A TWO AIR - GROUND MULTI-AGENT ROBOTIC SYSTEM

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ABSTRACT

The concept of building a two-component air - ground of the multi-robot system. Variants of construction and use of this type of multi-agent systems in a variety of scientific and engineering research applications. The focus is on the creation of a local co-operative navigation system uses the advantages of placing the equipment on the ground and aerial robots. The variants of the organization of communication and data transmission in a two multi-agent system, the aggregation of information obtained by the sensors of various physical nature. Theoretical calculations of the accuracy of determining the coordinates of the local radio system, the results of the experiment. It is shown that the multi-agent system can solve the problem of monitoring of various objects, detection and tracking of objects of interest in the creation of 3D maps of monitoring objects, as applicable, including the study of the planets of the solar system.

The article considers a variant of the solution of the problem of organizing communication, data transmission, and navigation for multi-agent systems, which are groups of ground mobile robots and unmanned aerial vehicles (UAVs). In solving the tasks of multi-agent robots, various systems can be applied: radio navigation system, inertial navigation system using optical and other sensors. More attention is paid to the radio navigation system with cooperative processing of range measurements.

1. INTRODUCTION

The work [1] considers multi-agent systems and proposes control algorithms that do not require global information and are easily implemented. The considered system can solve quite complicated navigational tasks. The article [2] presents a multi-agent system for navigating a mobile robot. Each agent has a similar output data structure for the purpose of easy integrating the system and ensuring the independence of agents from each other.

The article [3] considers distributed intelligent control of movement of mobile robots, which are a multifunctional system of agents. The system includes agents that solve the tasks of navigation, maps updating, communication, and traffic management. The article [4] describes the architecture of the system in which agents are used in a cooperative environment. In work [5] robots' navigation is considered in tasks of detour of obstacles, avoidance of collisions between them, and control of movement in a single direction.

Article [6] considers an autonomous mobile robot as an intelligent agent that explores an unknown environment with minimal human interference. There is considered a method of simultaneous localization and map development (SLAM) of a system with monocular vision, which is in the framework of detailed implementation of the object detection and comparison function and three-dimensional reconstruction using the multiple viewing geometry within the frames within extended Kalman filter.

In work [7] considers the problem of coordination of a team of unmanned ground vehicles and pilotless vehicles (UAVs) pursuing a group of deviators while developing a map in an unknown environment. In work [8] proposes a system of odometry and mapping of a mobile robot, which uses the full photometric information from a stereovisor system. This makes it possible to integrate the results of the researches into the stabilization cycle of the PV and the structure of walking robot mapping.

The article [9] considers an autonomous system in which the robot has to perform a cyclic motion. The article [10] considers the joint solution for the navigation task using several position sensors with different accuracy on different platforms for using their absolute and relative localization. Typical scenarios of application are swarms of UAVs and a group of robots.

The article [11] considered a unified concept of a robotic system consisting of a mobile robot, which serves as a transport, and charging stations for a light unmanned aerial vehicle with four rotors. The UAV serves as a far-sight system for the mobile robot. The images generated by UAV are stitched and converted into maps, which are used to navigate the robot. In [12], an attempt was made to create a reliable method for navigating an autonomous mobile robot in real time using a millimeter-wave radar and sensors of a vision system. Such approach is a promising option for autonomous ground vehicles, UAVs or even planetary robots.

The article [13] and [14] consider the use of several location sensors with different accuracy on different platforms for sharing them in navigation tasks. For this purpose, various sensors are installed on various sensor platforms, such as satellite navigation system receivers, magnetometers, barometric pressure sensors, stepping sensors, image sensors, such as digital cameras and Flash LiDAR, etc.

2. PROPOSED SYSTEM

The purpose of this article is to study the feasibility and feasibility of interconnecting data of a different physical nature in the task of positioning robots that make up a multi-agent group. At the same time, network organization of communication and data transfer between ground and air robotic devices is considered.

