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Geometric topology based cooperation for multiple robots in adversarial environments ☆

Dandan Zhang[a], Long Wang[a,*], Junzhi Yu[b]

[a]Intelligent Control Laboratory, Center for Systems and Control, College of Engineering, Peking University, Beijing 100871, PR China
[b]Institute of Automation, Chinese Academy of Sciences, Beijing 100080, PR China

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Abstract

This paper addresses the cooperation problem for a team of mobile robots in adversarial environments. Considering the mutual influence among the robots, two key factors are defined: the impact factor and the suffering factor. A stochastic assignment model is built, based on the geometric topology of the targets, through which the robots can exhibit temporal cooperation. To reduce computational complexity, a genetic algorithm is employed to optimize the relative weights of the impact factor and the suffering factor, and after that, the Improved Hungarian Algorithm is used to solve the assignment problem. Both simulation and experimental results demonstrate the effectiveness of the proposed method.

Keywords: Cooperation; Adversarial environment; Impact factor; Suffering factor; Multiple robots

1. Introduction

Recently, the problem of assigning a team of fighting units to attack targets has received considerable attention (Galati & Simaan, 2004; Li & Cruz, 2005; Rasmussen & Shima, 2006). A group of mobile robots are competent for such tasks for their flexibility, adaptability to unknown environments and robustness (Alighanbari & How, 2005; Antonini, Ippoliti, & Longhi, 2006; Beard, McLain, Goodrich, & Anderson, 2002; Tinós, Terra, & Bergerman, 2007). However, this kind of problem involves several significant challenges, including team composition, sensing capability, optimal task assignment and path planning, etc. In this paper, mainly the task assignment problem is concerned. Due to the adversarial nature of the battle environments, the robots cannot always be assumed to succeed in their tasks, but may fail. Particularly, in the heavily defended environments, the robots will take great risk on performing their assigned tasks. To fully utilize the integrated capabilities of the team, and maximize the number of the destroyed targets in limited time, the design of the cooperation method is crucial.

Lots of previous work on the task assignment problem in risky environments treated it as the Weapon Target Assignment (WTA) problem, which has been addressed for several decades (Hossein & Athans, 1990; Murphey, 1999a, 1999b; Rosenberger et al., 2005). WTA is usually viewed as a combinational optimization problem that is NP-hard. Several approaches to solve WTA have appeared, in which a common approach is the genetic algorithm (GA) (Juell, Perera, & Nygard, 2003; Lee, Su, & Lee, 2003; Shima, Rasmussen, & Sparks, 2005), which can reduce the computational complexity. However, most of these approaches did not consider the mutual coupling relation of the targets, thus the influence of the actions of the robots in previous stages on their performance in the following stages is ignored. Undoubtedly, cooperation methods taking into account such influence will improve the overall performance of the team.

The different work is from Alighanbari and How (2005), in which a stochastic model similar to formulations (2), (3) is presented. With this model, coordinated task assignment

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*Corresponding author.
E-mail address: longwang@pku.edu.cn (L. Wang).

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is exhibited with the additional knowledge of the implications of a UAV's actions on improving the expected performance of other UAVs in future steps. Taking advantage of the fact that the actions of each UAV can reduce the risk for other UAVs to achieve better performance, the model leads to coordinated plans of the robots which exploit optimally the coupling effects, thus to improve the survival probabilities and expected performance of the team. Thereafter, the assignment problem is solved by Dynamic Programming (DP) approach.

DP was originally developed by R. Bellman in 1957. It is an optimization technique for formulating problems in which decisions are to be made in multiple stages. The problem is divided into several stages or subproblems, and is solved sequentially by taking a decision at each stage. DP is an implicit enumeration approach, and normally yields a global optimal solution. Unfortunately, the computational cost increases very rapidly with the number of the state variables (Walsh, 1975). Thereby, DP approach cannot satisfy the requirement of real-time task assignment as the problem dimension increases, especially when the spatial distribution of the vehicles is considered.

