Spatial Reasoning for Human-Robot Teams

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Abstract

This chapter presents research designed to study and improve an operator’s ability to navigate or teleoperate a robot that is distant from the operator through the use of a robot intelligence architecture and a virtual 3D interface. To validate the use of the robot intelligence architecture and the 3D interface, four user-studies are presented that compare intelligence modes and interface designs in navigation and exploration tasks. Results from the user studies suggest that performance is improved when the robot assumes some of the navigational responsibilities or the interface presents spatial information as it relates to the pose of the robot in the remote environment. The authors hope that understanding the roles of intelligence and interface design when operating a remote robot will lead to improved human-robot teams that are useful in a variety of tasks.
Introduction

Robots have been used in a variety of settings where human access is difficult, impractical, or dangerous. These settings include search and rescue, space exploration, toxic site cleanup, reconnaissance, patrols, and many others (Murphy, 2004). Often, when a robot is used in one of these conditions, the robot is distant from the operator; this is referred to as teleoperation. Ideally, robots could be a useful member of a team because they could be used to accomplish tasks that might be too difficult or impractical for a human to perform.

The potential, however, for humans and robots to work as an effective team is limited by the lack of an appropriate means for the operator to visualize the remote environment and how the robot fits within the environment. As an example, several recent research efforts have investigated the human-robot interaction challenges associated with real-world operations including search and rescue and remote characterization of high-radiation environments (Burke, Murphy, Coover, & Riddle, 2004; Casper & Murphy, 2003; Murphy, 2004; Yanco, Drury, & Scholtz, 2004a). Across these disparate domains, researchers have noted that it is difficult for operators to navigate a remote robot due to difficulty and error in operator understanding of the robot’s position and/or perspective within the remote environment.

A primary reason for the difficulty in remote robot teleoperation is that for the overwhelming majority of robotic operations, video remains the primary means of providing information from the remote environment to the operator (Burke, Murphy, Rogers, Lumelsky, & Scholtz, 2004a). Woods, Tittle, Feil, and Roesler (2004) describe the process of using video to navigate a robot as attempting to drive while looking through a “soda straw” because of the limited angular view associated with the camera (Woods et al., 2004). The limited angular view of the camera presents problems for robot teleoperation because obstacles outside of the field of view of the camera still pose navigational threats to the robot even though they are not visible to the operator.

To alleviate navigational threats to the robot, current research at the Idaho National Laboratory (INL) is aimed at providing tools that support mixed-initiative control where humans and robots are able to make decisions and take initiative to accomplish a task. The goal is to create a set of capabilities that permit robots to be viewed as trusted teammates rather than passive tools. If this is to happen, the robot as well as the human must be enabled to reason spatially about the task and environment. Furthermore, true teamwork requires a shared understanding of the environment and task between team members in order to understand each others’ intentions (Dennett, 1981). The lack of an effective shared understanding has been a significant impediment to having humans and intelligent robots work together.

In response to this challenge, the INL has developed a mixed-initiative robot control architecture that provides a framework for robot intelligence, environment mod-
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