sciendo
DOI: 10.2478/agriceng-2023-0009

ISSN 2083-1587; e-ISSN 2449-5999
2023,Vol. 27,No.1, pp. 113-133
Agricultural Engineering
www.wir.ptir.org

ROBOTIC TECHNOLOGIES IN HORTICULTURE: ANALYSIS AND IMPLEMENTATION PROSPECTS

Taras Hutsol[a,b], Alexey Kutyrev[c], Nikolay Kiktev[d,e], Mykola Biliuk[f]

[a] University of Agriculture in Krakow, email: pro-gp@pdatu.edu.ua, ORCID 0000-0002-9086-3672;
[b] Department of Mechanics and Agroecosystems Engineering, Polissia National University
[c] Department of Technologies and Machines for Horticulture, Viticulture and Nursery, Federal Scientific Agroengineering Center VIM, e-mail: alexeykutyrev@gmail.com, ORCID 0000-0001-7643-775X
[d] Department of Automation and Robotic Systems, National University of Life and Environmental Science of Ukraine, email: nkiktev@ukr.net, ORCID 0000-0001-7682-280X
[e] Department of Intelligent Technologies, Taras Shevchenko National University of Kyiv
[f] University of Agriculture in Krakow, e-mail: biliuk1995@gmail.com, ORCID 0000-0001-6842-7746

* *Corresponding author: e-mail: nkiktev@ukr.net*

ARTICLE INFO

Article history:
Received: February 2023
Received in the revised form: April 2023
Accepted: May 2023

Keywords:
robot,
sensor,
navigation,
gardening,
platform

ABSTRACT

The article contains an analytical review and perspectives of robotic technologies in horticulture. Trends in the growth of production, implementation, and sales of robots in various regions of the world are revealed. The analysis showed a lag in the introduction of agricultural robots compared to other sectors of the economy, as well as a significant gap between the countries of the Asian region and other continents. A review of technical means of three main components of ground agricultural robots is considered: navigation systems, sensors, and platform design. Examples of constructing a tree trajectory using the A* algorithm and using the Rviz visualization tools and the Github PathFindings graphical web service are given. As a result of the conducted research, the use of Lidar sensors is recommended, which will make it possible to design the route of robotic platforms, build maps by scanning a previously unknown surrounding space and updating the resulting map at each step of the algorithm in real time. The use of existing modern sensors with an optical rangefinder with a resolution of 4.5 million pixels, a frame rate of 25 frames per second and the ability to automatically adapt to the light level in combination with stereo cameras and GPS/GLONASS navigation will improve the positioning accuracy of robotic platforms and ensure autonomous operation. To perform basic technological operations for the care of plantings with row spacing of 2.5-4 m, a tree crown height up to 3-3.5 m with intensive technologies, the following design parameters of a robotic platform are required: agro-treatment of at least 1200 mm, adjustable track width of 1840-2080 mm, weight not more than 400 kg, load capacity not less than 1000 kg, the power of the power plant is not less than 5 kW.

Introduction

A post-industrial society is characterized by the transition to automated and robotic production using complex cyber-physical systems. Autonomous industrial robots are one of such widely used systems . They have long been a cost-effective alternative to human labor across a range of industries. The development of agricultural robotics is relevant since the problem of environmental safety remains unresolved around the world (A Green Deal, 2022). According to McKinsey Global Institute (MGI), when using automated and robotic systems, savings in operating costs range from 15-90%, depending on the industry. In economically developed countries, the use of robots has shown effectiveness in various industries, which has led to an increase in demand for such technologies. According to IFR estimates, for 2016 to 2017 there was an increase in sales of industrial robots by 31%, and the total of 381,335 robots were sold (Fig. 1) (Analytical review of the global robotics market, 2019). According to IFR, in 2017, worldwide the total of 6055 robots for agriculture, which is a quite low number in the overall robotization trend. In 2017, the market for industrial robots reached $16.7 billion (without software) and $48 billion (including software) (Fig. 2), while sales of agricultural robots amounted to only $254 million and $750 million respectively. In 2018, the number of industrial robots sold rose to 421,000 units. It should be noted that despite the increase in demand for industrial robots, their cost is declining: the average price per unit decreased from $45,500 to $43,800 between 2016 and 2017. At the same time, the share of "inexpensive" robots is growing (Analytical review of the global robotics market, 2019).

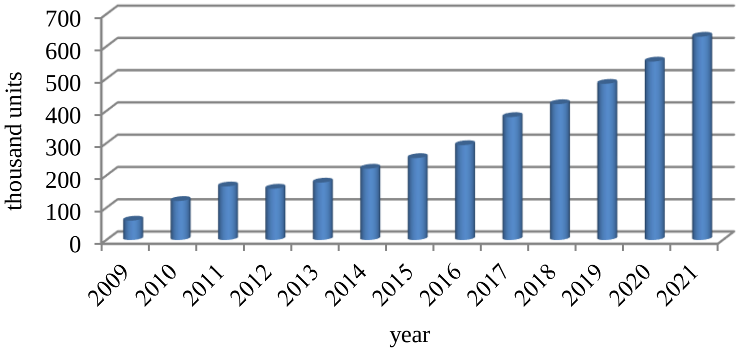


Figure 1. Dynamics of sales of industrial robots in the world in 2009-2021 (thousand units)

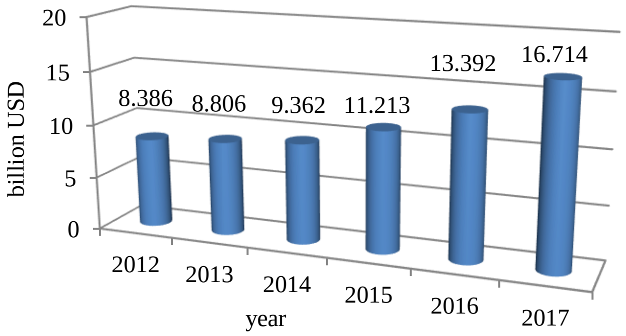


Figure 2. Annual growth of the volume of the world market of industrial robots in value terms for 2012-2017, $ billion

The significant growth of the agricultural robotics market (as well as industrial robots in general) is associated with several factors, primarily with the ongoing global modernization of the Chinese industry: 1/3 of all global sales of industrial robots are in China. Robotization is also facilitated by 3D printing technology with composite materials, as well as other new technologies applied in the production of robots. This allows for cheaper production, makes them more accessible to consumers and of better quality. The third important factor for increasing the production of robots is a significant increase in investment in this industry. According to The Robot Report (TRR), the total amount of funding for the ten largest transactions increased by more than 16 times in a year (from 2017 to 2018). Consider the geographical aspect of the robot market (Fig. 3). Today, the fastest growing robotics market in the world is the Asian region. This result is ensured primarily by the rapid development of China's economy. The second largest (but significantly lagging) is the European region. The Americas market (North and South) shows the least growth. More than 70% of sales of industrial robots in the world are in 5 countries: China, Japan, South Korea, USA, and Germany. At the same time, China is the undisputed market leader (Analytical review of the global robotics market, 2019).

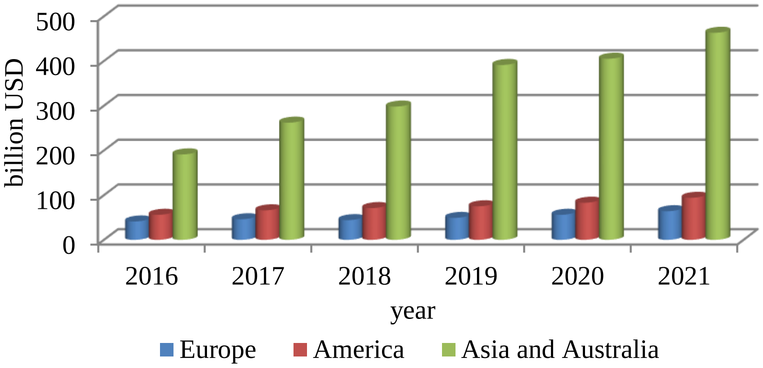


Figure 3. Dynamics of sales of industrial robots by regions

The distribution of industrial robots by industry is shown in Fig. 4. The sectors least covered by robotization include the nuclear industry, shipbuilding, aircraft manufacturing, mining, and agriculture. However, with a changing climate situation and an increasing world population, agricultural efficiency is becoming increasingly important. The food problem is one of the main problems in developing countries, where many people suffer from lack of food and malnutrition, which leads to serious problems in health, development, and education. In developed countries, including the EU, one of the key solutions to the food problem is sustainable agriculture, which takes into account environmental, economic and social aspects (A Green Deal, 2022). In addition, it is important to support and develop small and medium-sized enterprises in agriculture, creating jobs and improving living standards in rural areas, as well as reducing food waste.

