Control in Robotics & Automation; Sensor-Based Integration

Control in Robotics and Automation

Sensor-Based Integration

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Preface

In recent years there has been a growing interest in the need for sensor fusion to solve problems in control and planning for robotic systems. The application of such systems would range from assembly tasks in industrial automation to material handling in hazardous environments and servicing tasks in space. Within the framework of an event-driven approach, robotics has found new applications in automation, such as robot-assisted surgery and microfabrication, that pose new challenges to control, automation, and manufacturing communities.

To meet such challenges, it is important to develop planning and control systems that can integrate various types of sensory information and human knowledge in order to carry out tasks efficiently with or without the need for human intervention. The structure of a sensing, planning, and control system and the computer architecture should be designed for a large class of tasks rather than for a specific task. User-friendliness of the interface is essential for human operators who pass their knowledge and expertise to the control system before and during task execution. Finally, robustness and adaptability of the system are essential.

The system we propose should be able to perform in its environment on the basis of prior knowledge and real-time sensory information. We introduce a new task-oriented approach to sensing, planning, and control. As a specific example of this approach, we discuss an event-based method for system design. In order to introduce a specific control objective, we introduce the problem of combining task planning and three-dimensional modeling in the execution of remote operations. Typical remote systems are teleoperated and provide work efficiencies that are on the order of 10 times slower than what is directly achievable by humans. Consequently, the effective integration of automation into teleoperated remote systems offers the potential to improve their work efficiency.

In the realm of autonomous control, we introduce visually guided control systems and study the role of computer vision in autonomously guiding a robot system. As a specific example, we study problems pertaining to a manufacturing work cell. We conclude with a discussion of the role of modularity and sensor integration in a number of problems involving robotic and telerobotic control systems.

Portions of this book are an outgrowth of two workshops in two international conferences organized by the editors of this book. The first one, "Sensor-Referenced Control and Planning: Theory and Applications," was held at the IEEE International Conference on Decision and Control, New Orleans, 1995 and the second one, "Event-Driven Sensing, Planning and Control of a Robotic System: An Integrated Approach," was held at the IEEE/RSJ International Conference on Intelligent Robots and Systems, Osaka, Japan, 1996.

In summary, we believe that the sensor-guided planning and control problems introduced in this book involve state-of-the-art knowledge in the field of sensor-guided automation and robotics.

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SECTION I

Introduction

CHAPTER 1

Sensor-Based Planning and Control for Robotic Systems: An Event-Based Approach

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1 INTRODUCTION

1.1 Motivation

There is growing interest in the development of intelligent robotic systems. The applications of such systems range from assembly tasks in industrial automation to material handling in hazardous environments and servicing tasks in space.

The intelligence of a robotic systems can be characterized by three functional abilities. First, the robotic system should be controlled directly at the task level; that is, it should take task-level commands directly, without any planning type decomposition to joint-level commands. Second, the control systems of robots should be designed for a large class of tasks rather than for a specific task. In this respect, the design of the control system can be called task independent. Finally, the robotic system should be able to handle some unexpected or uncertain events.

Traditionally, robots were designed in such a way that action planning and the controller were treated as separate issues. Robotic system designers concentrated on the controller design, and the robotic action planning was largely left as a task for the robot users. To some extent, this is understandable, because action planning is heavily dependent on the task and task environment.

The split between robot controller design and robot action planning, however, becomes a real issue, because the action planner and a given control system usually have two different reference bases. Normally, the action planner, a human operator or an automatic planner, thinks and plans in terms of events. That is, the planner's normal reference base is a set of *events*. On the other hand, when it comes to the execution of planned actions, the usual reference frame for existing robot control systems is a time-based or *clocked* trajectory, typically a polynomial representation or decomposition of joint space or task space motions with time as a *driver* or independent variable. Eventually, this *clocked* trajectory representation can be combined with some expected or desired sensed events at the end of the trajectory. However, the main motion or action reference base of existing industrial robot control systems is *time*.

The two different reference bases for robot action planning and robot action execution or control (events versus time) cause unwanted complications and represent a bottleneck for creating *intelligent* robot control and *intelligent* robotic workstations. *Intelligent* robot control depends to a large extent on the capability of the robotic system to acquire, process, and utilize sensory information in order to plan and execute actions in the presence of various changing or uncertain events in the robot's work environment. Note that sensed events in a robotic work environment do not appear on a precise time scale. Hence, in reality, motion trajectories from start to destination cannot be planned on the basis of time alone. Instead, the executable representation of robot motion or action plans should be referenced to other variables to which sensed events are normally related. This would make the plan representation for control execution compatible with the normal reference base of the applied sensors.

The main motivation of this thesis work is to take a step toward intelligent robotic systems through the combination of event-based motion planning and nonlinear feedback control.

1.2 Review of Previous Work

There exists voluminous literature on the subject of motion planning. Motion planning consists of two basic problems, path planning and trajectory planning. Latombe [1] and Hwang and Ahuja [2] give excellent surveys and pertinent references in this area. Basically, there are two major approaches. One is based on the configuration space ideas proposed by Lozano-Perez and Wesley [3]. In order to use the configuration space approach, complete knowledge of environment is required, so the most useful results with this approach are for off-line path planning. The other approach uses a potential field method pioneered by Khatib [4]. It can be applied to real-time motion planning. However, to get the potential field of an environment again requires complete knowledge of the robot work space. Therefore, it is very difficult to apply this approach to a changing environment. The issues of motion planning in a dynamic environment are discussed by Fujimura [5]. However, most of the results were obtained under very strict assumptions, such as "the robot velocity is greater than all obstacle velocities," and they are valid only for a two-dimensional work space.

The common limitations of the existing motion planning schemes are twofold:

1. The planned motions are described as a function of time.
2. Complete knowledge of the work environment is assumed.

These limitations make it impossible to modify or adjust a motion plan during execution on the basis of sensory or other on-line information. Therefore, these schemes cannot accommodate a dynamic environment consisting of not sharply defined or unexpected events, such as the appearance of an obstacle. Of course, if some kind of logic function is incorporated in the time-based plan, it may be able to respond to some unexpected events. However, because of the very nature of time-based plans, complete replanning of the motion after a change in the environment or occurrence of an unexpected obstacle is needed in order to reach the final goal.