Group control algorithm in an uncertain environment with dynamic obstacles

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ПЕРВАЯ МЕЖДУНАРОДНАЯ ШКОЛА-КОНФЕРЕНЦИЯ ПО ТЕНЗОРНЫМ МЕТОДАМ В МАТЕМАТИКЕ И ЗАДАЧАХ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА

Problem statement

A system of n homogeneous mobile robots in a two-dimensional environment, hereinafter referred to as agents, is considered. Initially, all agents are randomly placed in an obstacle-free area of space. In the rest of the space, the obstacles are randomly located, the coordinates and characteristics of the obstacles are unknown before the start of the movement. Obstacle detection is carried out by a circular lidar with a limited viewing radius.

Agent dynamics

$$\begin{cases} \dot{q}_i = p_i \\ \dot{p}_i = u_i \end{cases}$$

$q_i = \begin{bmatrix} x_i & y_i \end{bmatrix}^T$ – a vector defining the position of the i-th robot in the Earth's coordinate system.
$p_i = \begin{bmatrix} v_{xi} & v_{yi} \end{bmatrix}^T$ – the velocity vector of the i-th robot
$u_i = \begin{bmatrix} u_{xi} & u_{yi} \end{bmatrix}^T$ – robot control vector

Definition of the formation

Let $\mathcal{V}$ be a set of agents. The interaction distance $r > 0$ is given, the set of edges $\mathcal{E}(q)$

$$\mathcal{E}(q) = \{(i,j) \in \mathcal{V} \times \mathcal{V} : \|q_i - q_j\| < r, i \neq j\}$$

A quasi α-lattice is a q configuration such that

$$-\delta < \|q_i - q_j\| - d < \delta, \quad \forall (i,j) \in \mathcal{E}(q)$$

where $\delta \ll d$ is the uncertainty of the edge length, d is the scale

Goal

Creating an algorithm that will control the movement of a group of mobile robots, ensuring that a given goal is achieved with a minimum number of collisions between robots and with external obstacles. In addition, this algorithm should ensure the connectivity of the group on the sections of the route that are free of obstacles.

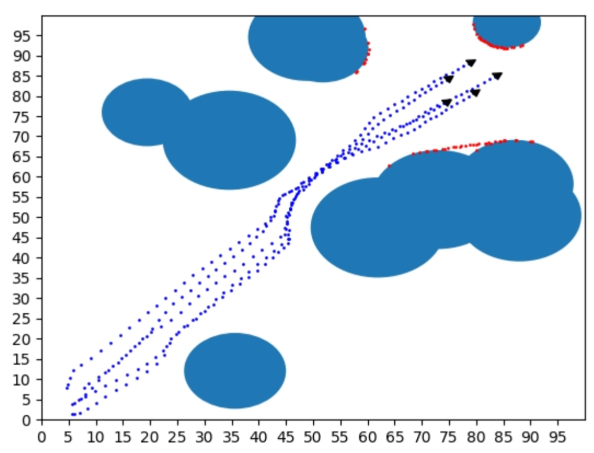

Figure 1. Moving a group of agents

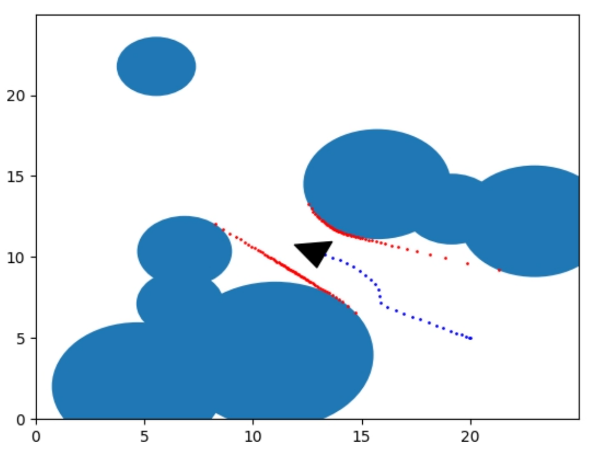

Figure 2. Replacing obstacles with their convex hulls

The method of potential fields

To solve the problem, it is proposed to use the method of potential fields. Each object: robot, obstacle and target will create repulsive and attractive potential fields. When summing up all the potentials, the acceleration vector of the robot will be determined.

