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Simulation Study on Multi-Robot Formation with Receding Horizon Particle Swarm Optimization

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ABSTRACT

This paper provides various simulation results of receding horizon particle swarm optimization (RHPSO)-based multi-robot formation control. The RHPSO is an optimization algorithm for quickly finding suboptimal solutions for multi-robot formation control problem with collision avoidance. However, the computational complexity of the RHPSO increases linearly as the number of candidate solutions and generations increases. Therefore, it is important to find a minimum number of candidate solutions and the number of generations to compute an acceptable suboptimal solution. This paper provides numerical simulation results to test how much formation error occurs when reducing the number of candidate solutions and generations in RHPSO. The results show that the RHPSO can find acceptable suboptimal solutions with a small number of candidate solutions and generations.

1. INTRODUCTION

As the multi-robot formation control problem can be effectively handled by using the receding horizon control (RHC), which is one of the optimization algorithms, many studies have been conducted on the formation control based on the RHC framework (Fukushima et al., 2013; Turpin et al., 2012). However, as the prediction interval of the RHC increases, the number of constraints for collision avoidance increases as well, which increases the computational complexity.

To deal with the problem, Lee and Myung (2015) proposed receding horizon particle swarm optimization (RHPSO) method for quickly finding suboptimal solutions satisfying the constraint for collision avoidance. The RHPSO has a great advantage that the constraint for collision avoidance can be satisfied without increasing the amount of computation However, the computational complexity of the RHPSO increases linearly with the number of candidate solutions and the number of generations. Therefore, it is important to find the appropriate number of candidate

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solutions and the number of generations to compute an acceptable suboptimal solution. In this paper, therefore, we analyze the control performance according to the number of candidate solutions and the number of generations with various simulation results.

2. Multi-Robot Formation Control with Receding Horizon Particle Swarm Optimization (RHPSO)

2.1 Multi-Robot Formation Control Problem

Multi-robot formation control problem with collision avoidance can be formulated as a constrained nonlinear optimization problem. Based on a receding horizon control (RHC) framework, the cost function J for each robot i to be minimized is designed as follows (Lee and Myung, 2015):

$$J\big(e(t),u(t)\big)=\int_t^{t+T}\big(e^T(\tau)Qe(\tau)+u^T(\tau)Ru(\tau)\big)d\tau \tag{1}$$

where $e(t)$ is the formation and tracking error, $Q>0$ and $R>0$ are positive definite symmetric weight matrices, and T is a prediction interval. The optimization problem in the RHC framework can be represented as

$$\min_{u(t)} J\big(e(t),u(t)\big) \tag{2}$$

subject to

$$\dot{e}(\tau)=f(e(\tau),u(\tau)) \tag{3}$$

$$d_{ij}(\tau)\geq d_{safe} \tag{4}$$

where f is a nonlinear function of the robot motion model, d_{ij} is the relative distance between the robot i and j, d_{safe} is the safe distance between robots for collision avoidance, and $\tau\in[t,t+\tau]$.

Collision avoidance between the robots should be considered during maintaining and switching their formation. To avoid collisions between the robots, the relative distances between robots have to maintain a safe distance. Generally, traditional optimization techniques for solving constrained nonlinear optimization problems such as sequential quadratic programming (SQP) take a longer computation time as the number of constraints increases. This approach therefore suffers from computational complexity problem as the prediction horizon T increases.

2.2 Review of Receding Horizon Particle Swarm Optimization (RHPSO)

The RHPSO proposed by Lee and Myung (2015) is a method for quickly finding the suboptimal solution satisfying the constraint for collision avoidance defined in Eq. (4). Since at least one candidate solution always satisfies the constraint condition, the RHPSO has a great advantage that the constraint for collision avoidance can be satisfied without increasing the amount of computation.

However, the computational complexity of the RHPSO increases linearly with the number of candidate solutions and the number of generations. Therefore, it is important to find the appropriate number of candidate solutions and the number of generations to compute an acceptable suboptimal solution. Lee and Myung (2015) proposed to use 50 particles and 100 generations.

3. Simulation Results

We performed various simulations to test how much formation error occurs when reducing the number of candidate solutions and generations in the RHPSO. The simulation was performed under the same condition proposed by Lee and Myung (2015) using 5 robots, and the formation error was measured by changing the number of candidates and the number of generations. The formation error is defined as follows:

$$E = \int_{t_0}^{t_f} e(t)dt \tag{5}$$

where $e(t)$ is the formation error generated at time t and E refer to the total amount of $e(t)$ for the running time from t_f to t_0.

For each case, the formation error defined in (5) are summarized in Table 1. The numerical values in parentheses indicate the percentage of the relative error based on the error (8.8484) when the number of candidate solutions is 50 and the number of generations is 100, which were recommended by Lee and Myung (2015). As can be seen in Table 1, when the number of candidate solutions is more than 20 and the number of generations is more than 40, the relative error is within 2%, which is acceptable to formation control.

Table 1. Formation Error according to the number of candidate solutions and the number of generations

Number of generations	Number of candidate solutions				
	10	20	30	40	50
20	11.5362 (30.38%)	11.3026 (27.74%)	9.7279 (9.94%)	9.8828 (11.69%)	9.0581 (2.37%)
40	11.8542 (33.97%)	9.1560 (3.48%)	9.0547 (2.33%)	9.1468 (3.37%)	8.9581 (1.24%)
60	9.0670 (2.47%)	8.9711 (1.39%)	9.0240 (1.98%)	8.900 (0.58%)	8.8719 (0.27%)
80	9.0061 (1.78%)	8.9859 (1.55%)	8.9021 (0.61%)	8.8739 (0.28%)	8.8193 (0.33%)
100	9.0930 (2.76%)	8.9327 (0.95%)	8.9557 (1.21%)	8.9173 (0.78%)	8.8484 (Ref.)

4. CONCLUSIONS

In this paper, we provided simulation results of the RHPSO to test the formation control performance as the number of candidate solutions and the number of generations decreases, which have the greatest effect on the RHPSO computation time. From the simulation results, we found that the RHPSO show a good control performance with a small number of candidates and a small number of generations.

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