Project Manual Bachelor (Year 2)

Project 2-2

Multi-agent Surveillance

Period 2.4, 2.5, and 2.6
Academic year 2021-2022
Data Science and Knowledge Engineering
Faculty of Science and Engineering
Maastricht University

Courses

Human-Computer Interaction and Affective Computing (KEN2410)
Theoretical Computer Science (KEN2420)
Mathematical Modeling (KEN2430)
Philosophy and Artificial Intelligence (KEN2120)
Simulation and Statistical Analysis (KEN2530)
Introduction to Video and Image Processing (KEN3238)

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The central topic of project 2-2 is multi-agent surveillance. A standard setting / world is described in which research can be executed.

1 Contents

1 Project description

Automated surveillance of different environments through cooperating mobile agents (robots) is among the most urgent and promising topics in multi-robot research.

In the past decade, criminal and terroristic developments have led to a tremendous interest in automated surveillance systems as a mean to improve security and safety.

In recent years, there has been a rapidly growing interest in using teams of mobile agents (surface robots, flying robots, etc.) for automatically surveilling environments of different type and complexity. This interest is mainly motivated by the broad spectrum of potential civilian, industrial and military applications of multi-robot surveillance systems. Examples of such applications are the protection of safety-critical technical infrastructures, the safeguarding of country borders, and the monitoring of high-risk regions and danger zones, which cannot be entered by humans in the case of a nuclear incident, a bio-hazard or a military conflict. Because of this broad application range, today mobile surveillance is considered as an urgent and promising field of research in various disciplines such as artificial intelligence and robotics.

Two interrelated key components of every multi-agent surveillance system are environmental *exploration* and *coverage*. The term "exploration" refers to the discovery of all traversable regions of the environment through one or several agents. The term "coverage" refers to the maximization of the total area covered by the sensors of the involved robots (within a certain time window). In a sense, exploration may be viewed as the initial phase of coverage. Both exploration and coverage typically rely on the following basic activities: map building, (self-)localization, environmental partitioning, path planning, and intruder detection and tracking. Not all of these basic activities are equally relevant for different surveillance tasks. Moreover, surveillance scenarios can differ in a number of characteristics such as: the shape, dynamics and predictability of the environment, the number of involved agents, the agents' sensing abilities (sensor ranges, and view angles), the agents' communication abilities (local versus global), the agents' movement speed, the organization of the agents (e.g., peers versus hierarchical structure), reliability of the agents, the agent's cognitive abilities (learning and planning), the degree of homogeneity/heterogeneity of the agents, the costs of moving around, and so forth.

This project consists of three phases.

1.1 Phase 1

In the first phase (period 2.4) a game controller and (at least) one algorithm to explore the map with multiple agents (exploration agents) are implemented. The game controller manages the simulation of the surveillance game, while the exploration agents should be able to move in the environment and explore the space. The map of the environment to be surveilled and its properties are defined in a file, which is given as input to the game controller and to the exploration agent, and both of them must be able to interpret it. Furthermore, the implementation of a simple GUI that shows the map and the simulation of the game is expected. As starting point, the incomplete implementation of a game

controller and the implementation of a random exploration agent are given. You do not need to use it and we do not guarantee the correctness, but it may be a good starting point.

The code of the game controller, the exploration agent and the GUI are expected as deliverable at the end of phase 1.

In order to evaluate the performance of your exploration implementation, we may give you a map as input after the presentation to see how quickly you explore this map. Therefore, please check the testmap we uploaded to Canvas and make sure that your implementation can handle all features from this testmap. Of course, you can already add other features and conduct nice experiments with them. You need to report on the time needed to explore the full map.

Moreover, in the presentation, an overview needs to be provided of which group member contributed to what and to which extent during the work in phase 1, together with a planning of the work for phase 2 (Gantt chart).

The planning should contain a concrete idea of which approaches will be implemented in phase 2 such that you can start phase 2 without doing another literature review. Make sure that you – by the end of phase 1 – know which algorithms have been implemented already to solve this or similar problems and which algorithms you choose to implement in phase 2.