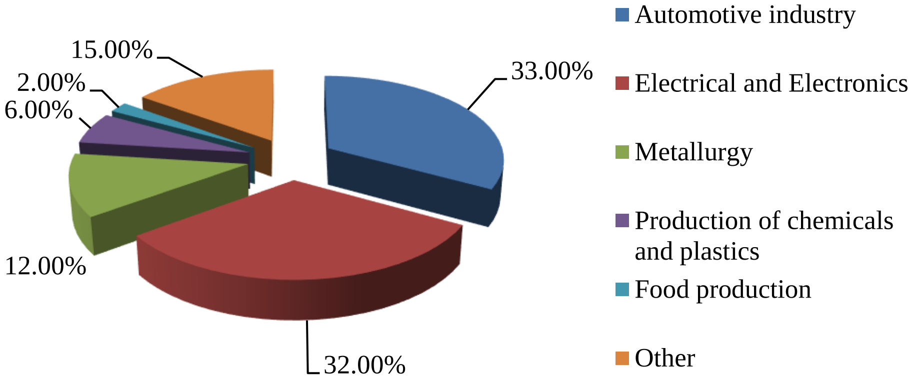


Figure 4. Distribution of robot capabilities by manufacturing industry in 2017

Horticulture plays a key role in providing the population with fresh fruits and vegetables. The growing demand for horticultural products and the lack of skilled workers threaten the efficiency of the industry. An important decision is the development of scientific and technological innovations in agriculture, including horticulture. In particular, the application of robotic technologies can increase the efficiency of food production and reduce labor costs. In this article, we will analyze the introduction of robotic technologies in horticulture, evaluate their effectiveness and the prospects for the development of this industry. We will look at the different types of robots and systems that are used in horticulture, as well as analyze the advantages and disadvantages of robotics in this industry. The classification of agricultural robotics is given in the dissertation work of Skvortsov (2017). It can be classified by the industry: used in animal husbandry, crop production and auxiliary industries (Fig. 5).

Intensive horticulture technologies are the most widely used in modern horticulture. These technologies are characterized by high yields in comparison to traditional technologies. The main disadvantages of these technologies are the high complexity of the processes. The main means of increasing the efficiency, competitiveness and dynamic development of industrial gardening is the development and application of digital technologies, automated and robotic technical means. The most promising development trend is automation and robotization, which allows the use of a precision approach to each plant and managing production and technological processes based on digital monitoring systems, artificial intelligence algorithms and automated positioning systems for robotic platforms in the field. *The purpose of the research* is to analyze the use of robotic technologies in horticulture, compare modern sensors and algorithms for controlling the movement of robotic platforms to perform basic technological operations for the care of plantings.

Materials and methods

To analyze and study the prospects for the development of robotic technologies in the world, the authors used research materials in this industry from leading scientific and industrial organizations in various countries of the world - China, the USA, India, Russia, Great Britain, Germany, Ukraine, and “Analytical review of the global robotics market” (2019). The study and conclusions are based on the study of goals of the following programs and agreements: "European Green Deal" (2022), the project "PROJECT ACTIVATE" (2022), associated with the development and implementation of engines on ammonia.

The Green Deal is the largest economic correction in the history of the EU. The project involves the formation of a carbon-neutral space in the EU. It is expected to achieve a 40 percent reduction in greenhouse gas emissions from 1990 levels by 2030. The project also provides for an increase in the share of energy from renewable sources to 32% in the total energy consumption and approximately the same energy savings. The plan takes into account all sectors of the economy, including agriculture, the circular economy. In addition, the Green Deal calls for 3 billion additional trees to be planted by 2030. With regard to horticulture, within the framework of the Green Deal, we propose to use robotization to increase the efficiency of this area, which will increase the yield, reduce electricity costs, harmful emissions into the atmosphere and provide the population with quality food.

PROJECT ACTIVATE is a joint Norwegian-Polish project aimed at reduction of CO_2 emissions into the atmosphere. The project has existed since 2022, is a consortium, funded by grants from Norway (85%) and the Polish government (15%). To counter the climate crisis, the project aims to replace fossil fuels with carbon-free energy sources. For a sector such as agriculture (including horticulture), there is a need for sustainable, renewable and carbon-free energy sources, which is ammonia (NH_3). This project aims to demonstrate the use of ammonia with biodiesel in the agricultural sector as a technology which is planned to be applied in horticulture in tractors and autonomous robotic platforms. The authors of this article proposed a draft design of a universal robotic platform for gardening using an ammonia engine (Kutyrev et al., 2022).

To determine the optimal route for the robotic platform in the garden, algorithms for finding the shortest path built into the GitHub web service were used. In particular, the comparison by Dijkstra's Algorithm, Vector Pursuit Algorithm, Navigation Algorithm, Feature Recognition Algorithm using Image Processing, SLAM Algorithms, Hybrid Navigation Algorithm, Path Planning and Path Following Algorithm and others are considered.

Results and Discussion

Autonomous navigation is the main component of automation in agriculture is. Extensive research on the use of unmanned automated platforms (UGVs, Unmanned Ground Vehicle) in horticulture is currently underway. They are used for pruning, weed and disease control as well as harvesting. Efficient and high-quality performance of the listed operations is possible under the following conditions - autonomous navigation for complex environments, fast operation without damage, target detection for complex backgrounds. Navigation in difficult agricultural environments, safe interaction of the robot with the crop, and the fusion of agronomic robots are considered to be of high scientific value and importance for advancing revolutionary advances in agricultural robot technology.

The successful implementation of technological operations largely depends on how justified the equipment of mobile platforms with sensors is to obtain the necessary information. We will group the review of hardware and software of robots used in gardening into 3 subsections: navigation and guidance, sensors, specially designed mobile platforms (UGV).

Navigation and guidance. Early navigation systems in agricultural areas used a camera as a sensor and were based on computer vision techniques (Hiremath et al., 2014). Navigation, guidance, and transportation include three levels of autonomy: conventional steering, controlled by the operator or an automatic system (under the control of GO) and a fully autonomous system. Navigation and guidance can be the primary task of the system, such as transporting crops from the field to the packing house or be a secondary task allowing the system to perform its primary task, such as the secondary task of spraying or transporting a robot from tree to tree during the harvesting process. Automatic control has been the most active area of research throughout the history of agricultural machinery automation (Nof et al., 2009). Available systems are based on two main approaches.

- platform (ground robot) follows a predetermined path based on data or from local positioning system (LPS) stations;
- from satellites of the global positioning system (GPS) (Lipiński et al., 2016; Pasichnyk et al., 2020).

