Adaptive Movement Control of a Collective of Mobile Robots Deployed in a Line

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Abstract

This work solves the problem of controlling the movement of a team of robots deployed in a line. The control method consists in the fact that in the process of movement at each moment of time t, the parameters of movement of each robot R_i, moving in parallel with the neighboring robot R_{i-1}, are rescheduled. Management is carried out using an alternative collective adaptation algorithm based on the ideas of the collective behavior of adaptation objects. The principles of functioning of one adaptation automaton are considered. The goal of controlling the slave robots is to minimize deviations. To implement the adaptation mechanism, the parameters of the vector are compared with adaptation automata that simulate the behavior of adaptation objects in the environment. The structure of the process of alternative collective adaptation has been developed, under the control of which the movement of a group of robots in a formation is carried out.

Keywords

Swarm of mobile robots, movement of mobile robots deployed in a line, group control, alternative collective adaptation.

1. Introduction

This work is devoted to the topical problem of mathematical modeling and control theory: the problem of decentralized control of a multi-agent system consisting of agents modeling autonomous robots in order to ensure the movement of a group of robots deployed in a line [1].

A group of drones deployed in a line can be used in search and rescue operations to quickly survey gigantic territories. Another use case: a coordinated attack on a swarm of unmanned aerial vehicles − they may have different tasks, for example, someone provides communication with the base, someone puts interference, and part of the swarm is loitering ammunition. Possible groups of robots used for plowing or harvesting in large areas [2].

Structurally, the robot includes propellers, manipulators and their grippers, motors, various sensors, communication devices, etc. The type of mover of the robot is determined by the way it moves in space, which, in turn, is determined by the environment in which the robot should function. The work assumes the use of propellers to move through the air and on the ground.

For uniform distribution of agents in the mission area, maintaining stable communication within the group and avoiding collisions, robots must observe a certain geometric structure when moving (a certain location relative to each other within the formation or relative to the center of mass of the group, forming a certain geometric figure). There is a need to work out a mathematical model describing the movement of a group of robots, and to develop a decentralized control rule and an

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algorithm that would allow effective control of the movement of agents while maintaining the geometric shape of the formation [3].

The purpose of this work is to develop a completely decentralized rule for controlling a group of agents modeling mobile robots, which would ensure the movement of a group of agents in compliance with a certain geometric structure of the order (certain mutual distances relative to each other), under conditions of complete autonomy of the agent and the possibility of obtaining information only from their nearest neighbors. In this case, the desired control rule must be efficient under the conditions of occurrence of emergency situations described in [4,5,6].

2. Controlling the motion of a group of robots deployed in a line

When two or more robotic complexes (*RC*) move together, it is important to know their relative position with high accuracy [7,8]. Each of the robots needs a set of sensors that allow it to receive information about the environment. Therefore, for the full-fledged operation of the mobile *RC*, the robots are equipped with radio frequency sensors for determining the relative position. Each intelligent agent (mobile robot) includes a solver that receives data from other devices over wireless channels. By processing them, the device generates commands for the autopilot. By processing the information read by the sensors, the motion control system solves the problem of constructing a path of movement [9].

The robots deployed in a line are numbered from R_0 − the leading robot to R_n − the last of the line of robots. This type of movement requires that each robot R_i (i=1,2,…n), except for the first (leading), move along a trajectory parallel to that along which the robot R_{i-1} moves, with the same speed V_i=V_0, observing a constant distance D between each pair of adjacent robots R_i and R_{i-1}, while the robot R_i aligns the trajectory with the trajectory of the robot R_{i-1}.

The lead robot R_0 can be equipped with a sensor system that allows it to plan a trajectory in an unpredictable environment, while the rest of the robots must simply follow the trajectory of their nearest neighbor. Figure 1. shows a diagram of the movement of a team of mobile robots, lined up in a row, relative to the baseline [9-10].

The paper considers systems in which agents move in ordinary Euclidean space with discrete time.