1.2 Phase 2

In the second phase (period 2.5), at least one type of intelligent surveillance agent (SAs, also known as guards) and one type of intelligent intruder agent are implemented. The code of the exploration agent implemented during the first phase can be used as a starting point for the guards. The guards should explore the environment, "discover" the intruder and then track it or surround it. The intruder should find a given target location before being caught by the guard (thus, as fast as possible). However, when spawning on the map, they do not know the map either but only the direction of the target.

In the presentation, an overview needs to be provided of which group member contributed to what and to which extent during the work in phase 2, together with a planning of the work for phase 3 (Gantt chart).

Furthermore, a report draft needs to be handed in. The draft should contain a full introduction including a literature review, the description of approaches for the intelligent guard and the intruder agent (method), the experiments conducted in phase 2 as well as their results, a discussion of these results and a conclusion. Feedback on the draft report will be given by the examiners in the pre-examination in phase 3.

1.3 Phase 3

At least a second intelligent surveillance agent is implemented. During the project weeks, the group focuses on experimenting with the system. This should be based on the research questions. Here a lot of options are open.

Examples of possible research issues (w.r.t. both exploration and coverage) are:

- What are the consequences of constraints on the perception (e.g. local variance of visibility) of the agents or constraints on the (range / radius of) communication between agents?
- What are the consequences of restrictions on the speed or acceleration of the SAs or the intruder?
- What impact does communication among the agents have? What should agents communicate?
- Sensitivity analysis: e.g.: What is the influence of the number of SAs on the performance?
- Can you (gradually) make the intruder more intelligent? How does the system respond to this? Is it possible to make the system adaptive?
- What happens when multiple intruders are introduced?
- What is the fault tolerance / robustness of the system, or its scalability?
- Which group has the best intruder or guard.
- Recognition of a target face via image recognition (you can choose what faces you want to recognize: the data can be for example your team members or a larger benchmark data set like labeled faces in the Wild

Obviously, a proper statistical analysis of your results is paramount. The results will be described in a scientific article. This report should also include the answer to the research questions defined in the previous phase. Please read the writing guidelines uploaded to Canvas for more information. Moreover, an overview should be provided of which group member contributed to what and to which extent during the work of phase 3.

2 The setting

This section describes possible properties of the environment the agents operate in. This is not an exhaustive list of properties. You can include all the following properties and, of course, are welcome to add more.

2.1 Velocities

Both the guards as the intruders have a base speed. Variation of this speed is possible, e.g. the intruder might be able to sprint for a few seconds and might need to rest a few seconds after each sprint.
Both agents have a limit on the speed at which they can turn (e.g. they cannot turn faster than X degrees/second) and may do this while walking. Proceeding at a faster speed, e.g. sprinting, may reduce the turning speed of an agent.

2.2 Visual capabilities

All agents have a base visual range with a limited viewing angle. The type of area in which the agent is situated might affect visual range and viewing angle. For example, if the agent is in an area with trees and shade the visibility range and viewing angle are reduced, or if the agent is on a sentry tower its visibility range might increase in the long range and decrease in the close range.

2.3 Audio capabilities

Hearing something means that you are aware of an unknown sound in the actual direction with normal distributed uncertainty with a standard deviation of 10 degrees. So everything makes the same sound, hence you cannot distinguish between guards, intruders and other sounds. Sounds thus only provide an awareness of a presence. A sound is produced by an agent moving in the environment or by an agent interacting with certain types of areas (e.g. see in Subsection 2.7. the example of an agent making sound when entering a structure from a door or window).
When moving, an agent can be heard depending on his speed. The faster an agent is moving, the further the noise can be heard. It is up to you to define these distances. A special type of sound is produced by guards, which can yell whenever they detect an intruder. A yell is distinguishable from other sounds and it is up to you to decide whether and how to exploit the ability of guards to yell. A yell is audible only up to a certain distance.

