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Optimization of the control algorithm for heterogeneous robotic agricultural monitoring tools

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Abstract. Nowadays, in the agricultural industry, area monitoring is carried out using drones that are not linked to other devices such as ground-based automatic harvesters or drip irrigation systems. This results in a lot of time-consuming decision-making for harvesting ripe different crops or for pesticide treatment of areas of crops that need it immediately. This problem can be solved by using a monitoring system with heterogeneous robotic means, which allows the distribution of tasks between aerial robotic means. The purpose of this work is to optimize the algorithm of the control system for a group of robotic assets using a multigeneric decision-making approach. Many methods of operator decision support, control algorithms for solving the task of agricultural monitoring, used by scientific teams in the development of heterogeneous robotic means do not solve the problem in full. The approach is based on model optimization, namely the theory of auctions within the developed system, allowing to find a robotic system providing the maximum probability of fulfillment of the set task.

1. Introduction

The issue of creating control systems for groups of robotic means is considered by the world's largest scientific teams in the field of robotics. The following major projects have been implemented: Swarm Farm (Australia), Swarmanoid project (Brussels Free University), Cognative Pilot (Russia). However, research in the field of group interaction [1, 2] has mainly focused on homogeneous interactions, single-type robots in a group.

Today in Russia such famous scientists as professor V.I. Gorodetsky, professor A.V. Timofeev, RAS corresponding member I.A. Kalyaev and professor S.G. Kapustyan and others [3-8] are engaged in problems of multiagent control. Abroad the most famous works of V. Lesser, K. Decker and P. Cohen [9, 10].

In this paper, we consider a particular issue of creating a control system for a group of robotic means, namely the issue of operator's decision support. To date, the issue of autonomous control of a group of robotic means in agriculture, is only beginning to be applied, and a fully autonomous system is not yet used anywhere. Automation of a number of stages of the operator's actions is advisable to consider in conjunction with machine learning algorithms, which will optimize a number of functions for monitoring, harvesting, pesticide treatment, etc.

2. Algorithms used in decision support

Decision-making tree. This decision support method is based on the use of a tree graph [11], a decision-making model that takes into account their potential consequences (with the calculation of the probability of this or that event), efficiency, resource-intensiveness. For business processes this tree is composed of a minimum number of questions, assuming an unambiguous answer - "yes" or "no". Consistently giving answers to all these questions, we come to the right choice. The methodological advantages of the decision tree are that they structure and systematize the problem, and the final decision is made on the basis of logical conclusions.

Naive Bayesian classifiers [12] belong to the family of simple probabilistic classifiers and originate from Bayes' theorem, which treats functions as independent for a given case (this is called a strict, or naive, assumption). In practice, it is used in the following areas of machine learning: detection of spam in emails; automatic linking of news articles to subject headings; detection of emotional coloring of text; and recognition of faces and other images.

Method of least squares. This method is basic in regression analysis, in particular with the help of linear regression to solve problems of fitting a line that passes through many points. Here is how it is done using the method of least squares [13], draw a line, measure the distance from it to each of the points (the points and the line are connected by vertical segments), transfer the resulting sum to the top. As a result, the curve in which the sum of distances will be the smallest is the desired one (this line will pass through the points with a normally distributed deviation from the true value). The linear function is commonly used in data selection for machine learning, and the method of least squares is used to minimize errors by creating an error metric.

Logistic regression [14] is a way to determine the relationship between variables, one of which is categorically dependent and the others are independent. A logistic function (accumulative logistic distribution) is used for this purpose. The practical significance of logistic regression is that it is a powerful statistical method for predicting events that involves one or more independent variables. It is in demand in the following situations: credit scoring; measuring the success of ongoing advertising campaigns; predicting profits from a particular product; and estimating the probability of an earthquake on a particular date.

Reference Vector Method (RVM). This is a whole set of algorithms necessary for solving classification and regression analysis problems. Assuming that an object in N-dimensional space belongs to one of two classes, the support vector method builds a hyperplane with dimension (N - 1), so that all objects are in one of two groups. On paper, this can be depicted as follows: there are points of two different kinds, and they can be linearly separated. In addition to separating points, this method generates a hyperplane so that it is as far as possible from the closest point of each group. RVM [15] and its modifications help to solve complex machine learning problems such as DNA splicing, determining the sex of a person from a photo, and displaying advertising banners on websites.

