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Theoretical issues construction and operation of agricultural mission robotic system

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Abstract: *Theoretical issues construction and operation of agricultural mission robotic system.* Theoretical issues and approach to the construction and operation of robotic systems for agricultural purposes were presented. To solve scientific problem of optimal design and use of intelligent mobile robots detailed considerations were undertaken on the base some equations.

Key words: robotic systems, mobile robots, structural and parametric synthesis, manipulation of equipment, intelligent control system.

INTRODUCTION

One of the perspective and necessary areas of modern robotics is a land mobile robots (MR), designed for a wide range of activities related to finding, harvesting, loading, transportation and processing of agricultural raw materials. The composition of these robots is manipulation system for manufacturing operations from raw materials, transportation system designed to deliver the manipulation of equipment to the venue of process operations and control system MR, which manages its executive nodes [Wild 1981; Smironov and Tyagunov 1998; Batanov et al. 1999].

Delivery of work equipment to the place of manufacturing operations conducted under conditions of uncertainty, when previously unknown routes MR and location of obstacle objects, with which it can interact during movement. In this regard, a crucial role in pressing MR start playing its terrain parameters (movement and maneuvers on surfaces with different coatings, poverty rises, the threshold noise, etc.) provided by its system of movements [Borzenkov 2002; Masłov 2005; Masłov et al. 2005].

Different aspects of development and use MR special purpose involved in a number of national scientific and industrial organizations and foreign companies operating in the field of mobile robotics firm such as REMOTEC, Foster-Miller, Cybermotion (USA), Alvis Logistics, Lockheed Martin (UK), Cybernetix, Giat Industries (France), Telerob (Germany) and others.

Despite of significant advances in development theory and practice of building special-purpose robots, some of the challenges relating with the creation and organization of operation MR extra-light class, settled in full. The analysis shows that the actual robotics is in a special issue of development and research of wheeled transportation MR extra-light class.

The aim of research is the further develop the theoretical foundations of mobile robotic systems (MRS) – engineering discipline within which developed a set of methods of analysis and synthesis of MRS, it is necessary to justify the rational variants of MRS and MR of agricultural functioning.

The research materials and methods. During the research we reviewed the theoretical question of approach, construction and operation of robotic systems, studied scientific problem of optimal design and use of intelligent mobile robots.

The results of research. To achieve aim of research it is necessary to solve the following scientific objectives:

1. Development of methods and models of analysis of the operation of discrete-controlled MRS.

2. Development of methodology of structural and parametric synthesis of MRS and organization their optimal functioning.

3. Development methodological bases of study requirements for the MRS based on the proposed methodology for their synthesis.

4. Development technical principles of construction and mathematical principles operation of the MRS and its main elements, provided that the proposed requirements to them.

In solving the first research problem is defined: the purpose of operation of MRS and solved its problem, MRS operating conditions in the course of agricultural operations.

In general, the degree of efficiency of the MRS is the value (G), which characterizes the degree of MRS process operations according to their importance:

$$G = \frac{\sum_{i=1}^{n} v_i N_{p_i}}{\sum_{i=1}^{n} v_i N_{oi}} \qquad (1)$$

where:

N_{0i} – the required number of technological operations “i” type, which should be enforced through services remain to be MRS;

N_{pi} – number of technological operations “i” type, which performed by MRS;

n – number of types of process operations;

v_i – the importance of technological operations “i” type.

In general, the problem statement MRS construction is as follows: to find the set of options (X) a variant of MRS (x) at which the maximum number of process operations with minimal financial (C) and time (T) costs.

A formal statement of research problems can be represented as a decision three criteria tasks:

$$G \to \max_{x \in X} C \to \min_{x \in X}. T \to \min_{x \in X}. \qquad (2)$$

As seen from (2) all criteria are controversial and find the best variant of MRS, which satisfies all the above conditions is extremely difficult. Without the development of theoretical and conceptual foundations of such systems that include a methods of optimizing the structure and parameters of the MRS, address smoked cigarettes dampened the problem impossible.

For problems of the first group – MRS analysis – characterized by the following two stages of research. In the first stage to build a conceptual model of MRS, and the second stage, based on accepted conceptual model is based mathematical model of dynamic discrete-controlled process in which: Saints-fledged control is MR; controlled parameters – indicators of the quality of MR; managers impacts – operational tasks to perform agricultural work. Also developed system of indicators and methods of evaluation of functioning MR. The result of analysis conducted within the framework of the theory of building MRS, are models of their operation processes and patterns that are inherent in these processes and systems in general. This – the value of cognitive analysis. Applied value due to its use results for setting the problem of synthesis.