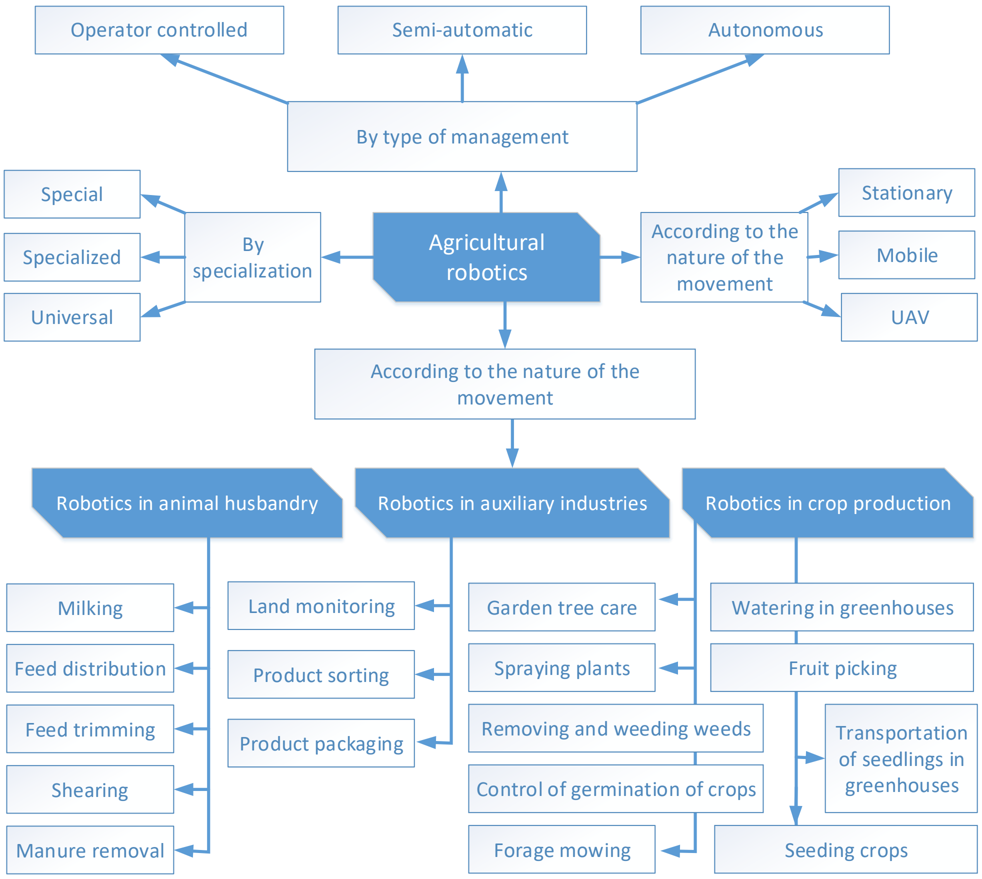


Figure 5. Classification of agricultural robotics

This approach is technically simple, but its disadvantage is the inability to respond to unexpected changes or events in the field (Stentz et al., 2002). In the second approach, the robot works relative to the seeding line, for example, along a row of plants, or the border between the plowed and unplowed soil, or between cut and stagnant forage, using a sensor system, usually machine vision (Astrand and Baerveldt, 2005). This approach allows the robot to tailor its work to individual plants as they change over time, but it is generally considered more technically difficult to define a crop line than to follow a specific path (Stentz et al., 2002). The effectiveness of ground robots (GROs) depends significantly on how well they can perceive the environment in which they move, especially if they move independently without relying on the intervention of a human operator. Obstacle avoidance capabilities are important for all drones, whether they operate in the air, on the ground, or on/in the water. Sensor fault detection is another important issue for all kinds of robotic platforms to keep them safe and reliable. Their navigation capabilities and the ability to observe certain physical quantities in their environment strictly depend on sensors and measuring systems, as well as on the data processing algorithms. The development of autonomous driving is also closely related to the ability to interpret and analyze information coming from sensors or combinations of sensors of various types (day and night vision camera, LiDAR, mm/ultrasonic radar, etc.) in order to take advantage of their various optimal operating ranges and collect information related to different sizes of their environment (Andžāns et al., 2016). Currently, for positioning robotic platforms in industrial garden plantations, several navigation methods are used: global navigation, local navigation, personal navigation (Luan and Thinh , 2020). Global navigation is used to determine the absolute coordinates of robotic platforms when moving along long routes between rows of plantations. Local navigation is used to determine the current position of the robotic platforms relative to some point, usually the starting position when positioned within a predetermined area. Personal navigation is used when robotic platforms position parts of their design and interact with the nearest identified objects with orientation in space using various types of marks, which is relevant for devices equipped with device manipulators (Khort et al., 2019). For positioning robotic platforms in the field, passive and active methods (systems) for receiving information are used (Zong et al., 2020). The passive system receives information about its own coordinates and other characteristics of its movement from external sources, global satellite systems GLONASS / GPS, radio beacons. An active navigation system is designed to determine the location solely by means of its own devices (sensors) of robotic platforms, inertial navigation systems, mechanical and optical gyroscopes, mechanical accelerometers, odometers, laser rangefinders, generators of radio or other signals (ultrasonic, infrared), stereoscopic cameras (Khort et al., 2021).

Sensors

For positioning robotic platforms in the field, it is necessary to select suitable sensors that can work in all weather and lighting conditions, and detect various obstacles with acceptable processing time. Sensor selection depends on the specific application and environmental conditions. Consider which sensors are used to perform a particular technological operation in horticulture. Active and passive sensors are used to detect plants and obstacles in rows of garden plantings. Passive sensors detect electromagnetic radiation or reflection of light from objects. They work well with visible, infrared, thermal infrared, and microwave segments. Passive sensors have their own energy source, emit pulsed energy, and receive reflected energy to detect objects. For positioning robotic platforms in the field, the following types of passive sensors are used: monovision and stereovision cameras (calculation of the distance to objects and depth estimation), RGB cameras (2D images for analyzing the color, texture and shape of objects in high resolution), thermal infrared cameras (positioning according to the generated thermal images), hyperspectral cameras (reading the spectral bands of materials in the image) (Almasri et al., 2015). Active sensors measure the distance to objects by sending impulse signals to an obstacle and receiving a reflected signal from them, based on the calculation of the flight time of laser, ultrasonic or radio signals to measure and search for objects. For positioning robotic platforms in the field, the following types of passive sensors are used: laser sensors (building a cloud of points, 3D environmental matrices), ultrasonic sensors (tracking the reflection of ultrasonic waves), radars (tracking the reflection of radio waves) (Sharma et al., 2014). Accelerometers, gyroscopes, and global satellite systems are used to control acceleration, movement speed and position changes in the working bodies in space. To recognize fruits on a tree, various computer vision methods are used, including neural networks (Smirnov et al., 2021; Khort et al., 2020).

The results of a comparison of various types of sensors used for navigating robotic platforms for working in the aisles of garden plantations are presented in Table 1.

Table 1.
Comparative analysis of various types of sensors used for navigation of robotic platforms

Sensor	Influence of weather conditions on the operation of sensors	Influence of illumination on the operation of sensors	Permission	Range	Work algorithm	Recognition of overlapped objects	Definition (identification) of depth
RGB camera	Yes	Yes	High	Medium	Convolutional Neural Network	No	No
Stereo camera	Yes	Yes	High	Medium	Stereo vision algorithms	Yes	Yes
Thermal infrared camera	Yes	No	Average	Medium	Image classification	Yes	No
Hyperspectral camera	Yes	Yes	High	Medium	Visualization-based processing algorithm	Yes	No
LiDAR sensor	No	Yes	Low	High	Point cloud classification	Yes	Yes
Radar	No	No	Low	Very high	Deep Learning	Yes	Yes
GPS and GLONASS	No	No	High	High	Satellite navigation system	No	No

