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Acceleration of the multilayer network operator method using MPI for mobile robot team control synthesis

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Abstract

The paper is devoted to the problem of machine-made synthesis of control for robotic teams. The goal of synthesis is to find a multidimensional control function that depends on the current states of all robots. The synthesised control function provides any time the optimal control values to allow each robot achieving the objectives with the best value of functional quality. The approach is based on multilayer network operator method that belongs to a symbolic regression class. Formations of multi-robot systems require individual robots to satisfy their kinematic equations while constantly maintaining inter-robot dynamic constraints. Verification of these dynamic constraints on each iteration of the evolutionary algorithm greatly increases the computational costs of the numerical synthesis. In the paper we propose to accelerate existing designs through taking advantage of newest programming tools of MPI framework for automatic parallelization. Experiments show that our approach reduces greatly computational time.

Keywords: group of robots; symbolic regression; network operator; parallel genetic algorithm; MPI.

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1. Introduction

Unmanned machines or robots are now our reality. Their brains are their control systems. And what is a challenge for us is how to make them produce their control systems by themselves, how to make machines to design control systems.

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The recent achievements in symbolic regression make it possible to automate the process of control system synthesis. Methods of symbolic regression [1-4] are looking with the help of evolutionary algorithm for a function describing the control system. During the search the function is specially coded. Software implementation of such approach allows us to automate the process of control system synthesis. Our research group is focused on the development and application of symbolic regression methods to the issue of control synthesis. We have developed our approach of the network operator [4] for designing a feedback controller in the form of multidimensional function that depends on the plant's state. We have also modified other methods of symbolic regression such as genetic programming [5] and analytical programming [6] so that they can be easily applied for such complex problem as control synthesis. We have successfully implemented them to control system synthesis for a mobile robot [5-7], flying robot [8] and even for a small group of two mobile robots [9].

In the present paper we address the problem of multi-robot control. And the design of feedback control systems for multi-robot teams is a rather different and very challenging task especially with an increasing number of robots in a team. Formally speaking, when a large group of moving robots is considered there become a great difficulty to take into account dynamical constraints that guarantee the absence of collisions between them. Verification of these dynamic constraints on each iteration greatly increases the computational costs of the synthesis.

One of the way we have proposed to overcome the mentioned computational complexity is the application of multi-layered version [10] of the network operator method (NOP). Such multilayer framework of the network operator makes it possible to present arbitrarily large network operator as a connected set of network operators of smaller dimension. And it allows solving the control synthesis problem for a group of robots without limitations to the number of robots in a group. But the computation is very time-consuming. So the acceleration of the MNOP method is a focus of the present paper. Several parallel implementations have already been proposed [11, 12]. However, on high-performance computing systems it is important to further accelerate existing designs through taking advantage of newest programming tools. To improve the performance of MNOP on several cores this paper proposes to use incorporated MPI framework for automatic parallelization. Experiments show that our approach reduces computational time more than 7 times.

2. Problem statement of control synthesis for a mobile robot team

We consider a team of swarm robots as a single system with extended state vectors and control vectors. This means that each robot in a team has a full information about other robots in his team. The mathematical model of each mobile robot in a team is described by the following differential equations

$$\dot{x}_i = u_{1,i}\cos(\theta_i),\ \dot{y}_i = u_{1,i}\sin(\theta_i),\ \dot{\theta}_i = \frac{u_{1,i}}{W}\operatorname{tg}(u_{2,i}),\ i = 1,\ldots,N, \tag{1}$$

where (x_i, y_i) are coordinates of the geometric centre of the robot i, θ_i is an angle between the roll axis of the robot i and x-axis of the fixed coordinate system, W is an overall dimensional parameter of robot, the same for each robot, $u_{1,i}$, $u_{2,i}$ are components of the control vector of the robot i, N is a number of robots.

Possible control is constrained

$$u_1^- \le u_{1,i} \le u_1^+,\ u_2^- \le u_{2,i} \le u_2^+,\ i = 1,\ldots,N. \tag{2}$$

Given a set of initial conditions for the team of robots

$$\mathrm{X}_0 = \{((x_1^{0,1}, y_1^{0,1}, \theta_1^{0,1}),\cdots,(x_N^{0,1}, y_N^{0,1}, \theta_N^{0,1})),\ldots,((x_1^{0,M}, y_1^{0,M}, \theta_1^{0,M}),\cdots,(x_N^{0,M}, y_N^{0,M}, \theta_N^{0,M})), \tag{3}$$

where M is a number of initial points in a space.

The control objective is defined by the terminal conditions