Handling uncertainty in control of autonomous robots

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Abstract. Autonomous robots need the ability to move purposefully and without human intervention in real-world environments that have not been specifically engineered for them. These environments are characterized by the pervasive presence of uncertainty: the need to cope with this uncertainty constitutes a major challenge for autonomous robots. In this note, we discuss this challenge, and present some specific solutions based on our experience on the use of fuzzy logic in mobile robots. We focus on three issues: how to realize robust motion control; how to flexibly execute navigation plans; and how to approximately estimate the robot's location.

1 I had a dream

It is Monday morning, and it is raining. I enter my office. Edi, my purple personal robot, promptly realizes my presence, and happily rolls out to get me some coffee. Down the corridor, it slips over the water left by somebody's shoes, and has to correct its trajectory by sensing the walls. The cafeteria's main door is closed, so Edi crosses the library and enters the cafeteria by its side door. Having obtained a cup of coffee from Gianni, the barman, it comes back by the same way, moving smoothly in order not to spill the coffee. Three people are smoking in the corridor, and Edi has to maneuver around them, and around a cart hiding behind them. I have just finished reading my mail when Edi comes in with my coffee on its head. It is still hot.

What makes this story a dream? After all, the task performed by Edi may not seem very complex to an outsider; and we know that industrial robots can perform seemingly elaborate tasks with high reliability. Yet, this story is probably close to the best that today's most advanced research robots can do. Having a commercially produced, inexpensive robot to reliably perform tasks of this type in our offices and houses is still a dream. Why?

A crucial observation to understand the difficulties involved is that control programs are typically based on a model of the controlled system. Control engineers use a mathematical description of the plant to design their regulators; and AI planning programs incorporate a symbolic description of the target system,
of its dynamics, and of the effects of our actions on it. Now, in the case of robot operation the controlled system is composed of the robot and its workspace, and we need to account for both these elements in our models — see Figure 1.

![Diagram](image)

**Fig. 1.** The two facets of the robotic problem. The external observer sees a physical agent (the robot’s body and its software) operating in an environment. The designer sees a control program controlling a physical system (the robot’s body and its workspace).

A reasonably accurate model of the robot on its own can usually be obtained. For industrial robots, a complete model of the workspace is also usually available. The workspace is highly engineered and completely determined at design time: we know where the workpiece will be, and we know that there will not be a child standing in front of it (if these assumptions are wrong, the robot fails to perform its task). Unfortunately, the same amount of knowledge cannot be obtained in general for the type of real-world environments where we would like our autonomous robots to operate.

There are two sources of problems in getting a reliable model of the “robot + environment” system. The first one is the environment. Our prior knowledge of unstructured environments is necessarily incomplete, uncertain, and approximate: maps typically omit some details and temporary features, spatial relations between objects may have changed since the map was built, and the metric information may be imprecise and inaccurate. Moreover, the environment dynamics is typically complex and unpredictable: objects can move, other agents can mod-