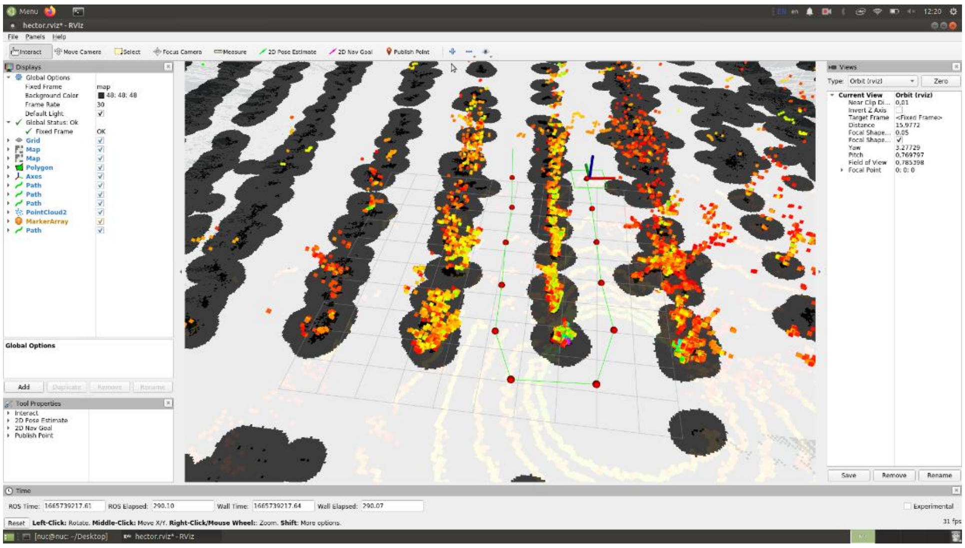
Building a trajectory

An analysis of existing sensors for building obstacle maps needed to calculate the trajectories of robotic platforms showed that the LiDAR (Light Detection and Ranging) sensor has a significant advantage due to a 360-degree view, which allows detecting obstacles around the robotic platform and plotting them on the map with an accuracy of several centimeters (Fig. 6). The LiDAR sensor allows the robotic platform to detect obstacles while generating large amounts of data, including data based on points or pixels. The processing of the received data is focused on segmentation, classification of point and pixel images, which allows clustering and positioning.

Navigation algorithms. An analysis of existing control systems for autonomous mobile power facilities (Sgorbissa and Zaccaria, 2012) showed that for navigation and control in the field it is possible to use the algorithms given in Table 2.

As a result of the analysis, it was found that the use of the A* algorithm for traversing the graph and finding the optimal path will allow positioning robotic platforms with a high degree of accuracy in the rows of garden plantations when moving along typical trajectories consisting of straight sections (in the aisle along a row of trees) and circular arcs (for arrival in the next row) to perform various technological operations (Kormen et al., 2011). An example of finding a path in a graph with obstacles (1-10) using the A* algorithm in the Github PathFindings web service is shown in Fig. 7.

One of the operations performed by the NBA is the detection and evaluation of fruit quality in orchards. In the early studies, simple monochrome cameras were used to detect fruits inside the crown. In addition to visible light RGB cameras and ultrasonic radar sensors, which are commonly used for object detection due to their affordable cost (Weltzien et al., 2006), advances in detection and imaging technologies have led to the use of sophisticated devices such as: infrared, hyperspectral cameras (Okamoto and Lee, 2009), LiDAR (Westling et al., 2018) or a combination of multisensors (Bulanon et al., 2009), which are adapted to new vision-based technologies for extracting spatial information from fruit images, detection, recognition, localization and tracking. The usual approach to fruit detection and counting is to use a single viewpoint, as in the case of the cucumber harvesting robot (Van Henten et al., 2006), or multiple viewpoints with additional sensors from one or more vision sensors that are not located on the robot. Examples of recent advances include automatic fruit recognition based on multiple images or fusion of color and 3D features, multiple pattern matching algorithm, symmetry analysis (Barnea et al., 2016). Combined color distance method and RGB-D data analysis for apples and sweet peppers, stereo vision for apple detection (Gongal et al., 2015).



Global Options
Fixed Frame: map
Background Color: 48; 48; 48
Frame Rate: 30
Default Light: ✓
Global Status: Ok
Fixed Frame: OK

Type: Orbit (rviz)
Current View: Orbit (rviz)
Near Clip Di...: 0,01
Invert Z Axis: ☐
Target Frame: <Fixed Frame>
Distance: 15,9772
Focal Shape...: 0,05
Focal Shape...: ✓
Yaw: 3,27729
Pitch: 0,769797
Field of View: 0,785398
Focal Point: 0; 0; 0

ROS Time: 1665739217.61 ROS Elapsed: 290.10 Wall Time: 1665739217.64 Wall Elapsed: 290.07

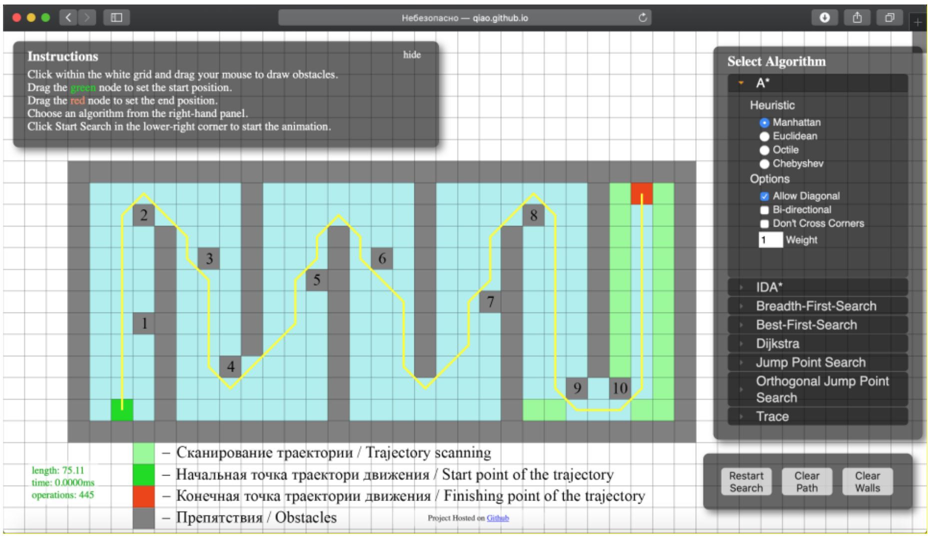
Left-Click: Rotate. **Middle-Click:** Move X/Y. **Right-Click/Mouse Wheel:**: Zoom. **Shift:** More options.

Figure 6. Building a motion trajectory by points in the Rviz visualization environment

Table 2.
Navigation and control algorithms

No.	Algorithm name	The essence of the method
1	Error algorithm	Bypassing an obstacle, going around an obstacle until it becomes possible to reach the intended goal
2	Navigation algorithm	Use of global satellite systems
3	Hybrid navigation algorithm	Use of global satellite systems in combination with active or passive sensors

4	Path planning and path following algorithm	Performing maneuvers through designated waypoints, by traversing the graph and finding the optimal path
5	Dijkstra's algorithm	Uniform cost search
6	Histogram vector field algorithm	Vector Field Histogram, representation of obstacles via histogram grids
7	Potential field algorithm	Application of an artificial potential field for positioning
8	Visual algorithm	Comparison of the difference between two successive images obtained at a given time interval, the use of computer vision cameras
9	Pursuit algorithm	Calculation of the shortest distance, construction of a trajectory taking into account the "curvature"
10	Vector pursuit algorithm	Path following method using screw theory
11	Feature recognition algorithm using image processing	Application of neural networks for image processing
12	SLAM algorithms	Simultaneous Localization and Mapping, building a map in an unknown space



Instructions

Click within the white grid and drag your mouse to draw obstacles.
Drag the green node to set the start position.
Drag the red node to set the end position.
Choose an algorithm from the right-hand panel.
Click Start Search in the lower-right corner to start the animation.

Heuristic
● Manhattan
○ Euclidean
○ Octile
○ Chebyshev

Options
☑ Allow Diagonal
☐ Bi-directional
☐ Don't Cross Corners
1 Weight

length: 75.11
time: 0.0000ms
operations: 445

🟩 – Сканирование траектории / Trajectory scanning
🟩 – Начальная точка траектори движения / Start point of the trajectory
🟥 – Конечная точка траектории движения / Finishing point of the trajectory
▨ – Препятствия / Obstacles

Figure 7. Finding the optimal path using the A algorithm (Github PathFindings web service)*

The results of studies of an electric vehicle that must move between fruit trees and perform some actions, such as plant protection or mulching, are presented in (Linz et al., 2014). The authors consider a 2D and 3D laser rangefinder, Time of Flight cameras, and ultrasonic rangefinder to be the preferred sensors for detecting trees and potential obstructions in a row. Moreover, these scanners can be used to detect the leaf walls of trees and manage the application of plant protection products, resulting in chemical savings and reduced environmental impact. The use of a 2D laser range finder for row navigation is quite popular and has been demonstrated by other research groups (Freitas et al., 2012). One way to find obstacles in a row is to use an oblique 2D laser scanner and generate 3D data by combining the scans with the distance traveled.

