Border Intrusion Detection with Mobile Robots

Project for Algorithm: Analysis and Theory

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Abstract. This project introduces the concept of border intrusion detection with mobile robots. It includes the brief introduction of weak/strong detection, the concepts and the definitions regarding min-move intrusion detection problem. Finally, it lists all the requirements and rules for each group. Please read this document carefully and complete the corresponding tasks.

Keywords: Intrusion Detection, Mobile Robot

1 Border Intrusion Detection Problem

Intrusion detection plays an important role in many security applications like battlefield surveillance, border protection, and airport intruder detection, etc. Nowadays we could use intelligent mobile robots to detect intruder actions. Such robot can detect any affairs within effective distance to its current location, so we could define a detecting disk centered at a robot to monitor the target area.

Assume you are required to protect a line entrance with length ℓ. Initially there are homogeneous n mobile robots placed in the plane around, each with radius r and location (x_i, y_i). Each robot can move freely everywhere, and its moving distance is the Euclidean length of the corresponding trajectory.

To achieve success intrusion detections for this line entrance, we define **weak detection**, **strong detection**, and k**-layer detection** as follows:

1. **Weak detection**: any straight intrusion trajectory coming from the orthogonal direction to this line entrance can be detected by at least one robot.
2. **Strong detection**: any free intrusion trajectory traveling across the line entrance can be detected by at least one robot.
3. k**-layer detection**: any intrusion trajectory going through the line entrance can be detected by at least k robots (should consider weak and strong versions separately).

Unfortunately, the initial robot placement may not naturally satisfy the requirement of weak/strong/k-layer detection, so we could move some robots to new positions to guarantee the detection requirements. However, the energy consumption for robot moving is far from that for detecting objectives. Thus we are always eager to reduce the overall moving distance of mobile robots.

Fig. 1 shows an example scenario of border intrusion detection. The line entrance has a length of ℓ, and there are 4 robots with detection radius r placed at their corresponding locations, shown as four black cycles. Two typical intrusions, the red lines I_1 and I_2, are viewed as exceptions for weak detection and strong detection respectively. Easy to see, to achieve a weak detection, robot v_4 should move straightly to the left until it "touches" the boundary of robot v_3 along the x-axis (the same direction as the line entrance). While to satisfy a strong detection, robot v_1 should move upper-right to fill the gap between itself and robot v_2. Similarly, robot v_4 needs to follow similar strategy. For k-lay detection, it can be viewed as multiple 1-layer detections together.

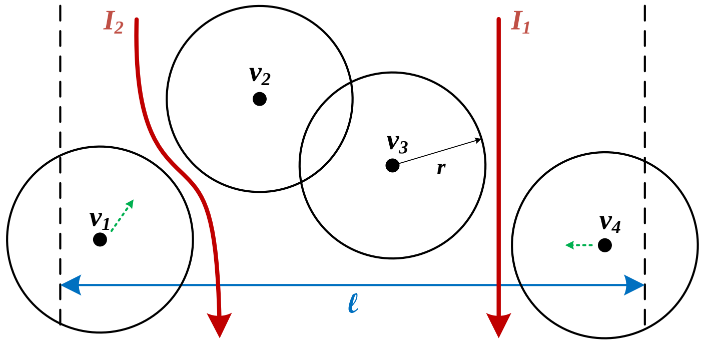

Fig. 1. An Illustration of Intrusion Detection

2 Tasks and Requirements

In this project, you are required to deal with weak detection, strong detection, and k-layer detection (two versions) respectively. We define our problem as *Border Intrusion Detection* problem (BID). Given n homogeneous mobile robots with radius r, initially placed at (x_i, y_i)'s, and a line entrance of length ℓ, design a trajectory schedule for mobile robots to satisfy weak/strong/k-layer detection respectively, such that the overall robot moving distance is minimized. For each of the problems, please finish the following tasks.

2.1 Problem Formulation

Please formulate the problem formally as a mathematical programming. You need to define variables carefully and model the description of every requirement and constraint mathematically. Moreover, can you convert your programming as an LP (Linear Programming) or ILP (Integer LP)?

2.2 Problem Analysis and Algorithm Design

Firstly, please judge the difficulty of your defined problem. Whether it is in P, NP, NP-Complete, or NP-Hard? Prove or clarify your conclusion.

Next, please design an efficient algorithm to solve the detection problem in polynomial time with respect to the input size. You need to describe your design first, introduce the necessary concepts, symbols, definitions, etc., and write the pseudo code of your design.

2.3 Theoretical Analysis and Performance Evaluation

For each variation of detection problem, you need to complete the following tasks:

Theoretical Analysis: For this part you are aiming to distinguish the theoretical properties of your problem and algorithm designs, including the following items:

1. Analyze the time complexity of your designed algorithm.
2. If the problem you are dealing with is in P, then prove the correctness of your design. Otherwise discuss the feasibility or the approximation property of your algorithm.

Performance Evaluation: it includes the following requirements:

1. For each question, visualize an example with more than 20 robots to illustrate your design. You should provide a table to show the coordinate information of each robot before and after movement. Your visualization should also include at least two figures to exhibit your algorithm before and after robot movement.
2. Test the efficiency of your design by simulations. To better describe the algorithm, define "redundancy rate" as $\frac{2rn}{\ell k}$, which should be vary from 1.25 to 2, in depth of 0.25. Given $\frac{\ell}{r}$ as 10, 20, 30, and 40 respectively. Additionally, k is set from 1 to 10. You need to set up other parameters appropriately for testing. Plot figures for comparisons, where the value of each point should be the average value of at least 50 different calculations. The more instances you calculate, the more accurate your results will be. Note that you may also try some heuristics for BID problem with faster executing time as comparison baselines.

2.4 Report Requirements

You need to submit a report for this project, with the following requirements:

1. Your report should have the title, the author names, IDs, email addresses, the page header, the page numbers, figure for your simulations, tables for discussions and comparisons, with the corresponding figure titles and table titles.
2. Your report is English only, with a clear structure, divided by sections, and may contain organizational architecture like itemizations, definitions, or theorems and proofs.
3. Please include reference section and acknowledgement section. You may also include your feelings, suggestion, and comments in the acknowledgement section.
4. Please define your variables clearly. If needed, a symbol table is strongly recommended to help readers catch your design.
5. Please also include your latex source and simulation codes upon submission.