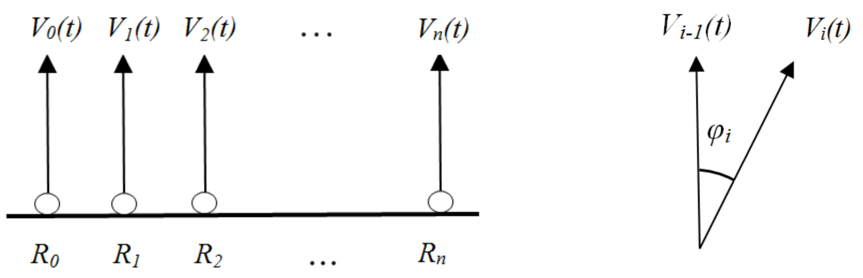

Figure 1: Movement diagram of a swarm of mobile robots deployed in a line

The vector $\boldsymbol{W_i}$=(x_i, y_i, α_i, h_i,V_i) of the state of each of the robots in the absolute coordinate system is known, where (x_i, y_i) are the coordinates of the location of the robot, V_i is the speed of movement of the robot, α_i is the angle between the vector V_i and the base the line *Line*, h_i − the modulus of the vector V_i. Given α_0 − for the leading robot and D − distance in the line between neighboring robots R_i and R_{i-1}.

Let us now consider the problem of controlling slave robots. The main idea is that the goal of controlling the slave robots is to fulfill (achieve R_i with the robot's course R_{i-1}) the equalities:

1. $V_{i-1}(t)=V_i(t)$.
2. $h_{i-1}(t)=h_i(t)$.
3. $x_i(t)-x_{i-1}(t)=D$.
4. $y_i(t)=y_{i-1}(t)$.
5. $\alpha_i(t)=\alpha_{i-1}(t)=\alpha_0$.

$\varphi_i(t)=\alpha_i(t)-\alpha_{i-1}(t)$ is the angle between $V_{i-1}(t)$ and $V_i(t)$.

The control method consists in the fact that in the process of movement at each moment of time t, the movement parameters of each robot R_i, moving in parallel with the neighboring robot R_{i-1}, are rescheduled. The error of the robot R_i is:

$$\delta_i=k_1(|D-|(x_i(t)-x_{i-1}(t)||+k_2|(y_i(t)-y_{i-1}(t)|+k_3|(h_i(t)-h_{i-1}(t)|)+k_4|(\alpha_i(t)–\alpha_0)|).$$

Robot movement error: $\Delta=\sum_i \delta_i$.

The programmed trajectory of each slave robot is formed as follows. The control law is limited to considering the kinematic model. The inertial and structural parameters of the robot are not taken into account here.

Maximum values of velocity deviation $\delta V=(V_i(t+1)-V_i(t))$ − and yaw angle φ_i: $\varphi_{i,i-1}(t+1)$ $\varphi_i(t)=\alpha_i(t)-\alpha_{i-1}(t)$ are set by the control system within acceptable limits.

Rule 1. (Elimination of the discrepancy between the course of the robot R_i and the course of the robot R_{i-1}). If $\varphi_i(t)>0$, then the angle $\alpha_i(t)$ between V_i and the base line *Line* is corrected in order to reduce $\varphi_i(t)$, in accordance with expression (5). The purpose of the correction is to minimize the value of $\varphi_i(t)$.

Rule 2. If there is a deviation $\varepsilon_h=h_i(t)-h_{i-1}(t)$ and the deviation processing time does not exceed predetermined threshold values, then the speed $h_i(t)$ of movement is corrected according to the current deviation from the given trajectory of the pseudo-target, in accordance with the expressions $h_i(t+1)=h_i(t)+\xi_v$. The goal of the correction is to minimize the value of ξ_v.

Rule 3. If $y_i(t)-y_{i-1}(t)=\varepsilon_y$ and $|\varepsilon_y|>0$, then the correction $y_i(t)=y_i(t)+\xi_y$ is performed. The goal of the correction is to minimize the value of $|\varepsilon_y|$.