This assumes a moving vehicle and accurate distance information. For the considered robot, a non-rotating 3D laser scanner or a Time of Flight camera was used. ROS (Robot Operating System) and Gazebo support a plug-in model for programming simulated sensors and actuators. These sensor drivers generate data in the same format as the actual sensor driver. Thus, the navigation algorithm cannot distinguish real world sensor data from simulated sensor data. In addition, ROS has the ability to save all timestamped data to a file and play them later on the system.

The equipment of ground-based robotic platforms essentially depends on the operations that they must perform. Tables 2, 3 present a set of sensors and equipment that should be equipped with ground-based autonomous robots (GARs) for monitoring plant growth (Table 3) (Vaeljaots et al., 2018; Bietresato et al., 2016), harvesting agro-robot complexes (Table 4) (Silwal et al., 2016; Hayashi et al., 2010). For better performance of technological operations in garden plantations, robotic ground platforms must be equipped with mapping equipment. Photographs of plantings make it possible to provide navigation for the robot, as well as the detection of fruits, determining their quantity and quality (Arnó et al., 2009). Viticulture is particularly suited to spatial and geodetic technologies due to the "fixed" nature of plantings and the perennial nature of crops (Bramley et al., 2005), and spatial analysis is critical for managing vineyard productivity and minimizing risks in small vineyards.

Platforms

The development of a robotic ground platform (GRP) that can autonomously move in the changing and dynamic conditions of the external agricultural environment is a complex and difficult task, but it is an important operation for any intelligent agricultural machine (Hagras et al., 2002). The efficiency of technological operations in gardens by robotic platforms (robots) largely depends on the equipment, and the sensors used to equip the platforms.

Unmanned Ground Vehicle (UGV) for agriculture. Ground-based mobile robots, equipped with advanced technologies for positioning and orientation, navigation, planning and sensing, have already demonstrated their advantages in outdoor applications in industries such as mining, agriculture, and forestry (Bechar and Vigneault, 2016). The commercial availability of Global Navigation Satellite System (GNSS) has provided easy ways to set up autonomous vehicles or navigation systems to assist drivers in the open, especially in agriculture where many high-precision vehicle steering systems have become available (Autopilot, 2019). These systems help operators accurately control ground mobile robots using LIDAR (Light/Laser Detection and Ranging) or GNSS technology, but do not endow the vehicle or instrument with any level of autonomy. Assessment of the level of autonomy of the robot is described in the article by Kutyrev et al. (2022). However, other important technologies must also be used to set up the UGV, such as safety systems responsible for detecting obstacles in the path of the robots and protecting people and animals in the environment of the robots, as well as preventing collisions with obstacles or other robots.

Finally, the communication of robots with operators and external servers (cloud technology) via wireless communication, which includes the use of cyber-physical systems (CPS) (Lee and Seshia, 2017) and Internet of things (IoT) methods (Ochoa, et al., 2017) will be essential. for incorporating decision making into systems based on big data analysis. This integration will extend decision-making to areas such as machine learning and artificial intelligence. Smart factories are based on the highly intertwined concepts of CPS, IoT, big data and cloud computing, and UGV for smart farms should be based on the same principles to minimize traditional delays in applying the same technologies in industry and agriculture.

Table 3.
Agro-robotic plant growth monitoring systems for various crops.

Culture	Perception	Results
No specific culture	A high-resolution stereo cameras, 3D lidar	Soil sampling. The results are not Provided.
No specific culture	CO_2 gas sensor, anemoscope, IR distance sensor	Gas source tracking. CO_2 concentration levels up to 2500 ppm have been recorded. while the robot was moving at a speed of 2 m/min.
Gardens	LiDAR, light meter	Estimation of the volume of the dome. System does not depend on lighting conditions. It features high reliability and data processing very fast.
Grape	RGB and IR camera, laser	The tasks of monitoring crops. Performance metrics not listed
Orchards and vineyards	Ranger Finder, IMU, pressure sensor, etc.	Monitor health and crown thickness. Terrestrial laser scanning (TLS): distance accuracy 2mm
Canola	LiDAR, OptRX sensor Ultrasonic sensors, NDVI sensors, IR thermometers, RGB camera	Collection of phenotypic data. Maximum measurement error: 2.5%

Table 4.
Features of harvesting agro-robot complexes for various crops.

Culture	Perception	The fastest collection	The fastest collection rate
Apple tree	Color camera, flight time considering three overall camera	7,5 sec/fruit	84%
Apple tree	Color CCD (Charge Coupled Device) Camera, Laser range sensor	7,1 sec/fruit	89%
Apple tree	high frequency light, camera	9 sec/fruit	80%
Cherry	3D vision sensor with red, IR laser diodes, pressure meter	14 sec/fruit	-
Strawberry	3D vision sensor with red, IR laser diodes, pressure meter	31,3 sec/fruit	86%
Strawberry	Echolocation camera sensor, binocular camera	8,6 sec/fruit	54,9%
Strawberry	Reflective type color CCD cameras, photoelectric sensor	11,5 sec/fruit	41,3% with suction device 34.9% without it
Strawberry	LED light source, tri-color CCD cameras, photoelectric sensor, suction device, Color CCD camera, visual sensor	10 sec/fruit	-

Custom designed mobile platforms. The design of a wheeled mobile platform depends on the following characteristics:

- *Number of wheels.* A minimum of three non-axial wheels ensures the static stability of the platform. However, most field robots are based on four wheels, which increases the reserves of static and dynamic stability (Garcia and Gonzalez-de-Santos, 2006).
- *Wheel Orientation Type:* Ordinary wheel can be mounted on the platform in a variety of ways which greatly determine the characteristics of the platform. The coordinated steering scheme: two fixed active wheels at the rear of the platform, combined with two passive orienting wheels at the front of the platform, is the most common wheel arrangement for vehicles. In order to keep all wheels in a pure rolling state during a turn, the wheels must follow curved paths with different radii emanating from a common center (Fig. 8) (Lakkad, 2004).

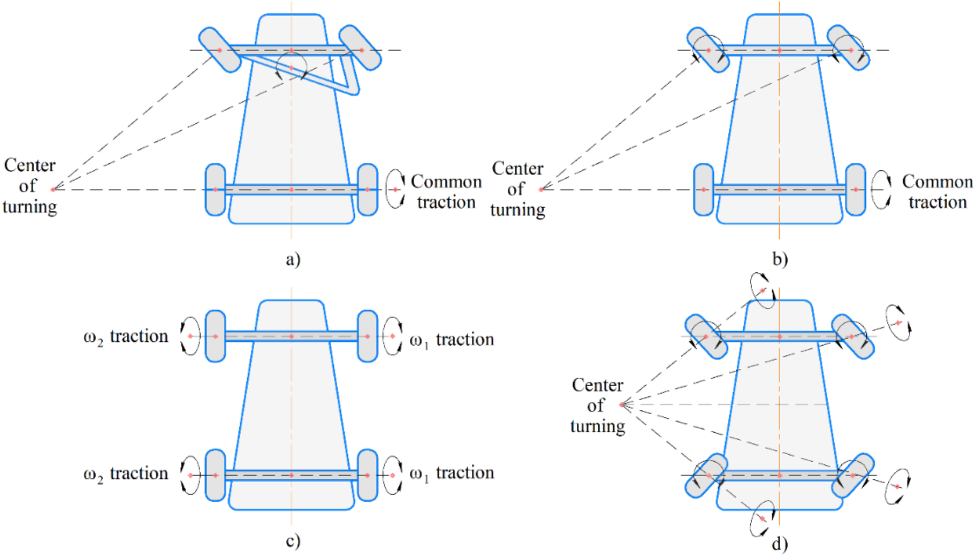


Figure 8. Steering systems: a) Ackerman steering system; (b) independent steering; (c) a skid-steer steering system; and (d) an independent steering and traction system.

Robot designs on wheels. The structure of the mobile platform on wheels depends on (i) the number of legs, (ii) the type of legs, and (iii) the location of the legs. The legs consist of steerable drive wheels with two degrees of freedom, as shown in Fig. 9.