The navigation system consists of two components: the aerial one that is placed on UAV and the ground one – placed on mobile robots (figure 1). Each of these two systems consists of the corresponding groups of multi-agent robotic systems that has navigation sensors of different physical nature in order to achieve high precision positioning of objects in a complex environment.

The radio navigation subsystem consists of a network of ground transmitting and receiving points (i=1÷N) made using the technology of software-defined radio systems and located at points with known coordinates. The objective of such a system is to determine the rectangular coordinates of ground and air robotic objects in the coverage zone.

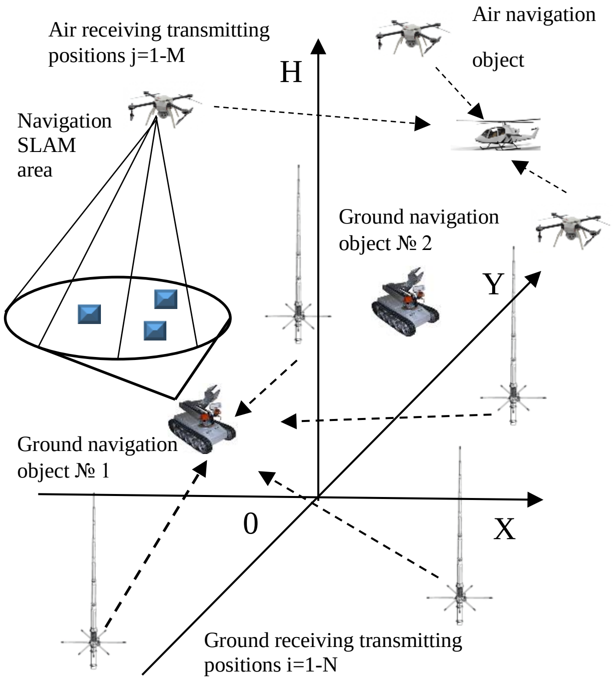


Figure 1. Multi-agent two-component navigation, communication and data transmission system

This system can be supplemented with measurements of global satellite navigation systems (SNS) and other sensing devices based on different physical principles. Another navigation component is SLAM navigation, which involves the use of lidars, video cameras, as well as the use of EKF-SLAM, FAST-SLAM, DP-SLAM technologies. The task of SLAM consists of multitude of subtasks: recursive filtering; finding landmarks in space; search for correspondences between landmarks; recounting the robot position; clarification of the landmarks positions on the map. Inertial navigation system (INS) imply the use of gyro-stabilized platform and strap down systems.

These systems can optionally be supplemented by odometer track sensors, small-distance meters based on ultrasonic meters, ultrawide-band short-range radars, triangulation infrared sensors, barometric altimeters, etc. The purpose of these sensors is to monitor short distances in order to avoid collision of robots with obstacles and with each other. Each of these sensors has a different range, accuracy, resolution, and scope.

Let us consider the solution to improve the accuracy of mobile robots and UAVs in a local radio navigation system with cooperative processing. The range of such a system is limited both by the potential of the radio link and by the line-of-sight range: $R = 4.12\left(\sqrt{h_{a1}} + \sqrt{h_{a2}}\right)$, where h_{a1}, h_{a2} - the corresponding antenna heights of the receiving-transmitting station and height of the antenna placed on the robot. To increase the range and expand the working area of the system for a given time, an air support on the UAVs can be deployed. After determining the coordinates of the UAVs, they can in turn be used as local land mobile robots receiving-transmitting navigation points used for their positioning in severe environment.