As the targets can defend one another, the topology relation among them is quite important for the robots to determine the assignment strategy. Due to the defense relation among the targets, the action of one robot can reduce the risk of other robots or itself in the following stages. To utilize the maximum integrated capability of the robots, the temporal cooperation taking into account the defense topology of the targets is quite desirable. In the presented task assignment model, the defense topology among the targets is involved. In addition, the robots can be reused after it performs one task successfully. The initial locations of the robots can be arbitrary. The goal is to optimize an objective function, which involves the defense topology information of the targets and implicates the temporal cooperation of the robots. To reduce the computational complexity, GA is employed to determine the coefficients of the impact factor and the suffering factor in the objective function, and after that, the Improved Hungarian Algorithm (IHA) is developed to solve the assignment problem. It is to mention that although GA is not a novel approach for solving the optimization problem, here it is utilized to obtain the "coefficients" in the model, which result in the temporal cooperation of the robots. This is an essential difference with other GA approaches, which optimize the assignment directly. The proposed method is then evaluated through simulations and a Cooperative Bombing Task, which is performed on the biomimetic robotic fish platform (Fang, Yu, Fan, Wang, & Xie, 2005; Zhang, Wang, Yu, & Tan, 2007).

The rest of the paper is organized as follows. Section 2 gives a detailed description of the task in the adversarial environment. In Section 3, the cooperation method is presented. The simulation results are given in Section 4, and the experimental results are given in Section 5. Section 6 concludes the paper.

2. Adversarial task description

2.1. The problem description

Fig. 1 shows a typical adversarial task scenario, which involves N_f robots and N_t targets. The task is to assign the robots to attack the targets. Each target has a defense region, in which the robot may be killed by the target. The defense regions of the targets overlap, thus the successful actions of the robots in the previous stage will improve the success probabilities of other robots when performing tasks in the following stages. The robots will take different risk degrees on attacking different targets. The spatial distribution of the robots is considered, and a robot can be reused if it survives the attacking task. The assignment is required to fully utilize the integrated capabilities of the robot team, and maximize the number of the destroyed targets within a finite stage T. Firstly the definition of *survival probability density* is given.

Survival probability density: The survival probability of the robot when passing the unit distance.

For robot $F1$, the example path types corresponding to different *survival probability densities* are shown in Fig. 1, with different colors. The yellow lines represent paths with low risk degree, the blue lines are paths with higher risk degree, and the dark red lines are paths with higher risk degree than the blue lines. Note that when the path is not in the defense region of any target, the path is called a safe path, represented by the black dotted line.

Based on above definition, the assignment problem can be formulated. The goal is to assign the robots to the targets within T, aiming to optimize an objective function, which is typically the expected accumulated value of the targets. Let s_i denote the value of target i and $p_{ij}(t)$ the

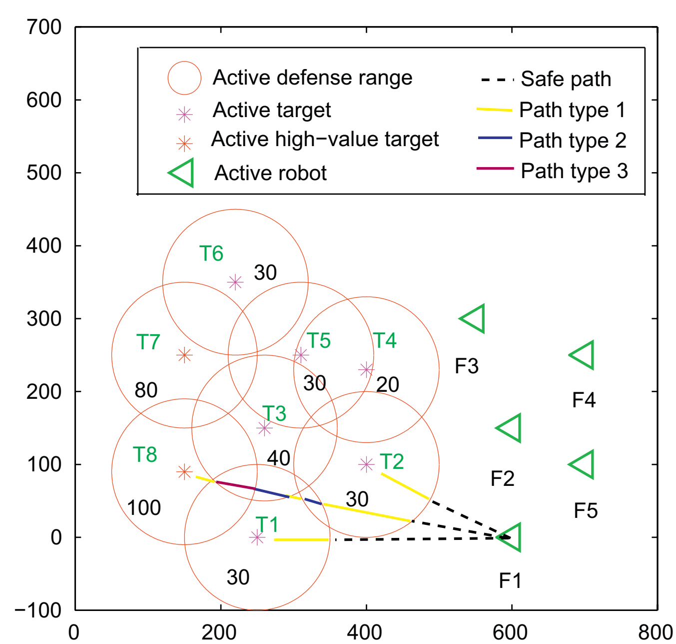

Fig. 1. The adversarial task scenario.