Modern trends in developing robotic systems in agro-industrial complex

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Abstract. The article is devoted to the issue of developing robotic systems in crop and livestock production. The author considers the trends in the improvement of robotic units used in the agro-industrial complex. In crop production, robots are used, as a rule, to perform such operations as sowing seeds, applying fertilizers, precise spraying of plants, monitoring the crop state, controlling weeds, and harvesting crops. The main directions of the robotic system development in agriculture are identified: in the field of crop production, they include increasing the versatility of aggregates, the accuracy of identifying fruits and plants during their treatment and harvesting, increasing the degree of the robotic systems’ autonomy including the use of solar panels, as well as, increasing the speed of performing working operations; in the field of animal husbandry - the development of technologies for "precision livestock farming", automation and digitalization of all technological operations, providing comfortable conditions for farm animals.

1. Introduction  
Despite the high level of agriculture technical equipment, there is a constant renewal and improvement of machines and tools used in the agro-industrial complex. In an effort to meet the needs of agricultural producers, the activities of technical manufacturers are aimed at developing more reliable, multifunctional, energy-saving machines that allow soil cultivating in gentle modes, avoiding unwanted external influences.

In order to increase the automation degree for various agricultural processes, agricultural machinery manufacturers are actively using the latest achievements in the field of agro-informatics, electronics and robotics [1]. The latter direction is actively developing and being implemented in a variety of areas of activity, including agriculture.

Currently, a large number of robots have been developed for work in the field of crop and livestock production. Every year the number of such developments is growing: the range of work performed is expanding, energy efficiency is increasing, quality is improving and the speed of operations is increasing.

The purpose of this research was to study modern trends in the development of robotic systems used in crop and livestock production.
2. Materials and methods
To analyze modern trends in the development of robotic systems in the agro-industrial complex, publications of Russian and foreign authors were studied: articles, books, Internet sources, as well as the patent base.

3. Results and discussion
In the field of crop production, robots are used, as a rule, to perform such operations as sowing seeds, applying fertilizers, precise spraying of plants, monitoring crop state, controlling weeds, and harvesting crop [2, 3, 4, 5].

Weed control is one of the most common tasks performed by agricultural robots [6]. In this case, weeds can be destroyed by physical (pulling out), chemical methods, laser and microwave radiation. For example, a robotic platform produced by Deepfield Robotics (Germany) destroys weeds by pressing them into the ground with an actuator. The weeding robot HortiBot has a similar functionality, which, using a special algorithm, recognizes 25 types of weeds and destroys them by spraying, laser or flame.

Robotic systems can be productive when harvesting, if a large number of monotonous operations are required. Unlike a human, a robot does not get tired and can work around the clock without interruption. One of such developments is the robot SW6010 produced by the Spanish company Agrobot [7]. The robot is able to independently move along the seed plots and collect fragile strawberry fruits. Due to the built-in sensors, it is able to determine the degree of berry ripeness. According to the developer, such a robot is able to collect strawberries from 800 acres in three days.

Modern trends in the development of robotic systems for harvesting are the following: firstly, to improve artificial intelligence, which recognizes the necessary fruits for harvesting and, secondly, to improve robot’s manipulators. For example, Fig. 1a shows a double manipulator: one "hand" moves out the leaves, and the other one grabs and collects the fruits. This manipulator is designed to collect eggplants. Fig. 1b shows a manipulator in the form of a "trunk", consisting of sequentially located segments and thus, it has a large degree of movement freedom [8].

An interesting development is a gardening robot designed by the Californian startup Farmbot (Fig. 2). It is in a form of a movable frame, a number of replaceable attachments is located on it. The operator, using an application on a computer or smartphone, can interactively select where and which plants will be located, the robot will do the rest by itself - sow seeds, water them and remove weeds. The device is weather-oriented, it can collect rainwater and is powered by a built-in solar panel.

When using solar panels, it is worth noting the tendency of their active introduction into agricultural robots in order to increase their autonomy and independence from power supply. Solar panels are installed, for example, on the robot Ladybird, developed in Australia. It allows weeding and
harvesting. In 2019, a commercial vegetable farm ACFR in Koura used agbots or robots powered by solar energy and capable of various types of monitoring, crop assessment, and weed control by spraying [9].

One of the trends in the development of field robots is to increase their versatility by creating mobile platforms with replaceable modules, as, for example, implemented in the robot BoniRob (Fig. 3). The unique platform configuration allows the robot to move independently, adapting to different field configurations. The multipurpose platform allows a farmer to move a payload weighing up to 150 kg and work autonomously for up to 24 hours. The manufacturer declared the possibility of changing modules in this platform depending on the current task.

The modular concept is also implemented in the domestic development of a robot for gardening by the All-Russian Research Institute of Agricultural Mechanization, Moscow. It is equipped with a vision system and various modules for processing garden plants, e.g. for laser irradiation of plants, monitoring yield, spraying plants, as well as a module for magnetic pulse treatment of plants [10].

Among Russian developments, one can also highlight, it is the wheeled unmanned robotic tractor AgroBot designed by Avrora Robotics. The tractor can work in autonomous mode due to the built-in artificial intelligence and perform various agricultural operations. Tractor control can also be taken over by an operator located nearby or in a dispatch center. One operator can simultaneously control several robotic tractors at the same time.

