials, space exploration, satellite communications, etc. There is a transformation from separate firms towards a united network of large and small companies based on the Internet and closely interacting in the field of technology, product quality control, innovation planning, the Internet of things. At present, the Russian economy in this area lags significantly behind the most developed countries, and reducing the gap in the information area is a priority task. The solution to this problem is the construction of a digital economy corresponding to the fifth technological mode, without which the creation and development of unmanned and robotic systems are impossible [TISHKINA et al. 2019; WORTMANN, FLÜCHTER 2015].

Russian, as well as, by the way, world agriculture, in general, is still lagging behind in the use of unmanned robotic systems in comparison with other sectors of the economy. Therefore, research in this direction will develop at an increasingly accelerated pace every year. The purpose of the current study is to analyse the test results and prospects for the use of unmanned systems in the conditions of the national centre for precision farming at Russian State Agrarian University – Moscow Timiryazev Agricultural Academy (RSAU-MTAA).

MATERIALS AND METHODS

To study the agroecological efficiency of precision farming technologies and techniques at the University's Field Station, a stationary field experiment was started with a total area of about 6 ha. It demonstrates two technologies for cultivating agricultural crops using the example of potatoes, winter wheat, spring barley, and annual grasses using a traditional system, and a system based on the principles of precision farming with the use of unmanned systems, such as automatic driving of tractor equipment (using an autopilot), unmanned aerial vehicles (UAVs) and, in the future, various robotic systems [AUBERT et al. 2012; BLACKMORE 1994; EL BILALI, ALLAHYARI 2018].

Within the framework of the national centre for precision farming, studies were carried out on the effectiveness of the use of automatic tractor equipment driving. The use of automatic navigation systems becomes possible after installing on a vehicle a special receiver constantly receiving signals about the location of navigation satellites and the distances to them.

EZ-Guide 500 Lightbar navigation device mounted on a John Deere 6920 wheeled tractor, was used in agricultural work and in testing the automatic driving effectiveness in the

conditions of the Centre for Precision Farming. Sowing grain crops (winter wheat and barley) was carried out using a single-furrow plow with a D9-30 Amazone seed drill (hereinafter referred to as D-9-30) using the Autopilot system and a marker [EL BILALI, ALLAHYARI 2018].

In the course of the experiments, the effectiveness of the autopilot system was tested in inter-row potato cultivation. An area on a slope was chosen to make the autopilot more challenging. The trajectories traversed by the potato planter were loaded into the computer of the autopilot system in the task for the ridge former.

Potatoes were planted with a GL-34T potato planter using the autopilot system and a marker method. The specified unit movement trajectory using the GPS system was repeated for the precision farming variant during the ridging course and the potatoes' seedlings. According to the traditional potato cultivation technology, this technique was carried out visually, i.e., the movement of the unit was controlled by a machine operator.

One of the promising areas in precision agriculture is the use of UAVs. Therefore, the RSAU-MTAA pays special attention to analytical research and field tests of various types of UAVs. Currently, studies are being conducted on the possibility and effectiveness of using various designs of automatic soil samplers in precision farming at the Land Reclamation and Construction Machine Department and the Centre for Precise Land Reclamation of the A.N. Kostyakov Institute for Land Reclamation, Water Management, and Construction.

RESULTS AND DISCUSSION

In the course of studying the effectiveness of the use of automatic tractor equipment driving systems, the deviations of the guess row spacing from the standard row spacing provided for by the design of the seeder were determined. In the case of sowing barley using a marker, their values were up to 4.3, and for winter wheat, they were up to 5.0 cm; using the autopilot, we obtained deviations lower 1.5 cm and 2.3 cm, respectively, which indicates the high accuracy and efficiency of the use of automatic driving systems (see Tab. 1). Despite the relatively good average deviation values, the barley sowing with a marker showed a greater discrepancy in the row spacing parameters. Such a mismatch in row spacings can have a negative meaning, especially when growing row crops. It should be noted that there are no such significant deviations were observed when using the Autopilot system.

Table 1. The guess row spacing width values and deviations from the standard row spacing values for the seeder D9-30 (using a single-furrow plow)

Crop	According to the marker		Autopilot	
	guess row spacing width	deviation	guess row spacing width	deviation
	cm			
Barley	14.0– 5.2	+(2.0–4.3)	12.3–13.5	+(0.3–1.5)
Winter wheat	16.3–17.0	+(4.3–5.0)	13.2–13.5	+(1.5–2.3)

Source: own elaboration based on data of EL BILALI and ALLAHYARI [2018].

One more important advantage of the autopilot system in comparison with the marker should be noted. When working in a no-till system, the track from the marker, especially at dusk, is not visible good enough. The autopilot system allows us to work around the clock. This circumstance alone can significantly increase the efficiency of work in agriculture: two machine operators can work in turn on one tractor without interruption 24 h a day and carry out sowing in the shortest and best agrotechnical terms.