2.4 Communication

Each agent is able to communicate with other agents. Two types of communication are usually distinguished: *direct* communication (by sending messages to other agents), and *indirect* communication via the environment (by placing certain markers in the environment which can be sensed locally by the other agents). **For this project, only indirect communication is allowed**. Indirect communication is also known as stigmergy-based or stigmergic or pheromone-based communication. We assume that the surveillance agents have up to five different types of markers available (e.g., markers of different color), where the meaning of the markers is not pre-specified (i.e., it is up to you to assign meanings). The same is assumed for the intruders. Indirect communication is not mandatory, that is, it is up to you to decide on using this form of communication to achieve

coordination among the surveillance agents (respectively the intruders). Obviously, you can also exploit sounds as a form of communication.

2.5 Victory

The goal of the intruder is to reach a target area, while the goal of the guard is to capture the intruder before this happens. Victory conditions should be defined accordingly. Possible examples of victory conditions are the following:

- The intruder wins if he is 3 seconds in any of the target areas or visits the target area twice with a time difference of at least 3 seconds.
- The guards win if the intruder is no more than 0.5 meter away and in sight.

For multiple intruders there are two modes: in the first mode, all intruders need to complete their objectives to win; in the second mode, any of the intruders needs to complete its objective to win.

2.6 Performance Criteria

Different teams of guards perform differently. Usual performance criteria are:

- Time it takes to win. ("Time costs", unit of time costs: seconds)
- Sum of distances the guards had to move around before they win. ("Distance costs" or "movement costs", unit: meters)
- In the case of indirect communication: number of markers placed by the guards in the environment before winning. ("Indirect communication costs")

Note that a team of surveillance agents may perform excellently w.r.t. (e.g.) "time costs", but at the same time may perform poorly w.r.t. (e.g.) "indirect communication costs".

2.7 Scenario

The scenario file contains the map, i.e. the play field. This consists of non-overlapping rectangular areas. Certain types of areas might affect the base agents' speed, visibility and/or sound. Moreover, if agents can interact with an area, sounds may be produced. In the example code, a sample of a scenario file is included. At least the following types of areas exist:

1. *Target area for intruder.*
   The location of this area is unknown to SAs. Even if a guard can see the target area, it cannot identify it as such (thus, camping agents waiting for the intruders are no possible solutions). Intruders do not know the exact location of the target area, but they know the general direction in which the target area is placed.
2. *Spawning area for SA.*
   This is the area where the SA(s) is/are spawned at the start of the game.
3. *Spawning area for intruder.*
   This is the area where the intruder(s) is/are spawned at the start of the game.
4. *Wall.*
   One cannot walk on and through walls and walls are visible from a given distance provided there is a line of sight. Walls can have doors and windows. Going through a door or window will take an intruder a certain amount of time on average (normal distribution with given std) and will produce a sound that can be detected at a given distance.
5. *Shaded areas that decrease the visual range.*

Think about trees and shades. When somebody is hiding there, the visual range even further decreases (see 2.2)

6. *Teleport.*
   Think stairs. A teleport takes you from one location to the next in a single direction to avoid looping.
7. *Textures.*
   This allows to give meaning to things. Whether a teleport is a staircase, elevator or actual portal only means something if you draw it. Textures do not do anything; they are just plotted on top.

Other types of areas should be defined. Below are some examples that you might want to implement, but you are welcome to add different ones:

8. *Windows.*
   Going through a window will take an intruder a certain amount of time on average (normal distribution with given std) and will produce a sound that can be detected at a given distance.
9. *Doors.*
   Going through a door will take an intruder a certain amount of time on average (normal distribution with given std) and will produce a sound that can be detected at a given distance.
10. *Sentry tower.*
    These are visible from a given distance, provided that you have sight, but for spotting whether these are manned, normal ranges apply. Entering a sentry tower takes a certain amount of time, during which the agent has no visibility and cannot hear sounds.

Design maps to keep the game interesting. We might have some nice ideas of our own.

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