Rule 4. If $x_i(t)-x_{i-1}(t)=\varepsilon_x$ and $|\varepsilon_x|>D$, then the correction $x_i(t+1)=x_i(t)+\xi_x$ is performed. The goal of the correction is to minimize the difference $(|\varepsilon_x| - D)$.

The proposed structure of the maneuver performed by the robot to correct the deviations of the parameters is as follows. First, the robot R_i changes the value of the parameter $\alpha_i(t)$ by the value δ_i, then during the time δ_t the robot moves with the new value of the parameter $\alpha^*_i(t)=\alpha_i(t)+\delta_i$. After the expiration of the time δ_t, the initial value of the parameter with which the robot continues to move is returned. The maneuver performed by the R_i robot is shown in Figure 2.

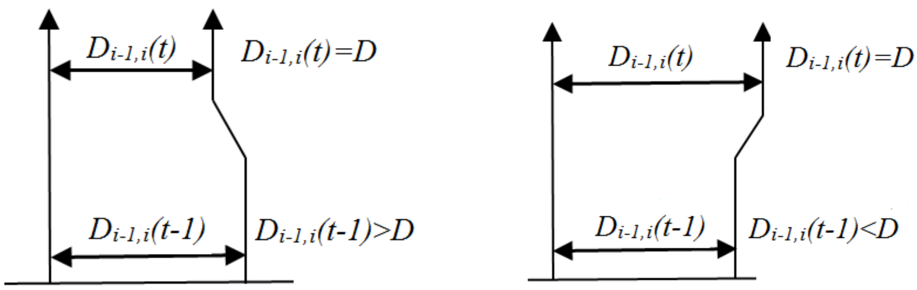

Figure 2: Scheme of the maneuver performed by the robot to correct the parameter $x_i(t)$

The first rule is intended to solve the control problem under the condition of exerting a control action on the direction of movement of the robot, and the second rule is intended for the provision of a control action on the agent's speed. For each control rule, its discrete analogue is presented.

When considering a pair of robots R_{i-1} and R_i, the parameters are: linear velocities $V_{i-1}(t)$, $V_i(t)$, angles $\alpha_i(t)$, $\alpha_{i-1}(t)$, $\varphi_i(t)$, coordinates (x_i, y_i) and (x_i, y_i), modules $h_i(t)$, $h_{i-1}(t)$ are input. In this case, $V_{i-1}(t)$, $\alpha_{i-1}(t)$, (x_{i-1}, y_{i-1}), $h_{i-1}(t)$, are disturbances of an indefinite nature, and the parameters of the robot R_i: $V_i(t)$, $\alpha_i(t)$, $(x_i, y_i)(t)$, $h_i(t)$ are used as parameters for controlling the movement of the robot. At the next step, the parameters of the robot R_i acquire new values $V_i(t+1)$, $\alpha_i(t+1)$, $\alpha_i(t)$, $(x_i, y_i)(t+1)$, $h_i(t+1)$.

3. Algorithm of motion of a group of robots developed in a line based on collective adaptation

To control the movement of a group of robots deployed in a line, an adaptive feedback algorithm based on the method of self-learning and self-organization has been developed.

The approach to solving this problem is to formalize the concept of deviation of the current position of the slave robot R_i from the required position. This is achieved on the basis of visual information and the search for such feedback control, which ensures that the rate of this deviation is reduced to zero. To control the movement of the robot parallel to the trajectory of the leading (previous) robot R_{i-1}, kinematic equations are used in state variables that characterize the fulfillment of the control goal. The problem of localizing robots using relative position has been solved.

The movement control of a group of robots deployed in a line is carried out using an alternative collective adaptation algorithm based on the ideas of the collective behavior of adaptation objects [10].

The objects of adaptation of the slave robot R_i are the parameters of the vector W_i considered as controls − the position and orientation of the robot in the absolute coordinate system, and the linear velocity of the robot, respectively.