The main advantage of using automatic driving systems is the reduction of errors (minimising the human factor) when processing fields. Practice shows that when traditionally spraying crops, most operators prefer to overlap adjacent rows to avoid skipping. As a result, the mutual overlap of rows, even with the use of foam markers, is at least 5%. The use of direction indicators with bow thrusters reduces the overlap to 2–3% or less.

On row crops, in addition to precise planting, inter-row cultivation is required. Therefore, when using navigation systems, high accuracy of the unit guidance is required.

The use of automatic driving when planting potatoes showed that the row spacing width between the aisles of the potato planter when using the marker and the autopilot differed insignificantly in individual years, constituting, according to traditional technology, the interval on average from 60–65 to 80–85 cm, i.e., the deviation from the standard row spacing of the planter (75 cm) was within the range from –15 to +10 cm. The use of the autopilot system provided a straightness deviation of adjacent rows from 2.8 to 3.0 cm.

An important condition for the full development of a potato stem is its location in relation to the central part of the ridge, which is shaped in the course of ridge formation after the emergence of shoots. Ridge formation in potato plantations cultivated according to traditional technology ensured the formation of potato stems with deviations of 10–15 cm from the centre. This led to a one-sided change in the growth of the vegetative part, uneven formation and development of underground tubers, and most importantly, a decrease in product quality due to the appearance of a large number of green potatoes.

When using the precision farming technology, the potato stems were located in the row centre with a deviation from 2.8 to 3.5 cm. The combination of two passes of the unit across the field, namely, planting and ridge formation of potatoes are presented in Table 2.

Table 2. The frequencies of occurrence (%) for potato stem deviations from the centre of the ridge in the RSAU-MTAA experiment

Deviation (mm)	Frequency (%)			
	according to the marker		autopiloting	
	minimum	breast	minimum	breast
0–2	14	17	40	41
3–5	35	20	48	37
6–8	25	24	10	15
9–11	17	25	2	6
12–14	7	14	–	1
>14	2	–	–	–

Source: own elaboration.

The autopilot easily coped with the tasks that would be very difficult for an ordinary machine operator as the tractor was pulled down the slope. The autopilot system was able to steer a tractor moving almost sideways. The result is perfectly straight ridges and subsequent friendly shoots even on a slope. Comparative qualitative indicators of various UAV types are presented in Table 3.

Table 3. Comparative indicators of different unmanned aerial vehicles' (UAV) types

Indicator	UAV type			
	drone	helicopter	plane	dirigible balloon
Model	DJIS1000+	AXH-E230	Bat-3	CB3000
Relative price	low	middle	middle	high
Aircraft weight (kg)	6	15	56	300
Payload (kg)	7	15	9	10
Speed (m·s^{-1})	12	23	33	15
Height (m)	500	3000	3000	125

Source: own elaboration.

The target possibilities of using UAVs in agriculture include an inventory of farmland, creating electronic field maps, assessing the scope of work and control of their implementation, operational monitoring of the state of crops, and assessing the germination of agricultural crops.

The main UAV types used in agriculture, according to their construction, are divided into drones, helicopters, dirigible balloons, and airplanes. All of these UAV types have their own advantages and disadvantages and are selected based on the tasks to be solved and the available budget [AUBERT et al. 2012; EVE et al. 2002; KIM et al. 2019].

Copter drones have the ability to take off and land vertically, hover over a specific geographic point and have a low cost. The disadvantages of such UAVs include short range and short flight time, sensitivity to weather conditions, and low payload.

Compared to copter UAVs, helicopter-type UAVs have a longer flight time and range and also a higher payload. In turn, they are also dependent on weather conditions and have a relatively high production and operation cost.

Dirigible balloons have vertical take-off and landing capabilities, high payload, and long flight times. However, their slowness, large geometric dimensions, poor stability in windy weather, and relatively high cost significantly limit the range of tasks they solve and are much inferior to copter UAVs and helicopter-type UAVs.

Aircraft-type UAVs have high speed and long-range and relatively high payload. However, their inability to hover at a specific geo-point and the lack of vertical take-off and landing also limit their use.

In order to carry out such work as the phenotyping of crops, UAVs can be equipped with digital cameras, multispectral cameras, thermal infrared cameras or thermal imagers, hyperspectral cameras, and synthetic aperture radars. The optimal set of information sensors is determined based on the tasks being

solved and the capabilities of the UAV in terms of the payload and the accuracy of the coordinate-time determination of its position.

Due to spectral characteristics in the visible and invisible wavelengths, the use of UAVs with multispectral sensors allows monitoring the planting area and the state of crop growth, as well as its biological and physical properties. Also, receiving and processing information from multispectral cameras allows us to assess the state of soils, the presence and condition of weeds in the early growing season, the water content and chlorophyll, and the nitrogen concentration in the leaves of the cultivated crop. Such information makes it possible to forecast the yield and create an electronic map of fields for timely and differentiated application of fertilisers and plant protection products [AUBERT et al. 2012; EVE et al. 2002; KIM et al. 2019].

