Intellectual Control System For Unmanned Energy Crop Combine

Yurii Gunchenko
Dept. of Mathematical Support of Computer Systems
Odessa I.I.Mechnikov National University
Odessa, Ukraine
gunchenko@onu.edu.ua

Sergey Shvorov
Dept. of Automation and Robotic Systems
National University of Life and Environmental Sciences of Ukraine
Kyiv, Ukraine
sosdok@i.ua

Volodymyr Lukin
Dept. of Automation and Robotic Systems
National University of Life and Environmental Sciences of Ukraine
Kyiv, Ukraine
lukin2008@ukr.net

Vitalii Mezhuyev
Faculty of Computer Systems and Software Engineering,
Universiti Malaysia Pahang
Gambang, Malaysia
vitaliy@ump.edu.my

Abstract-the purpose of the work is to develop methodical bases for the construction of an intelligent control system (ISC) for unmanned combines (UMs) of energy crops (EC) for biogas plants (BP). In order to achieve this goal, the functional structure of the ISC was substantiated in the work, the method of recognition and determination of the volume of biomass EC in fields with unmanned aerial vehicles (UAVs) was developed, the method of synthesis of compromise-optimal routes of the BP with the minimum length of their routes in the process of biomass collection was proposed. and taking into account passive (unmoving) and active (moving) obstacles. With the help of the proposed ISC, the following tasks are solved: monitoring of the EC cultivation process and the determination of EC volumes based on the use of UAVs; determination of the density of changes in the yield of EC, the coordinates of active and passive obstacles in the way of the UMs movement; distribution of UMs by fields and planning of optimal routes and speed parameters of their movement for EC collection. A prerequisite for efficient harvesting combine driving is the constant control of the technological process of harvesting energy crops. Deviations from the work plan in most cases occur due to malfunction of technical equipment or adverse weather conditions. However, there are situations in which the deviation of the "plan-fact" is influenced by other factors, which may lead to a failure of the plan, and vice versa. Failure to complete the plan may be due to a reduction in the intensity of the work or the assumption by the user of errors when entering the initial data into the system, which reduces the adequacy of the model to the real process. The increase in planned indicators may be due to an increase in the speed of technological operations, which may lead to additional losses of biomass or a decrease in its quality. To solve the tasks listed, the ISC is divided into a subsystem of monitoring, planning and operational management of energy cropping processes.

Keywords - intelligent control system, unmanned combine, energy culture, unmanned aerial vehicle, harvesting process.

I. INTRODUCTION

Today, the development and implementation of promising technologies for the industrial production of biomethane is one of the main keys to replacing natural gas. To obtain the maximum volumes of biomethane, it is necessary to use not only the waste from agricultural farms, agricultural farms of plant growing, sugar factories and poultry factories, but also specially grown energy crops for biogas plants. The development of this direction on a large industrial scale involves the development and use of intelligent control systems for the processes of collecting energy crops using unmanned combines. As practice shows, suboptimal planning of field work leads to the overlapping of routes for the equipment to collect, delays in its operation, and excessive consumption of fuel. In order to eliminate these shortcomings with the help of ISC, it is necessary to use the planning of harvesting work and the calculation of the optimal trajectories of the movement of harvest equipment, which are introduced into the navigation equipment of each harvest machine. The implementation of optimal trajectories in the process of harvesting work involves reducing fuel costs by minimizing the time delays of the harvest equipment and the number of overlapping routes of their movement, taking into account the features and geometric shape of the field.

However, methods for determining the volume and density of change in the yield of energy crops with UAVs, the planning of harvesting operations, the synthesis of compromise-optimal driving routes of promising unmanned robotic harvesting technology and the construction of intelligent energy harvesting control systems for energy crops for biogas plants have not been sufficiently studied.

II. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Analysis [1-8] shows that today global and local navigation methods for mobile robots (MR) are widely used. Global methods are based on the fact that before the start of the MR movement the map of the area is completely known. Knowing its location, finish point, location of all obstacles, MR uses the specified algorithm of actions and ensures finding the shortest path from start to finish, after which it overcomes this path. In practice, the most commonly used methods are the wave front, A *, the tree of squares, the visible graph [1-4]. The disadvantages of such methods include the need to save a map of the area (most often large) and increased computational complexity. Local navigation methods are used in cases where the MR does not know the stationary (passive) and dynamic (active) obstacles that may appear and disappear and change their location. In this case, the MR receives navigation information about the local area of the external environment, staying within the boundaries of its sensors. Such navigation methods for MR include methods based on the use of potential barrier fields [2], methods of the BUG family [5, 6], which use tactile sensors to obtain navigation information, as well as methods of the VisBUG family [6-8], which allow receiving navigation information from ultrasonic sensors. The advantages of local navigation methods include their computational simplicity. The disadvantages of these methods, compared with global navigation methods, lie in the deviation of the real trajectory of the movement of the RM from the optimal route and the more complex procedure for localizing MR in space. Both groups of MR navigation methods are characterized by the problem of timely determination of passive and, especially, active barriers to MR. In addition, the existing methods and algorithms for solving the problems of planning trajectories of movement of a ground MR are applied in two stages: first, a global trajectory is found from cartographic data, which is then periodically updated during the movement according to the data of the onboard technical vision system of the MR.

This approach is characterized by contradictions and shortcomings, due to a significant difference in the scale of the flow of information at these two stages. The use of UAV-based technical vision systems, which provides intermediate information between the stages of planning about terrain, allows one to quickly update the cartographic data, and on the other, to expand the viewing area of the airborne technical vision system MR by an order of magnitude, which increases the efficiency of solving all target tasks unmanned harvesting combines. Despite the considerable amount of research in this area, the problem of navigation with the use of UAVs to determine (clarify) the routes and different types of obstacles in the way of unmanned acquisition technology remains open.

Traditional raw materials for biogas reactors, in particular livestock and poultry wastes due to a decrease in the number of livestock, may not be enough to obtain the required amount of energy. In the EU countries, vegetable raw materials are used as additional sources for biogas production, namely, energy crops and crop waste, as shown in the works of A. Meyer et al. (2017) [9] and P. Schröder et al. (2018) [10]]. Crops of energy crops are planned taking into account, first of all, the areas of land unsuitable for crop production, for example, peat bogs (K. Laasasenaho et al., 2017) [11], as well as logistics for existing biogas reactors. Technologies developed to produce biogas from waste that accumulate at processing sites are adapted to specific raw materials (R. Ciccoli et al., 2018) [12], which limits their use for seasonal raw materials. K.Sahoo et al. (2018) [13] showed that crop residues have a certain economic potential for biogas production, however, there remains the problem of monitoring the volume of this raw material and optimizing logistics for its transportation to the reagent. The optimization of biomass transportation within the region was considered by J. Höhn et al. (2014) [14] for Finland, V. Burg et al. (2018) [15] - for Switzerland, but, first of all, places of prospective construction were evaluated stationary biogas reactors. The studies show that from year to year the location of biomass sources changes, which makes it difficult to resolve the issue of operational monitoring of the state and volume of biomass during the year to optimize logistics.

III. RESEARCH OBJECTIVES

The purpose of the research is to develop methodological foundations for constructing an intelligent control system for unmanned harvesting combines of energy crops for biogas plants.

To achieve this goal, the following tasks are:

- development of a method and algorithm for determining the volume and density of changes in yield of energy crops of biomass in the fields using unmanned aerial vehicles;
- substantiation of the method for the synthesis of compromise-optimal routes and the speed of movement of robotic harvesting equipment with a minimum length of the paths of movement of the UMs in the process of collecting biomass and taking into account the density of changes in the yield of EC, as well as passive (fixed) obstacles;
- development of a method and algorithm for the recognition of EC and active (moving) obstacles to the movement of the UMs;
- substantiation of the functional structure of the hybrid intellectual control system of the UMs by creating a knowledge base and system integration of the methods, algorithms and production rules of intellectual decision support.

Using the proposed intelligent control system, the following tasks should be solved: monitoring the process of growing energy crops, determining the volume and density of changes in the yield of EC based on the use of an unmanned aerial vehicle to recognize EC, active and passive interference in the path of unmanned harvesting combines, the distribution of PLC in the fields and planning the optimal routes for their movement to collect EC; operational management of the processes of loading and delivery of raw materials in biogas plants.