Let us consider the principles of implementing cooperative processing of a set of distance measurements in a multi-position radio system containing N receiving-transmitting positions, each of which is capable of receiving both its own signals and signals emitted by other positions of the system. In such a system, in general, it is possible to obtain three groups of measurements: inclined distances $\hat{R}_1, \hat{R}_2 \dots \hat{R}_N$, N(N-1) sums of distances $\hat{R}_{\Sigma 12}, \hat{R}_{\Sigma 21} \dots \hat{R}_{\Sigma N(N-1)}$ and 0.5N(N-1) $\hat{R}_{\Delta 12}, \hat{R}_{\Delta 13} \dots \hat{R}_{\Delta 0.5N(N-1)}$ differences of distances.

The physical essence of these measurements, obtained independently of each other, makes it possible to form a system of linear algebraic equations with respect to N unknown range estimates, which for N≥3 is essentially redefined [15]:

$$\begin{cases}\begin{cases}\hat{R}_1 = 1\cdot\tilde{R}_1 + 0\cdot\tilde{R}_2 + 0\cdot\tilde{R}_3 + \ldots + 0\cdot\tilde{R}_N\\ \hat{R}_2 = 0\cdot\tilde{R}_1 + 1\cdot\tilde{R}_2 + 0\cdot\tilde{R}_3 + \ldots + 0\cdot\tilde{R}_N\\ \vdots\\ \hat{R}_N = 0\cdot\tilde{R}_1 + 0\cdot\tilde{R}_2 + 0\cdot\tilde{R}_3 + \ldots + 1\cdot\tilde{R}_N\end{cases}\\ \begin{cases}\hat{R}_{\Sigma 12} = 1\cdot\tilde{R}_1 + 1\cdot\tilde{R}_2 + 0\cdot\tilde{R}_3 + \ldots + 0\cdot\tilde{R}_N\\ \hat{R}_{\Sigma 21} = 1\cdot\tilde{R}_1 + 1\cdot\tilde{R}_2 + 0\cdot\tilde{R}_3 + \ldots + 0\cdot\tilde{R}_N\\ \hat{R}_{\Sigma 13} = 1\cdot\tilde{R}_1 + 0\cdot\tilde{R}_2 + 1\cdot\tilde{R}_3 + \ldots + 0\cdot\tilde{R}_N\\ \hat{R}_{\Sigma 31} = 1\cdot\tilde{R}_1 + 0\cdot\tilde{R}_2 + 1\cdot\tilde{R}_3 + \ldots + 0\cdot\tilde{R}_N\\ \vdots\\ \hat{R}_{\Sigma N} = 0\cdot\tilde{R}_1 + 0\cdot\tilde{R}_2 + 0\cdot\tilde{R}_3 + \ldots + 1\cdot\tilde{R}_N\end{cases}\\ \begin{cases}\hat{R}_{\Delta 12} = 1\cdot R_1 - 1\cdot R_2 + 0\cdot R_3 + \ldots + 0\cdot\tilde{R}_N\\ \hat{R}_{\Delta 13} = 1\cdot\tilde{R}_1 + 0\cdot\tilde{R}_2 - 1\cdot\tilde{R}_3 + \ldots + 0\cdot\tilde{R}_N\\ \vdots\\ \hat{R}_{\Delta N} = 1\cdot\tilde{R}_1 + 0\cdot\tilde{R}_2 + 0\cdot\tilde{R}_3 + \ldots + 1\cdot\tilde{R}_N.\end{cases}\end{cases} \tag{1}$$

In the matrix form of recording, the system of equations (1) takes the form:

$$\hat{H} = A\tilde{S}, \tag{2}$$

where:

$\hat{H}^T = \left\| \hat{R}_1 \hat{R}_2 \ldots \hat{R}_N \hat{R}_{\Sigma 12} \hat{R}_{\Sigma 21} \hat{R}_{\Sigma N(N-1)} \ldots \hat{R}_{\Delta 12} \hat{R}_{\Delta 13} \hat{R}_{\Delta 0.5N(N-1)} \right\|$ – matrix (vector row) of primary measurements of dimension $1\times 0{,}5N(3N\text{-}1)$; A – matrix of coefficients for unknowns of dimension $0{,}5N(3N\text{-}1) \times N$, whose values are equal to one if the corresponding unknowns exist in the given equation, and zero otherwise; $\tilde{S}^T = \left\| \tilde{R}_1 \tilde{R}_2 \ldots \tilde{R}_N \right\|$ - matrix (vector - row) of unknown range estimates by dimension $1 \times N$.

