Robotics: Probabilistic Methods for State Estimation and Control

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Abstract: Probabilistic robotics is a new and growing area in robotics, concerned with perception and control in the face of uncertainty. Building on the field of mathematical statistics, probabilistic robotics endows robots with a new level of robustness in real-world situations. Probabilistic approaches have been discovered as one of the most powerful ways to address highly relevant problems in mobile robotics, including robot state estimation and localization. Major challenges in the context of probabilistic algorithms for mobile robot navigation lie in the questions of how to deal with highly complex state estimation problems and how to control the robot so that it efficiently carries out its task. Robots are inherently uncertain about the state of their environments. Uncertainty arises from sensor limitations, noise, and the fact that most interesting environments are – to a certain degree – unpredictable. When "guessing" a quantity from sensor data, the probabilistic approach computes a probability distribution over what might be the case in the world, instead of generating a single "best guess" only. As a result, a robot using probabilistic methods can gracefully recover from errors, handle ambiguities, and integrate sensor data in a consistent way. And, moreover, it knows about its own ignorance. Autonomous robots must act in the face of uncertainty - a direct consequence of their inability to know what is the case. When making decisions, probabilistic approaches take the robot's uncertainty into account. Some consider only the robot's current uncertainty, others anticipate future uncertainty. Instead of considering the most likely situations only (current or projected), many probabilistic approaches strive to compute a decision-theoretic optimum, in which decisions are based on all possible contingencies. This tutorial will discuss both aspects and present recently developed techniques based on particle filters for estimating the position of a mobile robot and for efficiently learning a map of an unknown environment with a mobile robot. We will furthermore describe how graph-based representations can be utilized to find maximum likelihood solutions. We will finally describe how the complexity of this state estimation problem can be reduced by actively controlling the vehicle. For all algorithms, experimental results will be presented that have been obtained with mobile robots in real-world environments.