Ensemble method. It is based on machine learning algorithms that generate a set of classifiers and separate all objects from the incoming data based on their averaging or voting results. Initially, the ensemble method [16] was a special case of Bayesian averaging, but later it became more complex and was enriched with additional algorithms: boosting - converts weak models to strong ones by forming an ensemble of classifiers (in mathematical terms, this is an improving intersection); bagging - collects complex classifiers, while simultaneously training basic ones (improving union); correcting output coding errors. The ensemble method is a more powerful tool compared to stand-alone prediction models.

Clustering algorithms [17] consists in distributing the set of objects into categories so that each category - cluster - contains the most similar elements. Objects can be clustered using different algorithms. The most commonly used are: based on the center of gravity of the triangle; based on connectivity; dimension reduction; density (based on spatial clustering); probabilistic; machine learning, including neural networks. Clustering algorithms are used in biology (the study of gene interaction in the genome, numbering up to several thousand elements), sociology (processing the results of sociological research by Ward's method, the output gives clusters with minimal variance and approximately the same size) and information technology.

The principal component method, or PCA [18], is a statistical orthogonal transformation operation that aims to translate observations of variables that may be somehow correlated with each other into a set of principal components - values that are not linearly correlated. The practical tasks in which PCA is applied are visualization and most procedures for compressing, simplifying, and minimizing data in order to facilitate the learning process. However, the principal components method is not suitable for situations where the original data are weakly ordered (that is, all components of the method are characterized by high variance). So its applicability is determined by how well the subject area is studied and described.

Singular Decomposition. In linear algebra a singular decomposition, or SVD [19], is defined as a decomposition of a rectangular matrix consisting of complex or real numbers. Thus, a matrix M of dimension [m*n] can be decomposed such that $M = U\Sigma V$, where U and V are unitary matrices and Σ is diagonal. One particular case of singular decomposition is the principal component method. The earliest computer vision technologies were developed based on SVD and PCA and worked as follows: first, faces (or other patterns to be found) were represented as a sum of principal components, then their dimensionality was reduced, and then they were compared with images from the sample.

Independent Component Analysis (ICA). It is one of the statistical methods that reveals hidden factors that influence random variables, signals, etc. ICA [20] forms a generating model for multivariate databases. The variables in the model contain some latent variables, and there is no information about the rules for mixing them. These latent variables are independent components of the sample and are considered non-Gaussian signals. In contrast to principal component analysis, which is associated with this method, independent component analysis is more effective, especially in cases where classical approaches are powerless. It reveals the hidden causes of phenomena and has thus found wide application in fields ranging from astronomy and medicine to speech recognition, automatic testing, and financial performance analysis.

3. Results and discussion

The proposed approach presents the possibility of implementing an algorithm for group interaction of heterogeneous robotic means (RTS), as well as the ease of integrating homogeneous types of RTS interaction into a heterogeneous control system. The proposed approach is based on optimization models, namely the theory of auctions within the framework of the developed system allows to find an RTS providing the maximum probability of performing the set task, selecting robots by its following parameters: battery charge, communication coefficient, location of RTS.

To distribute tasks among the heterogeneous robots in the group, let us represent in the form (1), which allows us to evaluate how suitable the RTS is. Coefficients α, β, γ are assigned a rank after sorting depending on the place in the sorted array.

$$Kr = TG\left(\alpha i\left(\frac{X*N1}{\sum_{i=1}^{i} Xi}\right) + \beta j\left(\frac{Y*N2}{\sum_{j=1}^{j} Yj}\right) + \gamma k\left(\frac{Z*N3}{\sum_{k=1}^{k} Zk}\right)\right) \tag{1}$$

where T - RTS functional; G - type of RTS, depending on the task; α, β, γ - sorting factor of values; N1, N2, N3 - number of sorted values; X, Y, Z - internal values of RTS parameters for efficiency evaluation.

The formula (1) will make it possible to improve the available models of homogeneous interactions and create an information management system for heterogeneous robotics.

Since the main disadvantage of all optimizing approaches is the computational complexity, the simplification of computational complexity is achieved by introducing a threshold value for each parameter of task distribution in a group of robots operating according to auction theory methods ("Vickrey auction").

The Vickrey auction is an algorithm for conducting a one-round closed auction. It is truthful and operates in dominant strategies. These advantages allow to use in the future the developed system not only for task allocation, but also for resource allocation when robots work on these tasks.

