Uncertainties in Adversarial Patrol

(Extended Abstract)

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ABSTRACT

In this paper, we study the problem of multi-robot perimeter patrol in adversarial environments, under uncertainty. In this problem, the robots patrol around a closed area, where their goal is to patrol in a way that maximizes their chances of detecting an adversary trying to penetrate into the area. Uncertainties may rise in different aspects in this domain, and herein our focus is twofold. First, uncertainty in the robots' sensing capabilities, and second uncertainty of the adversary's knowledge of the patrol's weak points. In this paper we provide an initial discussion and initial results concerning these two aspects of uncertainty in the multi-robot perimeter patrol problem. Specifically, we first consider the case in which the robots have realistic, and thus imperfect, sensors. These cannot always detect the adversary, and their detection capability changes with their range. We then deal with different possible choices of penetration spots by the adversary, and discuss possible optimal solution for the patrolling robots in each such case.

Categories and Subject Descriptors

I.2.9 [**Robotics**]: Autonomous vehicles; I.2.11 [**Distributed Artificial Intelligence**]: Multiagent Systems

General Terms

Algorithms, Security

Keywords

Multi-Robotics, Adversarial/game domains, Formal models of multi-robot plans, Multi-robot path planning

1. INTRODUCTION

The problem of multi-robot patrol has gained growing interest in the past years [4, 5, 8, 7]. In this problem, robots are required to repeatedly visit a target area while monitoring it in order to detect some change in the area's state. Most researches have concentrated on assuring some point-visit frequency criteria by the patrol algorithm. Agmon et. al. presented a new approach for multi-robot patrol in [2], where they addressed the problem of multi-robot patrol in adversarial environments, in which the robots' goal is to patrol in a way that maximizes their chances of detecting an adversary trying to penetrate through the patrol path. They have shown that this problem is inherently different from the frequency driven patrol problem, and discussed optimality of patrol algorithms in different adversarial environments.

Generally, when dealing with a system of robots, it is necessary to consider deviation from the expected behavior of the robots in order to adapt the system to real world constraints settings (e.g. [12, 13]). One of the aspects of interest is uncertainty in the robots' sensing [12]. In reality, it is rarely the case that robots sense successfully and accurately everything they are supposed to detect, and in this case it is important to address the probability that their sensing will fail. A second aspect is uncertainty in the capability and knowledge of the adversary (depending, for example, on its confidence in the information it attained on the patrolling robots). In this paper we address these two different aspects, and describe initial results concerning modeling the behavior of the system and possible solutions to finding the best patrol algorithm for the robots in each scenario.

A first attempt to deal with perception uncertainties in adversarial patrol was given in [1], which altered the model of multi-robot *open fence* (polyline) patrol to deal with cases in which the robots will detect penetration in their current location only with some probability $p_d \leq 1$. In this paper we attempt to expand this result for *perimeter* (closed polyline) patrol, and discuss possible other sensing capabilities of the robots.

Previous work in adversarial patrol has shown that the optimality of patrol algorithm depends on the adversarial model, specifically the knowledge obtained by the adversary on the patrolling robots. Theoretical optimality results were proven for a zero-knowledge adversary, in which the adversary choose as its penetration spot at random with uniform distribution, and for a full knowledge adversary, that is assumed to choose the weakest point of the patrol as its penetration spot. In the latter case the penetration spot is well defined. However, since the calculation of probability of penetration detection throughout the perimeter is not trivial, it is likely that the adversary will choose to penetrate through one of the weakest spots, and not through the exact optimal spot. On the other hand, the adversary might choose to penetrate through some physical proximity to the weakest spot. We discuss here a possible solution for a patrol algorithm based on these assumptions.

2. BACKGROUND

Systems of multiple robots, working together in order to patrol in some target area, have been studied in various contexts, where most of the studies concentrated on optimizing frequency criteria by the patrol [4, 5], without any reference to the existence of an adversary.

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Agmon et. al. [2, 3] introduced the multi-robot *adversarial* perimeter patrol along with the robotic model we base our work upon. They analyze the optimality of patrol algorithms in different adversarial models, where the models differ in the amount of knowledge obtained by the adversary on the patrol algorithm. They make very little reference to various sensing capabilities of the robots, and do not address the problem of uncertainty in adversarial choice.

Other closely related work is the work by Paruchuri et. al. [11, 10], which consider the problem of placing security checkpoints in adversarial environments. They use policy randomization for the agents behavior in order to maximize their rewards. They do not consider sensorial scenarios which depend on different sensorial models of the robots. Jain et. al. [9] continue this research to consider the case in which the adversary makes their choice based on their bounded rationality or uncertainty, rather than make the optimal game-theoretic choice. In our work we discuss both uncertainty in sensing and uncertainty in adversary's choice, and provide optimal polynomial-time solutions for both cases.

3. ROBOT AND ENVIRONMENT MODEL

We are given a team of k homogenous robots, required to patrol around a closed area (perimeter). The perimeter is divided into N segments, where the travel time of each robot through a segment is uniform, i.e., all robots travel through one segment per time cycle . Hence the segments' length is uniform in time, but not necessarily in distance.

The robots have directionality associated with their movement, i.e, if they go backwards they have to physically turn around. We model the cost of turning around in time, and denote time it takes the robots to turn around and stabilize in their new direction by τ.

The system of perimeter patrol is linear, meaning that at each time step the robots have one of two options: go straight or turn around. Therefore the robot's patrol algorithm is characterized by a probability p, i.e., at each time step go straight forward with probability p, or turn around with probability $q = 1 - p$.

4. UNCERTAINTY IN SENSING

In this part of the work we deal with uncertainty in the robots' perception. Specifically, we consider the case in which the robot could have imperfect sensorial capabilities. We discuss initial results concerning three possible models of sensing abilities. In the first model, the robots have sensing abilities that exceed the segment they currently reside on. In the second model, the robots' sensorial abilities might not be perfect. This leads us to the last and general model, that combines both models and deals with the case that the robots' sensing abilities exceed their current location, yet the reliability of the detection is not perfect. In all of these models, the new sensorial abilities dictate change in the algorithm for calculating the probability that the adversary will be detected at each segment along the perimeter. This therefore changes in optimal probability p characterizing the patrol algorithm, however the algorithm for finding the optimal p depends on the adversarial model.

5. UNCERTAINTY IN THE ADVERSARY'S PERSPECTIVE

In this section we turn to examine uncertainties in the adversary's point of view. Specifically, we try to bound the level of uncertainty the adversary has on the patrolling robots, and specifically on its optimal choice of penetration spot. Quantifying the uncertainty of the adversary is important in order to find optimal patrol algorithms that are suitable to the level of uncertainty of the adversary. In other words: Given a bounded region of the adversary's uncertainty, what is the patrol algorithm that maximizes the probability of penetration detection?

We suggest two general approaches for bounding the uncertainty level. In the first approach, we examine the case in which the adversary knows the probability p characterizing the patrol algorithm with some uncertainty. Unfortunately, we show that it is impossible to find an optimal patrol algorithm in this case.

We therefore begin to evaluate additional approaches, in which the uncertainty is reflected by the choice of penetration spot. In this case, we do not necessarily assume that the adversary calculates the exact patrol algorithm, but tries to estimate the weakest spot using two estimation methods - physical proximity, or closeness to the value of the weakest spot.

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