Solving a vector-matrix equation (2) by the known least-squares method, we get: $\tilde{S} = \left[\left(A^T J W^{-1} A \right)^{-1} A^T J W^{-1} \right] \hat{H}$, where - W - is the matrix of accuracy of primary measurements of dimension $0{,}5N(3N\text{-}1)\times 0{,}5N(3N\text{-}1)$, whose main diagonal contains dispersion errors of range measurements , the sums and differences of distances, the secondary ones reflect the possible correlation links between them; $J = diag\left\| j\, j \ldots j \right\|$ - is a variational diagonal matrix of coefficients of dimension $0{,}5N(3N\text{-}1)\times 0{,}5N(3N\text{-}1)$, the diagonal elements of which are equal to one (j=1), if the corresponding measurements participate in cooperative processing and zero (j = 0) – otherwise the diagonal elements of which are equal to one (j = 1) if the corresponding measurements participate in cooperative processing and zero (j = 0) - otherwise.

Assuming that the variance of the errors in the primary measurements of range, sums and distance differences are the same and equal σ_{R0}^2, then the variance of the distance determination errors in the example of a four-position system can be determined by the formula:

$$\sigma_{RC}^2 = diag\left(A^T A\right)\sigma_{R0}^2 = \\ = diag\begin{Vmatrix} \frac{4}{39} & -\frac{1}{117} & -\frac{1}{117} & -\frac{1}{117} \\ -\frac{1}{117} & \frac{4}{39} & -\frac{1}{117} & -\frac{1}{117} \\ -\frac{1}{117} & -\frac{1}{117} & \frac{4}{39} & -\frac{1}{117} \\ -\frac{1}{117} & -\frac{1}{117} & -\frac{1}{117} & \frac{4}{39} \end{Vmatrix}\sigma_{R0}^2. \tag{4}$$

Thus, increasing the accuracy of measuring distances with respect to each of the positions leads to an equivalent increase in the accuracy of determining the rectangular coordinates. To achieve high accuracy of the definition of rectangular coordinates, the considered method does not require restrictions on the hypothesis of the motion of the object. Increasing the accuracy of determining the location of an object can be achieved in a minimum time. It can also be shown that redundant measurements with respect to the rangefinder location method at $i \geq 4$

$$R_i = \sqrt{\left(X - x_i\right)^2 + \left(Y - y_i\right)^2 + \left(H - h_i\right)^2},$$

allow the rectangular coordinates of the object X, Y, H to be determined with high accuracy.

If there are n different variants of using navigation information sources (SNS, INS, SLAM, local radio navigation system with cooperative processing, etc.) in the multi-agent robotic system, it can be easily shown that the task of combining data from these meters can be solved as ($Z \Leftrightarrow \{X, Y, H\}$):

$$\tilde{Z} = \left[\left(B^T \Lambda D^{-1} B \right)^{-1} B^T \Lambda D^{-1} \right] \hat{G},$$

where: $\tilde{Z}^T$ - matrix (vector - row) of unknown coordinate estimates by dimension $1\times n$;
B - matrix (vector-row), consisting of units of the dimension $1\times n$; $\Lambda = diag\left\| \lambda\, \lambda \ldots \lambda \right\|$ - a variational diagonal matrix of coefficients of dimension $n \times n$, the diagonal elements of which are equal to one ($\lambda = 1$), if the corresponding coordinates participate in the integration of the results, and to zero ($\lambda = 0$) - otherwise;
D - the matrix of accuracy of primary measurements of coordinates of dimension $n\times n$, the main diagonal of which contains variances of errors in measuring the coordinates of the objects to be integrated, the secondary