With the help of multispectral imaging, a composite image of the farmland understudy is formed with a sufficiently accurate, up to several centimetres, coordinate reference, which in turn allows obtaining many vegetation indices (normalised difference vegetation index, perpendicular vegetation index, weighted difference vegetation index, and others) reflecting various qualitative and quantitative indicators in real-time [AUBERT et al. 2012; EVE et al. 2002; KIM et al. 2019].

The basis for obtaining high yields is the soil fertility cartogram. Sampling from each field is carried out on a grid; its nodes are set at a certain frequency and have precise coordinates thanks to the navigation system available. The grid for automatic sampling is set strictly in accordance with the capture area, and the step can be from hundredths to several square meters. After obtaining the agrochemical parameters of the soil, a contour map of the distribution of soil properties can be drawn up. The compilation of such maps is the basis of the technology for differentiated fertilisation [CHAO et al. 2007].

Soil fertility monitoring involves sampling various parts of the field and is carried out in two ways: contact and non-contact; the contact method is more often used. Such indicators determine soil fertility as agrochemical properties, the content of macro- and microelements, the presence of toxic substances, and bacteriological composition. To collect samples, automatic soil samplers are used, and mobile samplers were installed on various vehicles, from tractors to four-wheeled motorcycles (Tab. 4). The transport is equipped with a GPS receiver and a mobile computer, which allows obtaining the coordinates of sampling points during work [KIM et al. 2019; ZEYLIGER et al. 2019].

Soil sampling is carried out without human intervention; the soil sampling depth is up to 30 cm. The sampling location is fixed using a navigation system, so each soil sample is marked with unique location coordinates. In the absence of mobile communication coverage of the field, the data is recorded using a magnetic storage device and transferred to the information cloud when the apparatus occurs in the places where there is communication. After taking all samples at the site, soil samples are delivered to the laboratory, where the agrochemical properties of the soil are studied. According to the Goals, Objectives, Strategy, Tactics (GOST) requirements, it is recommended to carry out an agrochemical survey of the soil every five years. However, it is economically justified to conduct an annual survey in areas of soil fertility every season and on a grid of elementary plots at least once every five years [AUBERT et al. 2012; KIM et al. 2019; ZEYLIGER et al. 2019].

Table 4. Comparative indicators of soil sampler models

Indicator	Sampler model				
	Wintex 1000	N 2005	Auto Prob	Falcon	Robo PROB
Manufacturer country	Denmark	Germany	USA	USA	Russia
Number of samples without-echarging	1	1	manual, unlimited	12	36
Packaging and labelling	manual	manual	manual	manual	auto
Samples / hour	10–12	8–10	60	30	30
Cost per one sample (USD)[1]	32.2	43.8	47.9	77.9	10.4
Price (RUB thous.)	1,300	1,500	10,785	8,852	1,200
Cost of ownership (RUB thous.)	310	350	2,300	1,870	250

[1] Average exchange rate in 2021: USD1 = 73.7032 RUB.
Source: own elaboration.

Based on the analysis of literature sources and prototypes, it was found that the use of automatic samplers will improve the quality of soil samples, reduce the error level in determining the sampling point to 10% or less, the results of determining the characteristics of the sample to 5–8% and increase labour productivity in 5–10 times, as well as practically eliminate the influence of the human factor and ensure low labour costs. As a result, the analysis and sampling cost will not exceed 100–150 RUB [AUBERT et al. 2012; KIM et al. 2019; ZEYLIGER et al. 2019].

CONCLUSIONS

The development of modern digital technologies, such as global satellite positioning systems, geographic information systems, equipment for automatic driving of agricultural machinery and a number of others, have made it possible to create a wide range of unmanned vehicles such as UAVs, automatic samplers, robotic sprinklers, robotic lawn mowers and a number of others, which are increasingly used in agriculture.

Research of equipment for automatic agricultural machinery driving, as well as analytical research and testing of UAVs and automatic samplers carried out at the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy show the high efficiency of unmanned robotic systems. Their use allows obtaining a significant increase in productivity and a decrease in unproductive costs, and, therefore, significantly increases the economic efficiency of agricultural production.

The studies carried out show that the use of unmanned and robotic systems, as well as the introduction of new high-tech agricultural methods, not only allows obtaining consistently high yields and increase soil fertility, but will also contribute to the emergence of the Russian Federation agricultural complex on a new innovative development path. Robotic harvesters have higher accuracy than a human-machine operator and the ability to identify various obstacles that pose a danger to agricultural machinery (poles, stones, power lines, etc.) at any time of the day and in all weather conditions.

FUNDING

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