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Application of Bat Algorithm Based Time Optimal Control in Multi-robots Formation Reconfiguration

Guannan Li[1,2*], Hongli Xu[1], Yang Lin[1]

1. *State Key Laboratory of Robotics*, *Shenyang Institute of Automation*, *Chinese Academy of Sciences* (*CAS*), *Shenyang* 110016, *China*
2. *University of Chinese Academy of Sciences*, *Beijing* 100049, *China*

Abstract

This paper proposes a Bat Algorithm (BA) based Control Parameterization and Time Discretization (BA-CPTD) method to acquire time optimal control law for formation reconfiguration of multi-robots system. In this method, the problem of seeking for time optimal control law is converted into a parameter optimization problem by control parameterization and time discretization, so that the control law can be derived with BA. The actual state of a multi-robots system is then introduced as feedback information to eliminate formation error. This method can cope with the situations where the accurate mathematical model of a system is unavailable or the disturbance from the environment exists. Field experiments have verified the effectiveness of the proposed method and shown that formation converges faster than some existing methods. Further experiment results illustrate that the time optimal control law is able to provide smooth control input for robots to follow, so that the desired formation can be attained rapidly with minor formation error. The formation error will finally be eliminated by using actual state as feedback.

Keywords: Bat Algorithm, CPTD method, multi-robots formation control, time optimal control

1 Introduction

The Bat Algorithm (BA) is a metaheuristic algorithm inspired by the echolocation behavior of bats[1]. It is an efficient technique that has a balanced combination of the advantages of existing optimization algorithms, making it superior in solving optimization problems. So far, the BA has been successfully applied to various aspects, such as tuning the control parameters of PID controllers[2–7], getting the optimal location scheme for wells in oil production[8] and distributed generations in distribution system[9–11], reducing the side lobe level in symmetric linear array antenna[12,13], improving mechanical design[14–16] and improving the performance of artificial neural networks[17,18], and optimizing the performance of temperature regulation systems[19,20]. It has also been used to plan the sports training sessions[21] and classify crop type from multispectral satellite image[22]. The great application potential of the BA encourages the study to improve its performance. Consequently, multiple variants are emerging. Some variants aim at solving the premature problem in standard BA[23–25]. The parallel version of BA[26] and discrete version of BA[27,28] focus more on specific kinds of problems, and a parameter-free version of BA is proposed to make it easier for use[29]. Other variants focus on certain applications. In these cases, the improved versions of BA are usually obtained by combing the standard BA with other schemes, such as Differential Evaluation (DE)[30], cloud theory[31], supported vector machine[32], chaotic sequences[33]. In current applications, the BA is used to calculate the optimal solution of an optimization problem derived from an accurate model. However, in practical applications, an accurate mathematical model of a system is not always available, and sometimes the disturbance from the environment further worsens the situation. These problems are often confronted in the formation control of a multi-robots system, where the application of the BA still needs to be explored.

Multi-robots systems have great potential in both scientific and civil applications. As a fundamental problem for multi-robots coordination, the formation control of multi-robots system has been studied in different robot systems from marine robots that dive un-

***Corresponding author:** Guannan Li
E-mail: liguannan@sia.cn

derwater to satellites orbit in space. So far, different formation control algorithms have been proposed, such as behavior based method, artificial field based method and graph theory based method[34–36]. Some of them have already been employed in practical applications[37]. However, there still lack enough researches on time optimal formation reconfiguration problems.

As a multi-robots system is a complex nonlinear system, it is a challenging task to derive the time optimal control law for formation reconfiguration. Some researches have been made to solve this problem. A Control Parameterization and Time Discretization (CPTD) method is proposed in Ref. [38]. Time discretization converts the continuous control law into a set of parameters. Numerical methods can then be applied to calculate these parameters. Further explorations based on this method adopt different intelligent computation methods, *e.g*. Particle Swarm Optimization (PSO), hydroid PSO and pigeon inspired algorithm[39–42], to attain time optimal formation reconfiguration in UAVs. However, as the control law is derived based on the mathematical model of the system, ignoring the actual state of the system, the robots may fail to converge to the desired formation due to the inaccuracy of the model and disturbance from the environment. Besides, the control law obtained by this method usually changes drastically, making it hard for robots to follow. At present, this method has only been verified by simulation. Experiments with real robots have not been carried out yet.

On the other side, formation reconfiguration methods, such as line-of-sight based method, relies less on the accuracy of the model. It deals with environment disturbance for the robots by adjusting the actual state of the system. This method has been successfully applied to the formation reconfiguration of multi-AUVs system, which confronts much harsher environment with current flow and communication constraints[43]. However, due to the lack of theoretical basis, the formation may fail to converge fast enough.

In this study, a Bat Algorithm based Control Parameterization and Time Discretization (BA-CPTD) method is proposed to compute time optimal formation reconfiguration control law, dealing with situations where an accurate mathematical model of a multi-robots system is unavailable, and disturbance from the environment exists. The process of formation reconfiguration consists of two stages. In the first stage, an improved CPTD method inspired by the original CPTD method[38] is applied to convert the problem of seeking for an optimal control law into a problem of seeking for a set of optimal parameters. The BA[1] is then used to get the control law. As this control law is obtained purely based on the mathematical model of the system, formation error exists in field experiment. In the second stage, the line-of-sight based method is applied to introduce the actual state of the system as feedback information, thus eliminating the formation error.

The contributions of this paper are as follows:

(1) We propose a paradigm that converts time optimal formation reconfiguration problem into a parameter optimization problem, so that the BA can be applied to derive the time optimal control law.

(2) The variations of the control input are used as the parameters to be optimized, rather than the control input itself as in the original CPTD method. This way makes the control law become much smoother, and thus making it easier for robots to follow.

(3) Actual states of the system are introduced as feedback information by adding a compensation part to the control law. Afterwards the BA-CPTD method is applied to the situations where the model is inaccurate, or disturbance from environment exists.

(4) Field experiments are performed to verify the effectiveness of the proposed method.

The rest of the paper is organized as follows. The mathematical description of the problem and the BA-CPTD control law is introduced in section **2**. The two sub control laws of the BA-CPTD control law are then explained in detail. The control law obtained by an improved CPTD method and BA is presented in section **3**, and the control law according to line-of-sight based method is given in section **4**. In section **5**, several sets of experiments are carried out to verify the effectiveness of the proposed method, and finally, we conclude the paper in section **6**.

2 Problem description and multi-robots formation reconfiguration time-optimal control law

A paradigm is presented to convert the time optimal