Robotic Platform for Horticulture

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The modern level of development of infocommunication and computer technologies, microprocessor technology and equipment, communication and positioning makes possible the development and practical application of automated and robotic technologies and technical means to improve the efficiency of agricultural production. Currently, intensive horticulture is becoming increasingly widespread due to rapid fruiting and high yield rates. At the same time, the process of harvesting apples in intensive horticulture is the most time-consuming, and harvesting is carried out mainly by a team of pickers. In the production process of cultivating fruit crops, this is an important final stage which requires the development of automated devices and robotic platforms with a control system capable of offline harvesting.

Keywords: robotization of agriculture ; evaluation factors ; experts ; robot autonomy

1. Introduction

With the undoubted advantages of the known approaches to robotization of harvesting operations in gardens, the relationship between the indicator (degree) of autonomy of robots and the number of functions they implement, for example, performing various agricultural work on one robotic platform, has not been sufficiently studied. The creation of appropriate calculation methods will reveal the potential of expanding the functionality of mobile robots by increasing the degree of their autonomy.

At the same time, the issues of increasing the technical efficiency of solutions aimed at achieving a high level of robot autonomy require development. This can be achieved by applying intelligent approaches to the complex processing of data coming from a complex of information devices.

The autonomy of a robotic platform is the ability to perform a technological operation in time, in space, in conditions of changing tasks, under changing environmental conditions without the need to interact with other subjects or subjects of the highest level of the hierarchy (**Figure 1**).

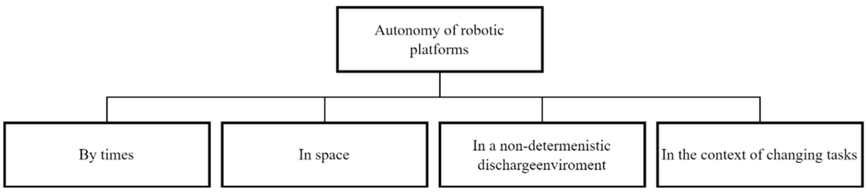

Figure 1. Classification of Autonomous robots.

The expansion of the functionality of the robotic platform by increasing the level of its autonomy using integrated onboard data processing is an urgent scientific task, the solution of which will allow the technological operation of autonomous harvesting of apple fruit to be carried out qualitatively.

2. Mechanization of Agriculture and Problem Statement

Mechanization of agriculture has significantly increased labor productivity. However, in many branches of agriculture, especially in horticulture, manual labor still accounts for up to 50% of costs [1][2][3]. In this regard, the development of robotic solutions for use in agriculture is actively developing. There are examples of commercial use of automated wheeled tractor equipment in the preparation and conduct of sowing operations, weed control and pest control, yield forecasting and harvesting of grain crops. The use of robots to automate gardening is still an actively developing area. Despite the fact that such robotic machines began to be created in the late 1960s, robots in gardening have not yet been brought to commercial use, although many prototypes have been developed [4][5]. In particular, there are prototypes of wheeled platforms for collecting fruits using manipulators. When moving in rows of horticulture plantings, the route is usually planned in advance by navigating through the aisles, and not by individual trees [6][7][8][9][10][11]. The platform presented by Australian researchers N. Shalal, T. Low, C. McCarthy and N. Hancock in [6], moved along a pre-designed map of the horticulture with correction based on laser scanning, and was able to move along the aisle and avoid obstacles. The platform presented by Northwest Nazarene University (USA) scientists A. Villemazet, A. Durand-Petiteville and V. Cadenat in article [7] implemented unmanned movement in horticulture using computer vision and ultrasonic sensors. Field tests in a peach horticulture with a length of 27 m and a width of 6.4 m showed that the RMS positioning error (RMSE) was 3.5 cm. A similar platform was presented by Chinese researchers Yan Song, Feiyang Xu, Qi Yao et al. in article [8]. Using 2D lidar processing using a particle filter (PF) and a Kalman filter (KF), field tests showed a positioning error of 5.5 cm for PF and 8.8 cm for KF. However, these platforms [7][8] cannot make turns between aisles in automatic unmanned mode. In article [9] by New Zealand researchers M.H. Jones, J. Bell, D. Dredge et al., a platform for moving containers through horticulture was presented. This GPS-based platform with four wheels and an independent control demonstrated 6.0 cm RMSE positioning during field tests. In the work of researchers Bayar G., Bergerman M., et al. [10], a robotic platform moved along the aisle using positioning based on laser scanning. As a result, the platform was able to move along the aisle, as well as from row to row. An interesting approach to planning the movement of a robotic platform in gardens based on the adaptation of the B-patterns approach, was presented by authors Bochtis D., Griepentrog H.W., Vougioukas S. et al. in [11]. In this case, the one with the greatest useful path was chosen as the optimal route.