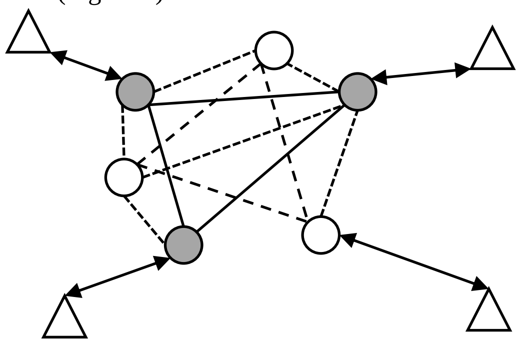
diagonals reflect possible correlation links between them; $\hat{G}$ - matrix (row vector) of primary measurements of dimension 1×n.

In case of SNS signals loss (interference, work in dense urban environments or in buildings), until the stable reception of signals is restored, INS is used. If the axes of the gyrostabilized platform and accelerometers are parallel to the axes of the geocentric rectangular equatorial coordinate system X, Y, H, then:

$$Z = Z_0 + \int_0^t \left(\dot{Z}_0 + \int_0^t a_Z dt \right) dt,$$

where: Z_0, $\dot{Z}_0$, - initial coordinates of the route point and initial speeds of the object movement; a_Z - measured accelerations along respective axes. Data transmission in the system under consideration is possible on the basis of self-organizing networks, i.e. - a wireless, dynamic, decentralized, mobile network that does not have a permanent structure (the coverage area of such a network does not need to be constant; it is a network with a variable topology).

In such a network, one can use existing protocols, wireless standards and technologies, and special protocols. The network is configured by itself, automatically, without human interference. The network requires the exchange of control, and in some cases, statistical information between nodes involved in the organization of the network for receiving and transmitting data (for example, for balancing the load and sending data about changing the network topology). The nodes making up the network can move in space, they can drop out of the network, and new devices, in turn, can join the network and participate in its organization (Figure 2).



△	Navigation signal receiver-transmitters
●	Unmanned Aerial Vehicles
○	Ground mobile robots
——	Connection between UAVs
- - -	Communication between mobile robots
-----	The connection between mobile robots and UAVs
◄►	Sending and receiving navigation messages

Figure 2. Variant of organization of communication and data transfer in a robotic system

3. RESEARCH RESULTS

Three spherical robots forming a multi-agent group were used as an experiment (Figure 3). The purpose of the experiment was to study the movement of a group of robots from the starting point, make a turn and return to the starting point (Figure 4). The navigation data was processed from three sources: the GLONASS / GPS satellite navigation system, the local radio navigation system and the inertial navigation system

Figure 3. Multiagent group of spherical robots

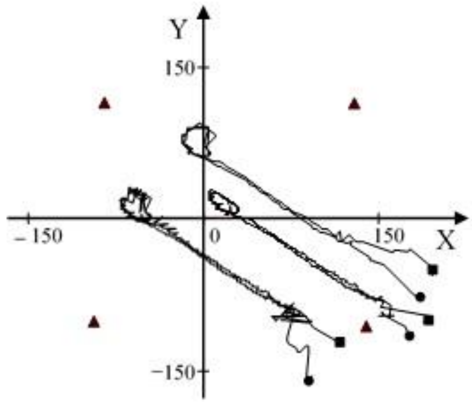


Figure 4. Spherical robots motion trajectory records

4. CONCLUSION

Here was considered a variant of solving the problem of navigational support of multi-agent systems using the procedure of data integration from several radio navigation systems.

Using a local radio navigational field with the use of UAV will permit to expand the working area of the navigation system.

The integration of sensors of different physical natures will potentially improve the accuracy of positioning mobile ground-based and air-based robots, particularly in the event of the loss of one or more sensors for some reason.

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