In the second group of problems of theory construction MRS is a major problem of the optimal synthesis, which aims to choose the way of the system that best suited to perform the specified functions. Methods of solving parametric synthesis problem includes next main steps. First – determined performance of each of the variants of MRS on the set of conditions of the system to select the best of them. In the second step methods to solve the problem of classification of situations on the basis of satisfaction accepted limits. Under the situation in the multidimensional space of the factor means variant solution and option terms of its implementation. For each point the situation is the calculation of performance indicators and compare the value of valid. To narrow the set of solutions in the third stage, the principle of Pareto optimization, which provides a valid set of Pareto-efficient solutions [Voronin et al. 1997]. Further narrowing the set of solutions associated with the conceptual choice of the variants of MRS with the entire set, providing a high enough (required) level of the target parameters and economic efficiency. The optimum solution to determine the range of valid values for MRS to implement these goals.

Methodological basis of the substantiation requirements of MRS based on methodology of synthesis and include the address of the third group of problems: modeling the dynamics of motion in MR obstacles and received by the target performance and economic efficiency – formulated requirements for a MRS. This justified the requirements for subsystems objective control, planning and management MR, hardware and software subsystems of MRS.

The fourth group of problems involves the development of technical principles of MRS. These are technical solutions which will provide the implementation of reasonable requirements for them. From a conceptual point of view of MRS is the integrated intelligent system, which first examines operational tasks, and then use special methods and models provides: optimal planning of MR to perform operational tasks, identifying optimal routes for the MR; forecasting performance of the set operational objectives and management MR.

Determination of optimal routes for the MR is to solve the problem of synthesis of compromise-optimal trajectories of a mobile robot with recognition of obstacles in a conflict environment.

Conflict environment is a set of different objects (movable and immovable), located in the area of search approach to mobile robot which is undesirable. Items that are conflicting environment, will be called conflicting. Thus, for the proper solution of the problem of synthesis of compromise-optimal routes for robots moving in conflict environments, it is necessary to design procedure of tracks allowed to take into account views of obstacles and on the basis of its properties, to quantify the impact of conflict on the environmental movement trajectory of mobile robot.

Recognition of obstacles includes several steps:

- perception of the image (technical measure);
- previous processing of the received signal (filtering);
- selection of appropriate (indexation);
- classification of obstacles and action.

After determining the type of obstacles solve the problem of synthesis of compromise-optimal trajectories of mobile objects in a conflict environment. To solve this problem the method of multicriterion dynamic programming, whose essence is as follows [Voronin 1992; Voronin et al. 1997; The approach... 2008].

Starting task is reduced to a discrete species. This region of state space covered by “n” network $N^{(1)} \times N^{(2)} \times \ldots \times N$, in this case considered that depicting the point can move only one node of the network to another.

Network nodes are located in prohibited areas will be called prohibited points. Desired trajectory can’t pass through these points under any circumstances.

In the network nodes located close to the conflicting objects and limits of prohibited areas (in when approaching the prohibited areas is undesirable), place (y^*, x^*) – point-to-medium potential danger. All other components of network points is permissible area in which you search and optimal trajectory.

To quantify risk approach this object to conflicting objects the method of potential functions [Voronin et al. 1997]. As the potential function of the selected function in the following form:

$$P(\rho) = K \cdot e^{-\alpha\rho} \qquad (3)$$

where :

$$\rho = \sqrt{(x - x^*)^2 + (y - y^*)^2}\ ;$$

(x^*, y^*) – coordinates of the points-carrier potential risk (passive conflicting disciplines);
(x, y) – coordinates of the MR;
α and K – positive factors that determine the gravity approximation to certain conflicting items (set heuristically).

Then for each point of the acceptable region defined by the total potential proximity to the conflicting items.
The length of the path is characterized by long transition from j – 1 level to coordinate the level of j. It is believed that this object, being in one of the valid points on the j – 1 level of network can move only in one of the valid points on the j – level.

The length of transition is determined by the formula:

$$l_{j-1,i}^{j,m} = \sqrt{(x_m - x_i)^2 + (y_j - y_{j-1})^2} \qquad (4)$$

where:
(x_i, y_{j-1}) – coordinates of the MR on the j – 1 level of network;
(x_m, y_j) – coordinates of the feasible point on j level of network.