Number of legs. The minimum number of legs required for static walking stability is four or three legs, providing support in the form of a stable tripod, while the other leg performs the swing phase (Gonzalez-de-Santos, 2006). Rail robots are also known, they are not very convenient for working in the fields, but they are quite suitable for performing operations in a greenhouse (Lysenko et al., 2021).

Discussion and perspectives

In this article we examined some aspects of the introduction of robotic technologies in the agricultural industry and, in particular, the use of robots in gardening. These robots have been tested and have proven themselves well when picking strawberries (Khort et al., 2019), apples (Khort et al., 2022), processing trees using hot fog (Khort et al., 2022). Prospects for the use of robots are monitoring orchards to determine diseases of fruits and leaves, sorting fruits, cutting weeds, electrophysical treatment of seedlings, etc. One of the most advanced technologies in this industry is the use of various neural networks to recognize fruit varieties and their quality (Kutyrev, et al., 2023). Also in the plans of the authors is the improvement of technical means of collection, the quality of capture mechanisms when picking fruits to reduce their deformation (Khort et al., 2021), the improvement of the electronic base (Khort, et al., 2020), as well as algorithms and navigation systems. In accordance with the European Green Agreement, the development of robotic platforms using ammonia engines is promising.

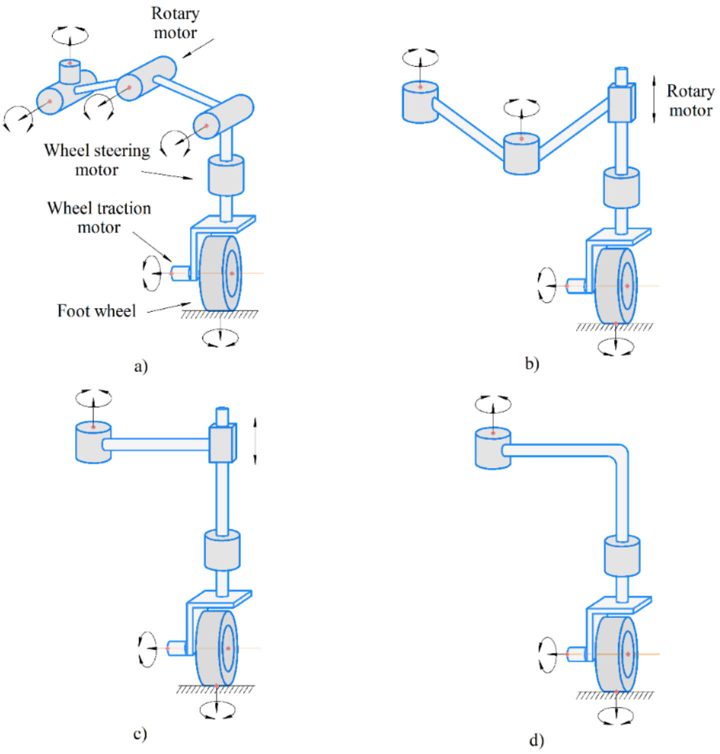


Figure 9. Wheel structures. a) articulated leg with four degrees of freedom; (b) SCARA support with 3 degrees of freedom; (c) SCARA support with two degrees of freedom; (d) 1-degree of freedom

The results obtained create the prerequisites for the expansion and implementation of artificial intelligence technologies in the cultivation of crops. The development of digital intelligent systems, Internet of Things technologies and telematic services will ensure the widespread use of the proposed methods for monitoring, predicting the state of biological objects and managing the group work of robotic tools in the cultivation of fruit and berry crops.

Table 5.
Robots designed specifically for agriculture.

Robot	Type of work*	Description
AgBot II (Westling et al., 2018)	P	Platform built according to the onboard steering scheme with two front fixed wheels (operating in drift or differential mode) and two rear caster wheels
Ladybug (Van Henten et al., 2006; Hemming et al., 2014)	p	Omnidirectional robot powered by batteries and solar energy. panels using an independent steering scheme
Greenbot (We put machines to work, 2019).	C	Self-driving robot for tasks in agriculture and gardening
Caesar (Autonomous system, 2019)	p	Remote controlled platform for temporary autonomous use in fruit plantations and vineyards
RIPPA (Bogue, 2016)	p	Lightweight, durable, and easy to use prototype vegetable cutter. Growing industry
Vibrocrop, Robotti (New Automated Agricultural, 2019)	C	Autonomous tracked platform with onboard steering. Scheme

In recent years, EU researchers have developed and are testing a platform for agricultural purposes: for sowing and other farming operations (Denmark, the Netherlands) and an autonomous system for spraying, tillage, fertilization, contour pruning, harvesting and transportation (Germany).

Conclusion.

This article contains an analytical review and perspectives of robotic technologies in horticulture. Trends in the growth in the volume of implementation and sales of robots in various regions of the world are revealed, the analysis showed a lag in the introduction of agricultural robots compared to other sectors of the economy. The analysis of technical means of three main components of ground agricultural robots is carried out: navigation systems, sensors, and platform structures.

1. It has been established that the use of the A* algorithm with the LiDAR sensor will allow finding the shortest path from the starting point of the trajectory to the specified intermediate and end points, analyzing all trajectory options step by step. The use of LiDAR sensors will provide the ability to design the route of movement of robotic platforms,

build maps by scanning a previously unknown surrounding space and updating the resulting map at each step of the algorithm in real time, which will provide a high degree of positioning accuracy in various lighting conditions at various speeds.

2. The use of existing modern sensors with an optical range finder with a resolution of 4.5 million pixels, a frame rate of 25 FPS and the ability to automatically adapt to the level of illumination in combination with stereo cameras and GPS / GLONASS navigation will further improve accuracy, ensure the autonomous performance of basic technological operations by the units with a deviation from a given trajectory is not more than 1.5-2 cm, which meets the agrotechnical requirements.
3. It has been established that in order to perform basic technological operations for the care of plantations with row spacing of 2.5-4 m, tree crown height of up to 3-3.5 m in intensive technologies, the following design parameters of the robotic platform are required: agro-clearance of at least 1200 mm, adjustable gauge 1840- 2080 mm, weight not more than 400 kg, load capacity not less than 1000 kg, power plant ~~power~~ capacity not less than 5 kW. A universal robotic platform that ensures the performance of technological operations in horticulture: planting monitoring, planting spraying, inter-row cultivation, robotic harvesting, and transportation of crops.

References

A Green Deal, (2022). Available online: https://ec.europa.eu/info/strategy/priorities/2019-2024/european-green-deal [Aaccessed on March 2022].

Almasri, M., Elleithy, K., & Alajlan, A. (2015). Sensor fusion based model for collision free mobile robot navigation. *Sensors,* 16(1), 1-24. DOI: 10.3390/s16010024.

Analytical review of the global robotics market 2019 [Analiticheskij obzor mirovogo rynka robototehniki 2019]. Online: https://www.sberbank.ru/common/img/uploaded/pdf/sberbank_robotics_review_2019_17.07.2019_m.pdf Accessed on 13.03.2023 [Accessed on March 2022] (In Russian).

Andžāns, M., Bērziņš, J., Durst, J., Maskaliunaite, A., Nikitenko, A., Ķiploks, J., Rogers, J., Romanovs, U., Sliwa, Z., Väärsi, K., et al. *Digital Infantry Battlefield Solution. Introduction to Ground Robotics, DIBS Project, Part I*; Romanovs, U., Ed.; Milrem: Helsinki, Finland, 2016

Arnó, J., Martínez-Casasnovas, J., Ribes-Dasi, M. & Rosell, J. (2009). Review. PrecisionViticulture. Research topics, challenges and opportunities in site-specific vineyard management. *Spanish Journal of Agricultural Research,* 7(4), 779-790. DOI: 10.5424/sjar/2009074-1092.

Astrand, B. & Baerveldt, A. J. (2005). A vision based row-following system for agricultural field machinery. *Mechatronics,* 15(2), 251-269. DOI: 10.1016/j.mechatronics.2004.05.005.