The theory of automatic control of wheeled platforms began to appear from the moment of miniaturization of computing tools able to be installed on the platforms. One of the fundamental works in this field was the equations of motion proposed in 1981 in the work of the American researcher Mac-Adam, C.C. [12]. In the research of scientists Nenajdenko, A.S., Poddubnyj, V.I., Valekzhanin, A.I. a multifactorial model of differential equations of motion of wheeled vehicles along a complex curved trajectory was considered, which made its configuration and application for work in the horticulture quite time-consuming and requiring qualified specialists [13].

Researchers D. Khort, A. Kutyrev, N. Kiktev et al. [14][15][16][17][18], carried out the development and implementation of robotic platforms for agricultural production in the horticulture. In particular, the features of the developed robotic platform for harvesting strawberries [15], apples [16], processing plants with a solution in the form of hot mist [14] were described. The control system was based on an Arduino microcontroller and control software written in Python. The article [18] provided a theoretical calculation of the main design and technological parameters, describes electronic components and assemblies. Robotic platforms are versatile, simple in design, easily adapt to various working bodies and actuators, which is important for their use in various technological operations in the garden. Modeling of multi-agent robotic systems for horticulture robots based on pre-compiled scenarios was described in article [17]. The task of evaluating the robotic platform and increasing its level of autonomy remains unresolved.

In article [19], researchers I.V. Ershova, O.O. Podolyak and A.V. Danilov described a methodology for evaluating the effectiveness of the introduction of robotic complexes (RTK) in the conditions of their growing use in the long term. The study sample consisted of 10 enterprises that implemented FANUC robotic equipment and have been successfully operating for more than a year. Based on an expert survey of enterprise specialists, a ranked list of efficiency factors was obtained: increased productivity, improved quality, reduced labor costs, elimination of hazardous operations, and production flexibility. A correlation–regression model of the dependence of annual savings on selected factors was constructed. After checking the factors for interdependence, four factors remained in the model: increased productivity (labor costs); reduction of defects (quality improvement); harmfulness of work; and the category of work before implementation. The comparison showed that according to expert estimates, the main factor is “productivity growth”, however, calculations showed that the factor “reduction of marriage” comes first. The greatest efficiency of RTK is provided in cases when there is a need to reduce the level of marriage. The authors found that on routine simple operations, marriage can be reduced by two times or more [19]. This technique can be adapted to evaluate agricultural robots, in the researchers' case—for use in horticulture.

In his dissertation, researcher E.A. Skvortsov [20] describes the methodology for substantiating the feasibility of introducing robotics and the methodology for evaluating the effectiveness of its use in agricultural organizations. The author classified agricultural robotics by branches of application: animal husbandry, crop production, auxiliary production, and robotics in crop production by types of work performed: sowing crops, treating plants with pesticides, picking fruits and vegetables, caring for vineyards and horticulture trees, etc. The author identified and systematized the main factors influencing the introduction and use of robotics in agricultural organizations: internal (financial condition of the organization, levels of moral and physical wear of equipment, availability of personnel capable of mastering and servicing robotics, etc.) and external (the price level of agricultural robotics compared to traditional technology, the level of competition among agricultural organizations, infrastructure development, etc.). This made it possible to reduce the influence of factors preventing the introduction of this technique, to increase the efficiency of its use. The principles of the introduction and use of robotics in agricultural organizations were highlighted [20]: priority, quality, complexity, environmental friendliness, economy, efficiency, and safety of use.

This scientific work is of interest, however, only economic factorsweare included in the methodology for evaluating the effectiveness of the use of robotics, while technical factors were not mentioned.

The study by the Cypriot author G. Adamides [21] presented the application of the heuristic evaluation method to test the usability of human-robot interaction systems (HRI) using the example of a semi-autonomous agricultural robot sprayer for vineyards. The following methods were used to design a robot control system: architecture and scalability of the platform, error prevention and recovery, visual design, information presentation, awareness of the robot's condition, efficiency and effectiveness of interaction, awareness of the robot about the environment, and cognitive factors. In each evaluation study, usability problems were identified and specific proposals for improving usability HRI were documented. In each iteration of the design, fewer usability issues were identified. The author conducted additional experiments that will focus on specific tasks, such as comparing different spraying methods (for example, using a robotic manipulator) and estimating the amount of chemicals saved for spraying, in addition to other gardening tasks to which robotics can be applied. This research is of interest but has a narrow focus—the interaction of a human and a robotic system.