Because the criterion that assesses risk of convergence “it’s” and “strange” objects should be minimal, the selected function $\psi = \psi(R_{\min.})$, that decreases with increasing distance between them:

$$\psi = \exp(\mu R_{\min.}) \qquad (5)$$

where:
μ – positive coefficient;
$R_{\min.}$ – distance between objects [Voronin et al. 1997; Lysenko 2011].

The problem of optimal trajectory synthesis in the given conditions is solved by dynamic programming with generalized optimality criterion for nonlinear scheme of compromises. Thus to determine the optimal path in each *m* limit point of coordinate *x j* level for each step is solved functional Bellman equation:

$$\Phi(j,m) = \min_{i\in I_{j-1}}.\left[\Delta\Phi^{j,m}_{j-1,i} + \Phi(j-1,i)\right],$$
$$j \in [1, J] \qquad (6)$$

with boundary conditions Φ(0, *s*) = 0, where:

j – number of levels in the transition coordinate *y* on the network;

I_{j-1} – number of valid points on the *j* –1 level of network;

s – number of initial points on the coordinates *x* at zero level of network;

Φ(*j*, *m*) – total loss of the generalized optimality criterion for transition from the starting point (0, *s*) to point (*j*, *m*) of network;

$\Delta\Phi^{j,m}_{j-1,i}$ – increment the generalized criterion of the transition from point (*j* – 1, *i*) to point (*j*, *m*) of network.

In the generalized criterion of quality of three individual criteria. The first quantitatively determine the degree of risk approach to the conflicting items. The second describes the length of the transition from point (*j*–1, *i*) to point (*j*, *m*) of network. The third criterion determines the degree of private risk approach to moving the “strange” object during the transition from point (*j*–1, *i*) to point (*j*, *m*) of network.

The structure of the generalized criterion is constructed in accordance with the methodology of nonlinear circuits compromises [Voronin 1992; Voronin et al. 1997; The approach... 2008] and defined by the expression:

$$\Delta\Phi^{j,m}_{j-1,i} = \frac{P_{\max}}{P_{\max} - P_{j,m}} + \frac{l_{\max}}{l_{\max} - l^{j,m}_{j-1,i}} + $$
$$+ \frac{\psi_{\max}}{\psi_{\max} - \psi^{j,m}_{j-1,i}} \qquad (7)$$

As an optimum *j* level is chosen and allowable point of this level, which corresponds to minimum total loss for a generalized optimality criterion.

The problem of synthesis of compromise-optimal trajectories of mobile objects in a conflict environment, consisting of active conflicting objects (active conflicting environment), are also invited to apply the method of multicriterion dynamic programming. The main difficulty in solving problems with conflicting active objects is a quantitative assessment of the degree of danger approaching them, which, as mentioned above, is determined by the values of the coefficients *K* and α in the expression (3). There are different approaches to solving this problem. For example, to determine the coefficients *K* and α can be used the method of expert evaluations. Under this method a group of experts in the field, for which the present calculation, determine the values of the coefficients based on personal experience and the available objective information about the active conflicting things. But this approach is quite a subjective. From our point of view to more effectively link the mathematical expression coefficients *K* and α characteristics specific to this active conflicting subjects. Thus the gravity approximation mobile object to the active conflicting items will be functionally dependent on the specific types of items used. In other words, the higher performance is this type of active conflict items, the higher the degree of danger it poses to the mobile object.

CONCLUSIONS

Using the methods, models and procedures of reviewed the theoretical foundations of mobile robotic systems allows to solve scientific and practical problems such as to provide the full range of works by the optimal design and use of intelligent mobile robots.

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Streszczenie: *Teoretyczne problemy konstrukcyjne i związane z obsługą zrobotyzowanych systemów stosowanych w rolnictwie.* W pracy przedstawiono teoretyczne zagadnienia i przykład podejścia do rozwiązywania problemów wykorzystania zrobotyzowanych systemów przeznaczonych do realizacji celów związanych z działalnością rolniczą. Na podstawie algorytmu obliczeniowego przedstawiono możliwości rozwiązywania naukowych problemów i optymalizacji w zakresie użytkowania zrobotyzowanych systemów w produkcji rolniczej.

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