To calculate the balance of computational power of RTS depending on the tasks, we calculate the total component of auction efficiency with the introduction of a threshold value:

$$H_0 = \frac{N^2}{N+1} + \frac{N*r^{N+1}}{N+1} - \frac{2N*r^{N+2}}{N+2} \quad (2)$$

where H_0 is the total component of task allocation efficiency for the system and for the robot; N is the number of robotic means; r is the threshold value, r=1/2.

According to the results of the calculations, it was found that the arithmetic mean for each parameter is optimal, regardless of the number of RTS (figure 1) in terms of filtering RTS in the allocation of tasks, as well as effective in terms of building a workable auction, allowing to find the most suitable, the robot for the task, according to the formula (2).

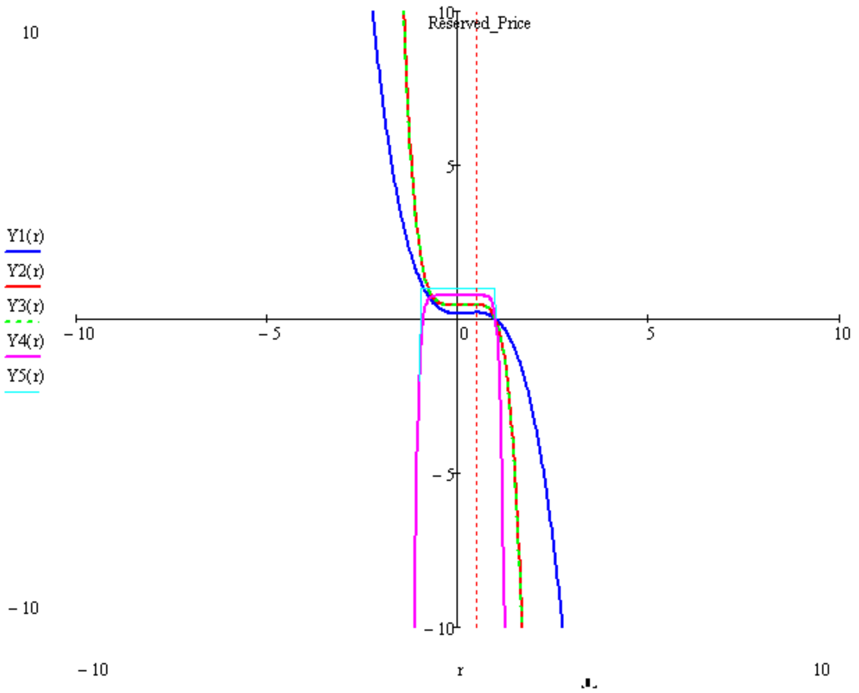

Figure 1. Graphs for different numbers of RTS, proving the correctness of the threshold. Number of RTS Y1(x)=1, Y2(x)=10, Y3(x)=25, Y4(x)=100, Y5(x)=1000.

Based on the results of the work, an algorithm was developed for the control system of a group of heterogeneous robotics (figure 3). The block diagram of this algorithm consists of the following stages: identification, formation of a task, division of a task into subtasks, division of a task between RTSs, monitoring of task execution, input of a new task, and a block for registering problems or errors.

The algorithm works as follows. At the stage "start" the system is started, and the robots are also started. In the block "system identification" is the distribution of encryption keys based on a two-factor communication, when the keys are available only to two operators. Then the block "task formation" - a task is entered through the operator. After that, the task is divided into subtasks based on artificial intelligence, namely using a decision tree algorithm. Since robotics has a limited range of actions, a general plan for the task is created from this list of actions. Based on the results of the creation of the action plan, the tasks are divided and allocated to the robotic means.

Note that at any stage of operation, the operator must be able to work with the control loop to be able to perform the following manipulations: stop the system, change the task, observe, and approve. The algorithm is designed in such a way as to inform the operator about changes in the internal parameters of the robot and take these data into account when the system works according to the planned plan, or when forming a new task.

