Decision-theoretic Planning under Uncertainty for Cooperative Active Perception

Matthijs T.J. Spaan
Institute for Systems and Robotics
Instituto Superior Técnico
Av. Rovisco Pais, 1, 1049-001
Lisbon, Portugal
mtjspaan@isr.ist.utl.pt

Pedro U. Lima
Institute for Systems and Robotics
Instituto Superior Técnico
Av. Rovisco Pais, 1, 1049-001
Lisbon, Portugal
pal@isr.ist.utl.pt

Abstract

This extended abstract summarizes our ideas on developing decision-theoretic planning approaches for active perception in networked robot systems.

1 Introduction

In our work we consider networked robot systems (NRS), in which robots interact with each other as well as with sensors present in the environment to accomplish certain tasks. For instance, in urban pedestrian areas, we can consider a group of robots assisting humans [1]. The primary task of the robots could be to identify persons in need of assistance, and subsequently help them, for instance by guiding to a desired location. Additional tasks could involve transportation of goods as well as performing monitoring and security duties. The pedestrian area in which the robots operate is equipped with surveillance cameras providing the robot with more information. Implementing such a system requires addressing many scientific and technological challenges such as cooperative localization and navigation, map building, human-robot interaction, and wireless networking, to name but a few. In our work, we focus on one particular problem, namely *cooperative active perception*.

2 Cooperative Active Perception

In our context, cooperative perception refers to the fusion of sensory information between the fixed surveillance cameras and each robot, with as goal maximizing the amount and quality of perceptual information available to the system. Active perception means that an agent considers the effects of its actions on its sensors, and in particular it tries to improve their performance. This can mean selecting sensory actions, for instance pointing a pan-and-tilt camera or choosing to execute an expensive vision algorithm; or to influence a robot's path planning, e.g., given two routes to get to a desired location, take the more informative one. Combining the two concepts, cooperative active perception is the problem of active perception involving multiple sensors and multiple cooperating decision makers.

In our work, we consider decision-theoretic approaches to cooperative active perception. In particular, we use Partially Observable Markov Decision Processes (POMDPs) [2] as a framework for active cooperative perception. POMDPs provide an elegant way to model the interaction of an active sensor with its environment. Based on prior knowledge of the sensor's model and the environment dynamics, we can compute policies that tell the active sensor how to act, based on the observations it receives. As we are essentially dealing with multiple decision makers, it could also be beneficial to consider modeling (a subset of) sensors as a decentralized POMDP (Dec-POMDP) [3]. The fact that sensors and robots are embedded in an environment that is physically distributed, allows for applying decentralized planning under uncertainty methods that exploit such locality of interaction, for instance along the lines we have been developing [4].

In a cooperative perception framework, an important task encoded by the (Dec-)POMDP could be to reduce the uncertainty in its view of the environment as much as possible. Entropy can be used as a suitable measure for uncertainty. However, using a POMDP solution, we can tackle more elaborate scenarios, for instance in which we prioritize the tracking of certain objects. In particular, POMDPs inherently trade off task completion and information gathering. Sensory actions might also include other sensors, as we can reason explicitly about communicating with other sensors. For instance, a fixed sensor could ask a mobile sensor to examine a certain location.

3 Applications

We have been applying these ideas in several problems. First, we considered the problem of dynamic sensor selection in camera networks [5]. Given the large resource demands of imaging sensors in terms of bandwidth and computing power, processing image streams of many cameras simultaneously might not be feasible. We proposed a decision-theoretic approach modeled as a POMDP, which selects k sensors to consider in the next time frame, incorporating all observations made in the past. We showed how, by changing the POMDP's reward function, we can change the system's behavior in a straightforward manner, and successfully applied our techniques in our testbed with 10 cameras [6]. Furthermore, we exploited POMDP representations of tasks for multirobot task assignment [7], as well as MDP models for sensor-aware path planning problems [8].

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