Autonomous system for agricultural purposes such as spraying, tillage, fertilization, contour cut, harvest, and transportation (2019). Available from: http://www.raussendorf.de/en/fruit-robot.html [Accessed: March 2023]

Autopilot (2019). Available from: http://www.trimble.com/Agriculture/autopilot.aspx [Accessed: March, 2022].

Barnea, E., Mairon, R. & Ben-Shahar, O. (2016). Colour-agnostic shape-based 3D fruit detection for crop harvesting robots. *Biosystems Engineering,* 146, 57–70. DOI: 10.1016/j.biosystemseng.2016.01.013.

Bechar, A. & Vigneault, C. (2016). Agricultural robots for field operations: Concepts and components. *Biosystems Engineering,* 149, 94-111. DOI: 10.1016/j.biosystemseng.2016.06.014.

Bietresato, M., Carabin, G., Vidoni, R., Gasparetto, A. & Mazzetto, F. (2016). Evaluation of a LiDAR-based 3D-stereoscopic vision system for crop-monitoring applications. *Computers and Electronics in Agriculture,* 124, 1–13. DOI: 10.1016/j.compag.2016.03.017.

Bogue, R. (2016). Robots poised to revolutionise agriculture. *Industrial Robot International Journal.* 43(5), 450-456. DOI: 10.1108/IR-05-2016-0142.

Bramley, R.G.V., Proffitt, A.P.B., Hinze, C.J., Pearse, B. & Hamilton, R.P. (2005). Generating benefits from Precision Viticulture through selective harvesting. *Precision Agriculture,* 5, 891-898.

Bulanon, D. M., Burks, T. F. & Alchanatis, V. (2009). Image fusion of visible and thermal images for fruit detection. *Biosystems Engineering,* 103(1), 12–22. DOI: 10.1016/j.biosystemseng.2009.02.009.

Freitas, G., Hamner, B., Bergerman, M. & Singh, S. (2012). A Practical Obstacle Detection System for Autonomous Orchard Vehicles. In *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). Proceedings of a meeting held 7-12 October 2012* (pp. 3391–3398). Vilamoura-Algarve, Portugal. DOI: 10.1109/IROS.2012.6385638.

Garcia, E. & Gonzalez-de-Santos, P. (2006). On the improvement of walking performance in natural environments by a compliant adaptive gait. *IEEE Transactions on Robotics,* 22(6), 1240-1253. DOI: 10.1109/TRO.2006.884343

Gongal, A., Amatya, S., Karkee, M., Zhang, Q. & Lewis, K. (2015). Sensors and systems for fruit detection and localization: A review. *Computers and Electronics in Agriculture,* 116, 8–19. DOI: 10.1016/j.compag.2015.05.021.

Gonzalez-de-Santos, P., Garcia, E. & Estremera, J. (2006). *Quadrupedal Locomotion: An Introduction to the Control of Four-Legged Robots*. London: SpringerVerlag*;* 2006. DOI|: 10.1007/1-84628-307-8.

Hagras, H., Colley, M., Callaghan, V. & Carr-West, M. (2002). Online learning and adaptation of autonomous mobile robots for sustainable agriculture. *Autonomous Robots,* 13(1), 37-52. DOI: 10.1023/A:1015626121039.

Hayashi, S., Shigematsu, K., Yamamoto, S., Kobayashi, K., Kohno, Y., Kamata, J. & Kurita, M. (2010). Evaluation of a strawberry-harvesting robot in a field test. *Biosystems Engineering,* 105, 160–171. DOI: 10.1016/j.biosystemseng.2009.09.011.

Hemming, J., Ruizendaal, J., Willem Hofstee, J. & van Henten, E. J. (2014). Fruit detectability analysis for different camera positions in sweet-pepper. *Sensors,* 14(4), 6032–6044. DOI: 10.3390/s140406032

Hiremath, Van der Heijden, G. W. A. M., Van Evert, F. K., Stein, A. & Ter Braak, C. J. F. (2014***).*** Laser range finder model for autonomous navigation of a robot in a maize field using aparticle filter. *Computers and Electronics in Agriculture*, 100,41-50. DOI: 10.1016/j.compag.2013.10.005

Khort, D., Kutyrev, A., Filippov, R. & Semichev, S. (2021). Development control system robotic platform for horticulture. In *E3S Web of Conferences, 1st International Scientific and Practical Conference ITEEA 2021.* 262, 01024. DOI: 10.1051/e3sconf/202126201024

Khort, D., Kutyrev, A., Kiktev, N., Hutsol, T., Glowacki, S., Kuboń, M., Nurek, T., Rud, A. & Gródek-Szostak, Z. (2022). Automated mobile hot mist generator: a quest for effectiveness in fruit horticulture. *Sensors, 22*, 8901. DOI: 10.3390/s22228901.

Khort, D., Kutyrev, A., Smirnov, I. & Pupin, D. (2021). Development automated capture device for picking apples. E3S Web of Conferences, 285, 07025. DOI: 10.1051/e3sconf/202128507025.

Khort, D., Kutyrev, A., Smirnov, I., Osypenko, V. & Kiktev, N. (2020). Computer vision system for recognizing the coordinates location and ripeness of strawberries. *Communications in Computer and Information Science,* 1158, 334-343. DOI: 10.1007/978-3-030-61656-4_22.

Khort, D.O., Kutyrev, A.I. & Smirnov, I.G. (2022). Research into the Parameters of a Robotic Platform for Harvesting Apples. In: *Hu, Z., Petoukhov, S., Yanovsky, F., He, M. (eds) Advances in Computer Science for Engineering and Manufacturing*, *ISEM 2021.* Lecture Notes in Networks and Systems, vol 463. Springer, Cham. DOI: 10.1007/978-3-031-03877-8_13.

Khort; D., Kutyrev, A., Filippov, R., Kiktev, N. & Komarchuk, D. (2019). Robotized Platform for Picking of Strawberry Berries. In *2019 IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T),* 8-11 Oct. 2019, Kyiv, Ukraine. DOI: 10.1109/PICST47496.2019.9061448.

Kiktev, N., Didyk, A. & Antonevych, M. (2020). Simulation of Multi-Agent Architectures for Fruit and Berry Picking Robot in Active-HDL. In *2020 IEEE International Conference on Problems of Infocommunications. Science and Technology (PIC S&T)*, Kharkiv, Ukraine, 2020, 635-640. DOI: 10.1109/PICST51311.2020.9467936.

Kormen, T., Leyzerson, Ch., Rivest, R. & Stein, K. (2011). Algorithms: construction and analysis [Algoritmy: postroenie i analiz]. *Moscow, Williams Publishing House*, 1296.

Kutyrev, A., Kiktev, N., Jewiarz, M., Khort, D., Smirnov, I., Zubina, V., Hutsol, T., Tomasik & M.; Biliuk, M. Robotic Platform for Horticulture: Assessment Methodology and Increasing the Level of Autonomy (2022). *Sensors, 22*, 8901. DOI: 10.3390/s2222890

Kutyrev, A., Kiktev, N., Kalivoshko, O. & Rakhmedov, R. (2023). Recognition and Classification Apple Fruits Based on a Convolutional Neural Network Model. In *Selected Papers of the IX International Scientific Conference "Information Technology and Implementation" (IT&I-2022). Conference Proceedings. Kyiv, Ukraine,* November 30 - December 02, 2022. *CEUR Workshop Proceedings*, 3347, 90–101. https://ceur-ws.org/Vol-3347/Paper_8.pdf.

Lakkad, S. (2004). Modeling and simulation of steering systems for autonomous vehicles. *Master thesis. The Florida State University, US.* https://www.academia.edu/37918621/Modeling_and_Simulation_of_Steering_Systems_for_Autonomous_Vehicles.