To solve the above problems, the ISC should include subsystems for monitoring, planning, and operational management of energy raw materials collection processes. In addition, one of the most important tasks that is solved with the help of ISC is the placement of crops of various energy crops, monitoring of their condition and their differentiated feeding on a specially defined area, taking into account geophysical features for each crop.

The experience of using biogas plants and plants in European countries, especially Germany, suggests that a substantial increase in biogas production requires the use of popcorn hybrids. The proportion of maize silage mixed with other co-substrates can range from 2 to 99%. Analysis of existing biogas technologies shows that in Germany already in 2012, about 1 million hectares of land was used for the production of energy crops (mainly corn). In this case, there is a need for further study of methods and technologies for collecting EC.

IV. PRECISE AGRICULTURE

Currently, more and more attention is paid to "precise agriculture", which ensures maximum productivity of agricultural work. The most promising is the use of unmanned aerial vehicles for planning and controlling the movement of unmanned harvesting equipment, depending on the availability of crops and obstacles in each section of the field.

The process of planning the content and time of the work is divided into several stages, namely: sowing of early winter crops and their collection, sowing of the following EC and their harvesting. Each of these planning stages has its own characteristics, and for their implementation it is advisable to provide a data and knowledge base in the ISC.

The EC monitoring subsystem is a geographic information system that receives data on the quantity and quality of raw materials from information sensors located on UAVs, as well as from other information sources. Based on these data, a lot of feasible solutions are formed to improve the state of energy crops, as well as organize the collection and further use of organic raw materials in biogas plants..

As the results of experimental studies show, conventional digital UAV cameras can be effectively used to determine crop volumes and identify various obstacles to the movement of the UMs in each section of the field. After taking photographs on an electronic map of the field, based on the statistical processing of the RGB signals, several contrasting zones (sections) are determined by the optical characteristics. For each of these zones, the control crop volumes, which are used to train the neural network, are experimentally calculated. Using special software for processing the spectral characteristics of digital images of each area using the apparatus of neural networks, the volumes and density of crop changes along the path of unmanned combine harvesters are determined, which ensures prompt decision-making for their distribution, route planning and control of the speed of the UMs.

The basis of the subsystem is special methods and pattern recognition algorithms that help to solve the following problems: image perception (technical measurement), preliminary processing of the received signal (filtering), highlighting the necessary characteristics and image classification (decision making). For this, the synthesized neural network structure is checked and the corresponding multilayer perceptron is checked for adequacy. Processing of graphic data based on the results of photography with UAVs is carried out using information technology based on the use of special software produced by the NUBiP LDE - Land damage expert. The program has the ability, on the basis of statistical processing of RGB signals, to determine the coordinates of obstacles for the UMs on an electronic map of the area and the volume of EC.

V. FIELD PLANNING

As practice shows, suboptimal planning of field work leads to the imposition of traffic routes for harvesting equipment, delays in its operation and, as a result, excessive fuel costs. In order to eliminate these shortcomings with the help of ISC, planning of harvesting operations and calculation of optimal trajectories of movement of harvesting equipment, which are introduced into the navigation equipment of each assembly tool, should be provided. Based on the information on biomass from UAVs, it is possible to plan movement routes and to distribute UMs in technological areas using dynamic and linear programming methods. In addition, with the help of ISC, a decision is justified on the advisability of attracting the required number of robotic harvesters and unmanned vehicles to the collection of EC.

When developing a method and algorithm for planning harvesting equipment, it is assumed that the planning process for harvesting is a controlled multi-stage dynamic process, which at each stage is characterized by two types of parameters: control parameters (number of unmanned combines planned) and state parameters (volume of biomass collected at each stage) . In the form of restrictions, the total resource of the time of harvesting and fuel consumption allocated for the harvesting campaign appears. The ultimate goal of harvesting planning in each field is the maximum amount of harvested EC.

In the planning subsystem, depending on the availability of robotic technical means and the forecasted conditions of the harvesting campaign, a lot of options for the execution of the UMs work are generated. Among the existing many options, one is determined that ensures maximum profit from the sale of biomethane. With the help of GIS, the electronic map of the area is formed and crop volumes are determined at each site, as well as compromise-optimal routes of harvesting equipment movement in fields with obstacles and complex geometric shapes are determined. The application of the proposed technology implies a higher responsiveness and accuracy of the UMs control, as well as a reduction in the cost of the cleaning campaign.

