Decision-Theoretic Robotic Surveillance
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Surveillance can be informally defined as “a close watch kept over something or someone with the purpose of detecting the occurrence of some relevant events”. The person or thing to be watched should be understood to include humans, animals, areas, places, parts of aerospace, et cetera. What events are considered relevant depends on the type of surveillance and the reason why we do it.

Most surveillance tasks are very mundane and automating them is highly desirable. Automated surveillance typically concerns itself with detection and recognition of relevant events. A system of CCTV cameras, microphones or smoke detectors can be used to detect interesting events or to analyse patterns of behaviour. Most of the existing work on robotic surveillance is on recognition of relevant events.

However, event recognition is only one aspect of surveillance. Another aspect, and the concern of this thesis, is that of selecting the right places to focus the surveillance attention on. A solution to this is essential in situations where using fixed surveillance sensors is either not possible, or not practical, or where mobile platforms are more socially acceptable since people then know they are being observed. Further, a solution to the problem of selecting the optimal places to focus attention on can be important not only to robots but also to human security guards.

Commonly, the reason for focusing attention on one area is that relevant events are more likely to be detected there either because they are intrinsically more likely to occur, or because the area has not been observed for a while - increasing the chance that something is there. Because the robot is not omnipresent, this becomes a problem of limited resource allocation. With enough knowledge of the structure and the parameters affecting the decisions, this allocation problem can be automated.
1.1 Surveillance as a planning task

By reviewing surveillance in section 2.1, three main capacities in which an artificial or human agent can be involved in a surveillance task are identified. They are those of:

**coordinator** An agent that determines or constrains which resources can be used for the surveillance task. The coordinator of a surveillance task may decide on the available budget, on the types of sensors to be used, on its relative importance compared with other tasks, et cetera.

**planner** An agent that decides how to use the available resources (sensors and actuators) to perform the surveillance task. Typically, a planner has a clear goal like exploration or cost minimisation. It should be seen as something much more task-specific than a coordinator.

**sensor** An agent that gathers information and transmits it to the planner. A security camera is an example of sensor.

One way a robot can be used in surveillance is in the capacity of a (flexible) sensor. In that case, the planning of the surveillance task would be typically done by a human operator. An example is a security guard teleoperating a robot that inspects a hazardous environment.

However, it is the next level that concerns us here. The subject of this thesis is the investigation of autonomous surveillance planning for an office-like environment. The main concern is to develop strategies or algorithms that move the robot in a way that the expected cost of relevant events remaining undetected is minimised. To make the discussion simpler we will focus on one type of relevant events, namely that of fires. A detailed justification of these choices is given in the next chapter.

1.2 Approach in this thesis

Humans can perform surveillance tasks quite well most of the time. However, the process that makes this possible is not immediately clear, which makes it hard to replicate it and hard to assess its optimality. In the case where the probabilities and costs are known, we would like to get a structured understanding based on an analysis of surveillance as a probabilistic decision process. We are eventually interested in an algorithmic implementation of such a decision process.

The detailed exposition of the surveillance problem in the rest of the thesis will make it clear that instances of it for simple environments and simple events are still computationally very hard. So it is not clear how a robot should compute solutions to such instances if results are to be found in a reasonable time.
Approximation is a possible solution to the computational issues. However, approximations, in turn, have the problem of departing from optimal. A difficult balancing act exists between the need to approximate and the computational need to get an approximation that is within some reasonable bound to the optimal.

The approximations proposed in this thesis are based on abstracted representations of the environment. Eventually, decisions are taken among different routes of the abstract environment nodes. A mix of theoretic and simulation experiments are presented to support our discussion.

1.3 Thesis overview

This thesis is divided into the following chapters:

Chapter 2 - Issues in Robotic Surveillance. An overview of current and past research in robotic surveillance is given to provide some context. It should become clear from the discussion that most existing work on robotic surveillance addresses event recognition and that not much is on planning. On the basis of this review the decision was taken to concentrate on surveillance planning. In the rest of this chapter some surveillance planning-related issues which affect our work are mentioned.

Chapter 3 - Problem Formalisation and Complexity. The specific problem of fire surveillance is set using several formalisms like (PO)MDPs or decision theory. These formalisms are shown to be equivalent and conveying the exponential nature of surveillance planning viewed as an optimal search problem with the aim of minimising the expected cost of fires. Because of its exponential nature, simple n-step strategies cannot solve this problem optimally, and consequently approximation methods for the surveillance planning problem become a priority.

Chapter 4 - Hierarchy and Strategies. A “cost barrier” problem defined on a specific office-like building is presented as an example of what a simple n-step look-ahead strategy cannot solve. Then a hierarchical abstraction of this environment is given along with a first ad-hoc expected cost approximation, which does not solve the problem in all circumstances, but demonstrates the promise of abstraction.

Chapter 5 - Path-based Clustering. This chapter deals with abstracting in a more principled manner. A much better assignment of the abstracted expected costs can be produced if the geometry of the environment is considered in more detail. After discussing some general desiderata for clustering an office building, we concentrate on the specific case of the corridor-based office building containing a “cost barrier”. A better method for assigning
expected costs is produced which differentiates between different types of routes that visit abstract nodes.

**Chapter 6 - Path-based Decisions.** Given the abstraction, a decision procedure for choosing between clusters is necessary. Several decisions concerning the look-ahead and the type of decisions needed are discussed. Then the fixed cluster route strategy which works on the route-generated abstraction of the environment is presented. It is shown to work well in most cases and to have some robustness with reference to abstraction choices.

**Chapter 7 - Conclusions.** This chapter briefly draws general conclusions from the specifics of the other chapters.