Decision-Theoretic Robotic Surveillance
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The subject of this thesis is the investigation of autonomous surveillance planning for an office-like environment. 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”. Humans perform surveillance tasks quite well, integrating sensing, action, and decision-making flawlessly. Automation of each of these aspects to enable robotic surveillance is non-trivial. In this thesis, we focus on the decision-making involved in “where to go next”.

We approach this problem of surveillance planning by viewing it as a probabilistic decision process, ignoring for now the separate problem of knowing the probabilities and cost in actual situations. We are eventually interested in an algorithmic implementation of such a decision process, so we need to consider aspects of formalisation as well as of efficient computability.

To simplify the discussion we focus on one type of relevant events. The events considered are probabilistic, independent of each other, localised within office rooms and produce some costly damage when present. We took an idealised version of fire as an example of such an event.

Surveillance planning is a relatively new field and few quantitative results are known. For this exploratory research effort, various representations and solution methods of a decision-theoretic nature are considered. The problem can be mapped into formalisms like (PO)MDP or classical decision theory in many seemingly different ways, which are in fact thought to be equivalent. The formalisation conveys the exponential nature of surveillance planning viewed as an optimal search problem. Consequently, this thesis emphasises the computational issues raised by the desire to compute decisions in reasonable time.

The first option for dealing with the computational issues is to limit the look-ahead of the search. This is what is typically done in optimal search problems to control the size of the search space. However, if a small look-ahead is used, the results generated are not acceptable because they fall prey to local minima problems: if a certain area is not important enough to be visited, it may also
prevent other areas beyond it from being explored.

Our solution is to move up from the details and to abstract the problem. An abstracted representation of a target environment for surveillance can be constructed by grouping similar locations into clusters. The decisions then are taken among the various ways in which the clusters can be visited. Search methods based on abstraction boost the effective look-ahead but are necessarily approximate. This creates a hard balancing act between finding a method that is coarse enough to be computable and fine enough to closely approximate the optimal solution. Deciding on this dilemma is not easy, but we show that the structure of the problem can be useful. In our surveillance planning problem for an office building, the topology and the pattern of costs of the environment largely guide the actions of the robot and this should be reflected in appropriate clusterings. It turns out that for office buildings, a sensible general method can be presented for grouping locations of similar topological structure into clusters shaped as stars and corridors.

A new decision strategy for such an abstracted building called the fixed cluster route strategy is proposed. The fixed cluster route strategy computes the expected cost for a predefined route within a cluster instead of giving a heuristic estimate of the cost for all possible routes within the cluster. Three route types are considered: explore, transit and ignore. The robot then commits itself to the predefined route it selects by comparing the expected costs at a fixed decision-level.

The fixed cluster route strategy is still heuristic, but simulation results show that it beats other simpler strategies, also presented in this thesis, in cases where local minima are present. It is believed that this strategy can be further improved, since it loses from a simple one-step look-ahead minimisation of time between visits when no cost structure is present. The main contribution of this thesis is probably to the theoretical understanding of the surveillance planning problem. The fixed cluster route strategy suggests that abstraction may be the route to achieving automated surveillance planning.
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