Many authors of publications have investigated the autonomy of robots. The main component of automation in agriculture is autonomous navigation. Currently, extensive research is underway on the use of unmanned automated platforms (UGV) in horticulture. They are used for pruning, weed and disease control, and harvesting. Efficient and high-quality execution of the listed operations is possible if the following conditions are met: autonomous navigation for complex environments; fast operation without damage; and target detection for complex backgrounds. Early navigation systems in agricultural areas used a camera as a sensor and were based on computer vision methods (Santosh A. Hiremath, Gerie W.A.M. van der Heijden et al.) [22]. Navigation, guidance, and transportation included three levels of autonomy: conventional steering, operator-controlled or automatic system (under the control of GO), and a fully autonomous system. Navigation and guidance can be the main task of the system, for example, transporting the crop from the field to the packaging shop, or be an auxiliary task that allows the system to perform its main task, for example, an auxiliary task of spraying or transporting the robot from tree to tree during the harvesting process. Automatic control has been the most active area of research throughout the history of automation of agricultural machinery (Hagras, H.; Colley, M. et al.) [23]. The available systems are based on two main approaches. In the first case, the platform (ground robot) follows a predetermined path based on data from either local Positioning system (LPS) stations or global positioning system (GPS) satellites (Lipinski, A.J., Markowski et al.) [24]. This approach is technically simple, but its disadvantage is the inability to respond to unexpected changes or events in the field (Stentz, A., Dima, C. et al.) [25].

With the second approach described by the authors Astrand, B., & Baerveldt, A. J. [26], Bak, T., & Jakobsen, H. [27] the robot operates relative to the sowing line, for example, along a row of plants, or the boundary between plowed and untilled soil or between cut and standing feed, using a sensor system, usually machine vision. This approach allows the robot to adapt its work to individual plants, as they change over time, but it is usually considered that it is technically more difficult to determine the culture line than to follow a certain path [27]. The development of a robotic ground platform that can move autonomously 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 [23].

Automatic steering systems for tractors with LPS or GPS control offer farmers the opportunity to: reduce operating costs and increase productivity and profitability (Rovira-Más, F., Chatterjee, I., & Saiz-Rubio, V.) [28].

The cconomic benefits include: reduction of overlaps or omissions during fertilization and pesticides, increased timeliness of operations by providing a 24-h work schedule and management in conditions of limited visibility, improved accuracy of water and water. fertilization based on measurements and mapping of plant needs, as well as more effective implementation of accurate farming methods (Bergtold, J.S., Raper, R.L., & Schwab, E.B.) [29]. Authors from France Thuilot, B., Cariou, C. et al. [30] and Japan Nagasaka, Y., Umeda, N., et al. [31] developed an automatic guidance system based on a single RTK-GPS., to guide the tractor along pre-recorded routes.

The tractor course was obtained by American researchers from the University of North Carolina Welch, G., & Bishop, G. in accordance with the reconstruction of the Kalman state [32], and a nonlinear control law independent of speed was developed.

Although modern navigation systems for agricultural vehicles rely on GPS as the main sensor for steering, an alternative method is still required in cases such as horticulture, where the crown of trees blocks satellite signals from a GPS receiver or [33].

Currently, robotic autonomous platforms are widely used to perform various technological agricultural operations. Research and development in the field of robotic harvesting began in the 1980s, when Japan, the Netherlands and the USA were the pioneer countries.

The efficiency of performing technological operations in gardens by robotic platforms (robots) largely depends on the equipment and sensors, as well as 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. The development of autonomous driving is closely related to the ability to interpret and analyze information coming from sensors or combinations of sensors of different types (day and night vision camera, LiDAR, millimeter/ultrasonic radar, etc.). Such sensor combinations are characterized by various optimal operating ranges and allow collecting information related to different sizes of their environment (Andžans, M., Berzinš, J. et al.) [34].

Ukrainian researchers T. Lendiel, I. Bolbot et al. [35] developed a mobile robot with optical sensors for remote assessment of the state of plants and atmospheric parameters in the industrial greenhouse of PJSC “Greenhouse Plant” (“Teplychnyi”), of Kyiv region, Brovary district, village Kalinovka. The algorithm and process of moving a mobile robot in a greenhouse, where its movement is provided by color marks, were described. A non-contact method for assessing the state of plants (the formation of the number of flowers in an inflorescence, the number of fruits on a branch, the average weight and ripeness of the fruit, weight gain) was carried out using wavelet analysis. In this case, each image obtained using a video camera located on a mobile robot is decomposed into wave functions. Training was conducted to gain experience of trial and error of the robot route. It was determined that as experience was gained, the number of unsuccessful attempts and travel time decreased, and the number of incentives received increased. The researchers believe that this movement algorithm does not sufficiently ensure the autonomy of the robot, since the mathematical apparatus is based on the clustering of greenhouse sections. In addition, in the greenhouse it is possible to use the rail robot described by the authors, while in the garden a wheeled platform is needed, the movement of which the researchers plan to describe using differential equations in the X, Y coordinate system.

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