A collective of adaptation objects (their totality) of a group of robots deployed in a line corresponds to an optimization object (*OO*).

To implement the adaptation mechanism, each object (parameter p_{ij} of the vector $W_i =(x_i, y_i, \alpha_i, h_{i,}V_i))$ is matched with an adaptation automaton *AA*, which simulates the behavior of the adaptation object in the environment. The adaptation automaton (Figure 3) has two groups of states: $C_1=\{c_{1l}|l=1,2,\dots,g\}$ and $C_2=\{c_{2l}|l=1,2,\dots,g\}$, corresponding to two alternatives A_1 and A_2 behavior of the adaptation object in the environment: A_1 − change the size of the parameter, A_2 − leave it unchanged. Thus, the output alphabet of the adaptation automaton is: $A=\{A_1, A_2\}$. The number of states in a group is specified by a g parameter called memory depth. The input alphabet $Q=\{+, -\}$ includes possible responses of the environment: "reward" (+) and "punishment" (-). The graph-diagram of *AA* transitions is shown in Figure 3. A signal “encouragement” or “punishment” is given to the input of the adaptation machine, depending on the state of the adaptation object (the corresponding parameter of the vector W_i) in the environment. The sign (+) marks the transitions in *AA* under the influence of the "encouragement" signal, the sign (-) marks the transitions under the influence of the "punishment" signal.

Without loss of generality, let us consider the principles of functioning of one *AA*. Initially, *AA* is in one of the initial states (in the figure, these states are in bold).

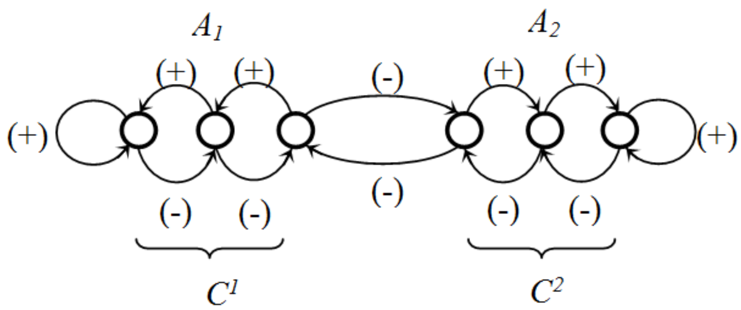

Figure 3: Adaptation machine structure

The local goal of the adaptation object is to achieve a state in which its score is equal to 0.

The global goal of the collective of adaptation objects is to achieve such a state S (i.e., such values of the parameters of the robots) at which the "error of movement" of the robots is $\Delta=\sum_i \delta_i \rightarrow min$.

The process of alternative collective adaptation, which controls the movement of a group of robots deployed in a line, is carried out in four cycles for each robot at each step t (Figure 4).

Rescheduling of the parameters of the movement of robots R_i is performed at each moment of time t.

At the first cycle of collective adaptation, for each Ri, the values of the parameters of the vector W_i are calculated.

On the second clock cycle, for each adaptation automaton, responses from the environment are generated: "reward" or "punishment".

For each parameter p_{ij} of the vector W_i, the deviation $\mu_{ij}(t)$ from its value in the vector W_{i-1} is calculated.