Lee, E.A. & Seshia, S.A. (2017). Introduction to Embedded Systems - A Cyber-Physical Systems Approach. 2nd ed. *Cambridge, Massachusetts: MIT Press.* https://ptolemy.berkeley.edu/books/leeseshia/

Linz, A., Ruckelshausen, A., Wunder, E. & Hertzberg, J. (2014). Autonomous service robots for orchards and vineyards: 3d simulation environment of multi sensorbased and applications. In *12th International Conference on Precision Agriculture,* At: Sacramento, CA, USA https://www.hs-osnabrueck.de/fileadmin/HSOS/Homepages/COALA/Veroeffentlichungen/2014-ICPA_2014_Autonomous_Service_Robots_for_Orchards_and_Vineyards_3D_Simulation_Environment_of_Multi_Sensor_Based_Navigation_and_Applications.pdf

Lipiński, A. J., Markowski, P., Lipiński, S., & Pyra, P. (2016). Precision of tractor operations with soil cultivation implements using manual and automatic steering modes. *Biosystems Engineering*, 145:22-28. DOI: 10.1016/j.biosystemseng.2016.02.008

Luan, P.G. & Thinh, N. T. (2020). Real-Time Hybrid Navigation System-Based Path Planning and Obstacle Avoidance for Mobile Robots. *Applied Sciences,* 10, 3355.

Lysenko, V.P., Bolbot, I.M., Lendiel, T.I., Amirgaliyev, Y., Nurseitova, K. et al. (2021). Mobile robot with optical sensors for remote assessment of plant conditions and atmospheric parameters in an industrial greenhouse. *Proceedings of SPIE - The International Society for Optical Engineering, 2021.* doi: 10.1117/12.2613975

New Automated Agricultural Platform–Kongskilde Vibro Crop Robotti. Available from: http://conpleks.com/robotech/new-automated [Accessed: March 2023]

Nof, S. Y. (2009). *Springer handbook of automation* (pp. 1379-1396). S. Y. Nof (Ed.). Berlin, Heidelberg: Springer Berlin Heidelberg.

Ochoa, S.F., Fortino, G. & Di Fatta, G. (2017). Cyber-physical systems, internet of things and big data. *Future Generation Computer Systems*, 75, 82-84. DOI: 10.1016/j.future.2017.05.040.

Okamoto, H. & Lee, W.S. (2009). Green citrus detection using hyperspectral imaging. *Comput. Electron. Agric*., 66(2), 201–208. DOI: 10.1016/j.compag.2009.02.004.

Pasichnyk, N., Komarchuk, D., Lysenko, V., Opryshko, O., Miroshnyk, V., Shvorov, S., ... & Lendiel, T. (2020, October). Substantiation of the Choice of the Optimal UAV Flight Altitude for Monitoring Technological Stresses for Crops of Winter Rape. *In 2020 IEEE 6th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC)* (pp. 141-145). IEEE..

PROJECT ACTIVATE, (2022) Online: https://ammoniaengine.org/ [Accessed on 15 March 2022]

Sgorbissa, A. & Zaccaria, R. (2012). Planning and obstacle avoidance in mobile robotics. *Robotics and Autonomous Systems,* 60, 628-638. DOI: 10.1016/j.robot.2011.12.009.

Sharma, K. R., Honc, D., & Dušek, F. (2014, September). Sensor fusion for prediction of orientation and position from obstacle using multiple IR sensors an approach based on Kalman filter. In 2014 *International Conference on Applied Electronics* (pp. 263-266). IEEE.

Silwal, A. Davidson, J., Karkee, M., Mo, C., Zhang, Q. & Lewis, K. (2016). Effort towards robotic apple harvesting in Washington State. In *Proceedings of the 2016 American Society of Agricultural and Biological Engineers Annual International Meeting,* Orlando, FL, USA, 17–20 July 2016. DOI: 10.13031/aim.20162460869

Skvortsov, E.A. *Improving the Efficiency of Robotization of Agriculture* [Povyshenie Jeffektivnosti Robotizacii Sel'skogo Hozjajstva]. Ph.D. Thesis, Federal State Budgetary Educational Institution of Higher Education "Ural State Agrarian University", Yekaterinburg, Russia, 2017; p. 182. (In Russian).

Smirnov, I., Kutyrev, A. & Kiktev, N. (2021). Neural network for identifying apple fruits on the crown of a tree. In *E3S Web of Conferences. International scientific forum on computer and energy Sciences, WFCES 2021,* 01021. DOI: 10.1051/e3sconf/202127001021.

Stentz, A., Dima, C., Wellington, C., Herman, H. & Stager, D. (2002). A system for semi-autonomous tractor operations. *Autonomous Robots,* 13(1), 87-104. DOI: 10.1023/A:1015634322857.

Vaeljaots, E., Lehiste, H., Kiik, M. & Leemet, T. (2018). Soil sampling automation case-study using unmanned ground vehicle. *Eng. Rural Dev.*, 17, 982–987. DOI: 10.22616/ERDev2018.17.N503.

Van Henten, E. J., Van Tuijl, B.A.J, Hoogakker, G.J., Van Der Weerd, M. J., Hemming, J., Kornet, J. G. & Bontsema, J. (2006). An autonomous robot for de-leafing cucumber plants grown in a high-wire cultivation system. *Biosyst. Eng.,* 94 (3), 317–323. DOI: 10.1016/j.biosystemseng. 2006.03.005.

We put machines to work (2019). Available from: http://www.precisionmakers.com/greenbot/ [Accessed: March 2023] .

Weltzien, C., Harms, H.-H. & Diekhans, N. (2006). Automotive Radar Sensor for Object. *Agricultural Engineering, 61*(5), 250–251. DOI: 10.15150/lt.2006.1114.

Westling, F., Underwood, J. & Örn, S. (2018). Light interception modelling using unstructured LiDAR data in avocado orchards. *Computers and Electronics in Agriculture,* 153, 177-187. DOI: 10.1016/j.compag.2018.08.020

Zong, C. G., Ji, Z. J., Yu, Y. & Shi, H. (2020). Research on obstacle avoidance method for mobile robot based on multisensor information fusion. *Sensors and Materials, 32(4),* 1159-1170. DOI: 10.18494/SAM.2020.2540.

Zautomatyzowane technologie w ogrodnictwie: Analiza i możliwości wdrożenia

Streszczenie. Niniejszy artykuł zawiera przegląd analityczny i perspektywę dla technologii robotycznych w ogrodnictwie. Przedstawiono kierunki rozwoju produkcji, wdrożenia oraz sprzedaży robotów w różnych regionach świata. Analiza pokazuje przepaść między wprowadzeniem robotów rolniczych w porównaniu do innych gałęzi gospodarki oraz dużą różnicę między krajami regionu Azji a innymi kontynentami. Wzięto pod uwagę przegląd trzech głównych części naziemnych robotów rolniczych: systemy nawigacji, czujniki oraz projekty platform. Przedstawiono przykłady konstrukcji trajektorii drzewa za pomocą algorytmu A* oraz narzędzi wizualizacyjnych Rviz oraz sieciową usługę graficzną Github PathFindings. W wyniki przeprowadzonego badania zarekomendowano stosowanie czujników Lidar, co pozwoli na zaprojektowanie trasy dla platform robotycznych, stworzenie mapy przez skanowanie znanej wcześniej otaczającej przestrzeni i aktualizację takiej mapy na każdym etapie algorytmu w czasie rzeczywistym. Zastosowanie istniejących nowoczesnych czujników z optycznym dalmierzem o rozdzielczości 4,5 miliony pikseli, częstotliwości wyświetlania klatek 25 klatek na sekundę i możliwości automatycznej adaptacji do poziomu światła w połączeniu z kamerami stereo, a nawigacja GPS/ GLONASS ulepszy dokładność pozycjonowania automatycznych platform i zapewni działanie autonomiczne. Aby wykonać podstawowe operacje technologiczne na nasadzeniach o rozmieszczeniu 2,5-4 m, o wysokości korony drzewa do 3-3,5 m za pomocą intensywnych technologii, następujące parametry projektu platformy automatycznej są konieczne: agro-operacja co najmniej 1200 mm, szerokość jazdy 1840-2080 mm, waga nie przekraczająca 400 kg, obciążenie nie większe niż 1000 kg, moc silnika nie mniejsza niż 5 kW.

Słowa kluczowe: robot, czujnik, nawigacja, ogrodnictwo, platforma