Control algorithm

We will implement control in the form of the sum of three controls: u_i^γ - implements attraction to the target, u_i^α - implements attraction and repulsion of physical agents to maintain order so that the distance between neighbors is d, u_i^β - implements repulsion from obstacles.

$$u_i = u_i^\alpha + u_i^\beta + u_i^\gamma$$

A full description of the algorithm is not provided due to the extensive description. He is described in detail in [1].

Problems

The controls u_i^α, u_i^β depend on r, r' - the interaction distance, which corresponds to a limited view of the circular lidar.
This algorithm allows you to form a formation and achieve the goal in the absence of obstacles. When obstacles appear, problems may arise due to the fact that the robot falls into the area of the minimum potential function, this may be due to non-convex obstacles, a certain location of obstacles and other reasons.
When calculating the controls $u_i^\alpha, u_i^\beta, u_i^\gamma$ are used the constants: c_1^α, c_2^α, c_1^β, c_2^β, c_1^γ, c_2^γ, which correspond to how much more strongly the components of a certain control are taken into account. Their optimal values need to be determined.

Heuristics

Non-convexity

Suppose that after scanning the area with lidar, we get $O = \{O_1, O_2, ..., O_k\}$ - a set of obstacles. Then, if we replace O with $\hat{O} = \{conv(O_1), conv(O_2), ..., conv(O_k)\}$, then we can get rid of the minima of the potential function associated with non-convexity.

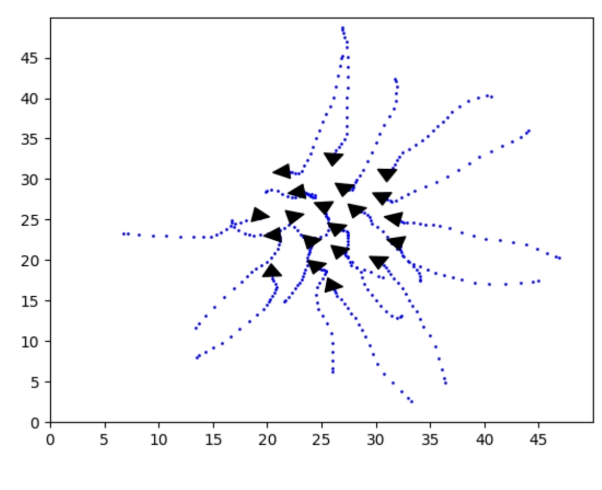

Figure 3. Flocking agents

Heuristics

Selection of constants

In solving this problem, it is proposed to introduce metrics T - performance time, C - group connectivity.

$$C = \frac{k}{|\mathcal{V}|}\frac{1}{T}\sum_{i\in\mathcal{V}}\int_0^T \sum_{j\in\mathcal{N}_i} |\|q_i - q_j\| - d|$$

where k is the normalization coefficient for correlation with T.
$\mathcal{N}_i = \{j \in \mathcal{V} : \|q_i - q_j\| < r, i \neq j\}$ - neighbors i
Because the speed of the group and its connectivity are important to us. Then it is suggested to choose the final metric $J = T^2 + C^2$. Using the J metric, you can select the optimal constants by iterating over the grid or using heuristic algorithms.

Modeling

A program was written to simulate this task.
In the absence of obstacles and a set goal, agents group together to organize a quasi α-lattice.[Fig. 3]
The control described above has been implemented, which successfully allows you to achieve the goal and maintain the formation in the absence of obstacles.
When interacting with convex static obstacles, the agents successfully go around it, and after passing the obstacles they are grouped again.[Fig. 1]
It is also implemented to replace obstacles with their convex hulls, which greatly affects the achievement of the goal for some maps.[Fig. 2]

Conclusion

During the simulation, the algorithm based on the method of potential fields successfully shows itself in the case of static convex obstacles. This suggests that small heuristic improvements can quite effectively eliminate the disadvantages of the method.
In the future, I would like to select the optimal algorithm parameters and test the algorithm in an environment with dynamic obstacles. Also, if necessary, you can add the methods of getting out of the minimum described in the literature [2]

References

[1] Reza Olfati-Saber. Flocking for multi-agent dynamic systems: Algorithms and theory. Technical report, Control and Dynamical Systems California Institute of Technology, 2004.

[2] Белоглазов Д.А., Гайдук А.Р., Косенко Е.Ю., Медведев М.Ю., Пшихопов В.Х., Соловьев В.В., Титов А.Е., Финаев В.И., and Шаповалов И.О. *Групповое управление неподвижными объектами в неопределенных средах*. ФИЗМАТЛИТ, 2015.