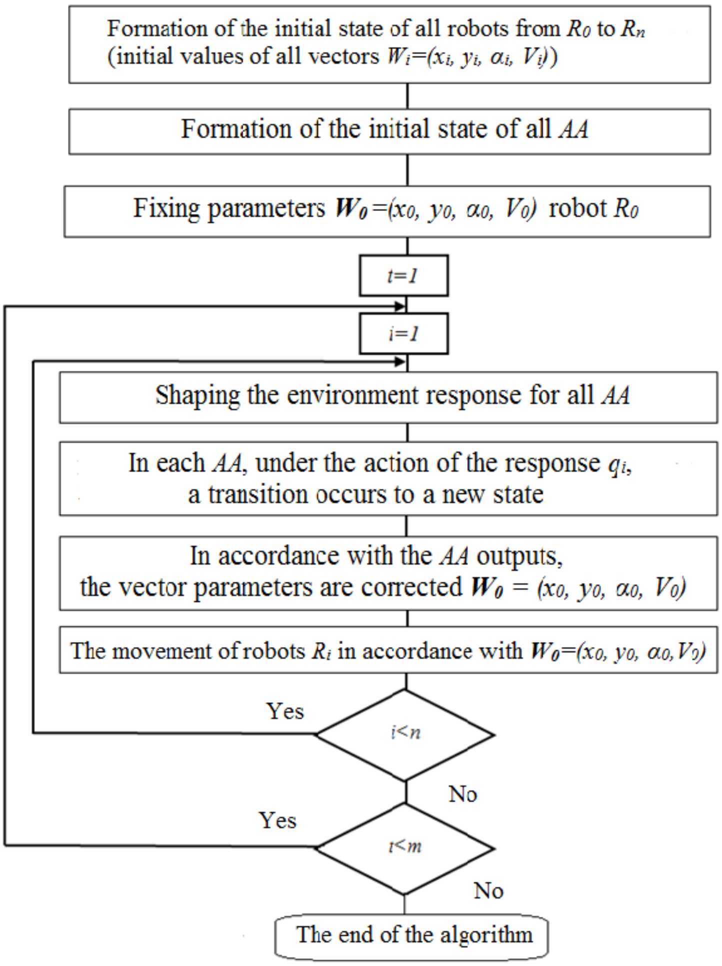

Figure 4: The structure of the motion control algorithm of a team of robots deployed in a line

If $sgn(\mu_{ij}(t))=0$, then a signal “encouragement” (+) is generated for the corresponding *AA*.

If $sgn(\mu_{ij}(t))\neq 0$, then the “punishment” (-) signal is generated for the corresponding *AA*.

On the third cycle, in each adaptation automaton, under the action of the response fed to its input, a transition to a new state is carried out.

On the fourth cycle, for each adaptation object, an alternative is implemented in accordance with the *AA* outputs:

1. If *AA* is in one of the states of the group C^1_{ij}, then the value of the parameter p_{ij} does not change.
2. If *AA* is in one of the states of the group C^2_{ij}, then the value of the parameter p_{ij} changes by an amount proportional to the deviation $\mu_{ij}(t)$.

4. Conclusion

The work has developed new mathematical methods for simulating the movement of robots. The problem of controlling the movement of a team of robots deployed in a line is considered. The control method consists in the fact that in the process of movement at each moment of time *t*, the movement parameters of each robot R_i, moving in parallel with the neighboring robot R_{i-1}, are rescheduled. Management is carried out using an alternative collective adaptation algorithm based on the ideas of the collective behavior of adaptation objects. The principles of functioning of one adaptation automaton are considered. The goal of controlling the slave robots is to minimize deviations. To implement the adaptation mechanism, the parameters of the vector are compared with adaptation automata that simulate the behavior of adaptation objects in the environment. The structure of the process of alternative collective adaptation has been developed, under the control of which the movement of a group of robots deployed in a line is carried out.

Original rules for controlling parameters have been developed, which have a number of advantages over other methods: complete decentralization of control in combination with dynamic correction of the parameters of robots that specify the position and orientation of the robot in the absolute coordinate system, and the linear velocity of the robot, respectively. The structure of a maneuver performed by a robot to correct parameter deviations is proposed. The control is carried out using the algorithm of alternative collective adaptation. It is based on the ideas of the collective behavior of adaptation objects, which makes it possible to efficiently handle emergency situations, such as the failure of agents, changes in the number of agents due to failure or sudden acquisition of connection with the next agent, as well as in the presence of measurement errors and noise satisfying certain restrictions.

5. Acknowledgements

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6. References

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