Unmanned tractors are no longer something new [11]. Back in 2017, CNH Industrial introduced an unmanned tractor without any driver's cab. Such a tractor is equipped with a GPS sensor, radar, video cameras, laser radar and other devices. Based on pre-programmed operations, the tractor calculates the optimal travel path by itself, taking into account the size of the field, the terrain, the location of other
machines in the field and other factors. Built-in safety systems, including proximity sensors, minimize the risk of the tractor colliding with other objects. Such a tractor is controlled remotely via a personal or tablet computer. [12]

It is worth noting the use of unmanned aerial vehicles in agriculture, which can also be attributed to robotic systems. Agricultural drones can be used for selective fertilization, monitoring crop state, mapping the area, scaring away wild animals [13, 14, 15]. One of the most popular agricultural drone manufacturers is DJI company. For example, the model DJI Agras MG-1P (Fig. 4) is equipped with a tank of 10-liter capacity for precise spraying of plants. The droplet diameter is 130 - 250 µm (depending on working conditions and spray speed).

![Agricultural drone](image)

**Figure 4. Agricultural drone DJI Agras MG-1P.**

The disadvantage of agricultural drones is still their short flight period duration. For example, in the above model, the hovering time is from 9 to 20 minutes, depending on the spray container load.

Considering the development of digital systems in animal husbandry, one can note trends in the development of technologies for “precision livestock farming” [16, 17, 18]. Such technologies provide an individual approach to each animal: identification of animals by special "smart" tags and chips, including tracking important indicators of animals - body temperature, activity, weight change, milk yield, etc. To monitor the condition of pasture and livestock, complex systems are offered by using drones and special tags attached to animals. Such devices transmit signals from a GPS sensor, accelerometer and thermometer to drones in real time. Thereby, it becomes possible to control each animal and respond to special situations in time, e.g. an animal is outside the pasture territory, appearance of predators, etc. [19].

There are active developments in automation of milking, feeding and manure removal processes [18, 20, 21, 22, 23]. For example, the Dutch company Lely has developed and produced a whole line of robots in the field of animal husbandry [24]. The milking robot Lely Astronaut has a noiseless hybrid arm and an innovative system for mammillar detection, these elements provide a comfortable milking environment for cows. The robot Lely Juno can be controlled by a mobile device and, based on pre-entered data, automatically moves the feed at a predetermined frequency and optimally levels it. The manure cleaner Lely Discovery does not push manure in front of it like conventional cleaning robots, it removes manure by vacuum. The robot Lely Luna, equipped with a special rotating brush, improves cows’ health by cleaning their skin and stimulating blood circulation.

At present, more than 1000 farms in Europe have installed automated animal feeding systems using robots, which reduces the cost of finished products. Feeding robots that move on overhead tracks or on the floor and gently lay flat swaths-strips of a single-component feed or feed mixtures to the animals, as, for example, the feed wagon MixMeister 3000 works.

To improve the well-being of farm animals, digital technology such as virtual reality (VR) is also used. At one of the farms near Moscow, special VR glasses were tested on cows to show them a summer field. In the course of the study, it was found that this technology can improve the emotional state of animals and increase their milk yield [25].

In recent years, there has been a centralization of the computing power of robotic and digital systems: data from sensors located in the field, on animals and agricultural machines are sent to the
server, where they are processed, analyzed and recommendations are sent to the farmer's phone for making decisions, as well as corrective signals for robotic machines. This system is widely used in the so-called "smart farms" (Fig. 5) [26, 27]. According to experts, the use of smart farms, where the processes of feeding, milking and monitoring of animal health are automated, allows a more rational use of the feed base and an increase in milk yield by 30-40% [28]. An important factor is the maintenance of the microclimate in the livestock building with the use of digital intelligent monitoring and microclimate control systems [29].

Figure 5. Concept of a smart farm [27].

Considering the publication activity in the field of agricultural robotics, it can be noted that for field and farmer robots, the number of patents exceeds the number of scientific articles. According to the INNOGRAPHY database, the most common topics in the field of agricultural robots are: robotic manipulators and imaging systems, and the development of robots for such purposes as livestock raising, harvesting, milking and grass mowing [30].

4. Conclusions
Analyzing information about emerging new robotic systems for agriculture over the past few years, one can come to the conclusion about the main trends in their development:
- in the field of crop production: increasing versatility of robotic aggregates, improving accuracy of identifying fruits and plants during their processing and collection, increasing the autonomy degree of the aggregates - including the use of solar panels, and increasing operation speed of robotic systems;
- in the field of animal husbandry: developing technologies for "precision livestock farming", automation and digitalization of all technological operations, providing comfortable conditions for farm animals.

Thus, robotic systems are becoming more widespread in agriculture. Their value truly manifests itself in conditions of dangerous and harmful factors for humans - for example, during chemical processing of plants, in conditions of monotonous repetitive work (harvesting), as well as in conditions of heavy work - loading, unloading and transporting heavy objects. It should be noted that in the near future robots will increasingly be introduced into agriculture and increase the efficiency of the agro-industrial complex.

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