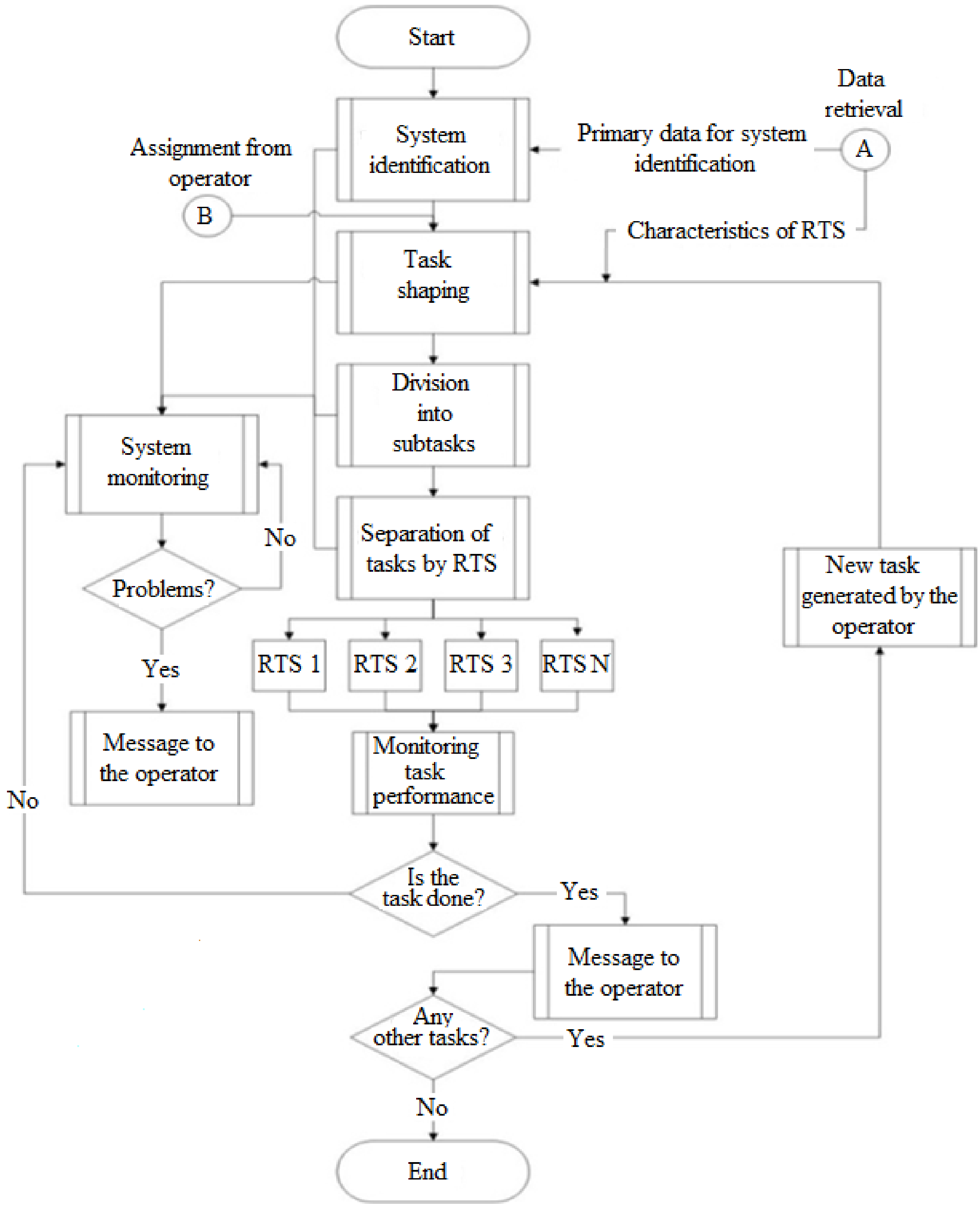

Figure 2. Block diagram of the task distribution algorithm in a group of robots.

4. Conclusion

In recent years, robotic means have been increasingly used for a wide range of tasks. Systems capable of controlling groups of robotic means, both heterogeneous and homogeneous, are of the greatest interest. Russia does not yet have experience in creating such systems. In this connection, it is important to investigate the possibilities of developing control systems for groups of heterogeneous robotic means on Open Software software, which allows to significantly increase the speed of developing such systems and reduce development costs. In this connection, in this paper:

- an analysis of models of implementation of group interactions of robotic means of foreign and domestic scientific teams was carried out;
- the creation of the system of heterogeneous RTS interactions based on the optimization model was proposed;
- applicability of auction theory ("auction of Vickrey") in creating a control system for groups of heterogeneous RTS was substantiated;
- an algorithm for distributing tasks between robots within a group, taking into account the resources available to them, was developed.

In the future, it is planned to conduct full-scale experiments to confirm the obtained results and implement the algorithm for task distribution in a group of heterogeneous RTS.

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