Thus, a method for planning the harvesting of the UMs has been developed, with which, based on the use of the dynamic programming procedure, the optimal distribution of unmanned combines between the fields is carried out with time restrictions, provides informed decision-making on the use of the UMs.

The formulation of the problem of the synthesis of compromise-optimal driving routes of unmanned combines consists of the following: the known information is the coordinates of the area on which the biomass is located, the initial location of each UMs, and the endpoint of its route, the coordinates of passive interference and the coordinates of sections without biomass obtained using the subsystem monitoring the state and determining the volume of energy crops with UAVs. It is necessary to find such compromise optimal routes of movement of the UMs, in which the minimum path of movement of the UMs, a detour of obstacles, a detour of sections without biomass is provided.

VI. ROUTE SYNTHESIS METHOD

The method of synthesis of compromise-optimal driving routes of unmanned combines includes the following operations: the starting task is reduced to discrete form; to quantify the danger of approaching unmanned combines to interference, the method of potential functions is used [2]; the length of the path is determined by the length of the possible transitions from the initial to the final point of the field, taking into account the unmanned combine detour of obstacles and areas where there are no energy crops; The task of synthesizing the optimal trajectory of unmanned combine harvesters under given conditions is solved by the method of dynamic programming with a general optimality criterion using a nonlinear compromise scheme [16]. In order to determine the optimal path to each feasible point according to the coordinates of each level at each step, the functional Bellman equation is solved. The structure of the generalized criterion is constructed in accordance with the methodology of the non-linear compromise scheme, taking into account the risk of unmanned combines approaching interference, the length of the movement route of unmanned combines, and the likelihood of unmanned combines taking measures in the absence of energy crops.

The implementation of optimal trajectories during the harvesting process involves reducing fuel consumption by minimizing the time delays of harvesting equipment and the number of overlapping routes of their movement, taking into account the features and geometric shape of the field.

An analysis of previous studies showed that currently there are unresolved issues of constructing decision support systems for managing harvesting equipment in real time, taking into account the conditions of a dynamic and partially defined external environment. In order to eliminate deviations between the planned and actual performance indicators of technological units, it becomes necessary to solve the problem of operational management and redevelopment of work. The procedure for solving this problem consists of these very points, and the procedure for solving the planning problem differs only in the initial data.

The subsystem of operational management of the EC collection processes is built on the basis of a hybrid intelligent decision support system (DSS), the main components of which include a knowledge base, a simulation unit of the UMs, monitoring, planning, control and management subsystems, a training module, and an interface. When developing the knowledge base and ISC, a systematic integration of models and algorithms and production rules was carried out, based on classical methods of modeling and optimization of systems and methods of artificial intelligence, provides an effective solution to the problems of planning, control and operational management of the processes of collection and processing of various types of organic raw materials.

A prerequisite for effective management of the harvesting campaign is the constant monitoring of the process of collecting EC. Deviation from the work plan in most cases arises as a result of a malfunction of technical equipment or in adverse weather conditions. But there are situations when other factors influence the deviation of the “plan-fact”, as a result of which it is possible to underperform the plan, and vice versa. Underfulfillment of the plan may be the result of a decrease in the intensity of work or the assumption by the user of errors when entering the initial data into the system that reduces the model's adequacy to the real process. The increase in planned indicators may be due to an increase in the speed of technological operations, which can lead to additional losses of biomass or a decrease in its quality. Also, at the stage of introducing an intelligent system into the harvesting process, it becomes necessary to train the system in order to obtain more adequate solutions.

The practical use of ISC in the Terezino additional liability company allowed to reduce the length of the harvesting equipment movement routes and the total costs of the harvesting campaign by 12-15% by quickly determining the amount of energy crops, planning harvesting work and implementing compromise-optimal harvesting equipment movement routes . Proceeding from this, the profit of the enterprise when applying ISC increased by more than 12%. In addition, as the results of the practical application of ISC show, the time spent on making informed decisions is significantly reduced due to the processing of large volumes of information by the system.

VII. CONCLUSION

Thus, based on the analysis of EC collection processes, methodological foundations have been developed for constructing an intelligent control system for unmanned combine harvesters of energy crops for biogas plants, a reasonably functional structure of the ISC for the collection of EC for the conditions of industrial production of biomethane.

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