Guest Editor's Introduction
Virtual Environments and Mobile Robots: Control, Simulation, and Robot Pilot Training

It is hard to develop a good operator interface for a mobile robot. The designers must decide what information the robot should collect and how the interface should present that information so the operator can effectively navigate and perform tasks in the remote environment. Because the robot moves, the entire visual scene can change with each information update. The operator can easily become disorientated if she loses sight of the reference landmarks that correlate with her mental map of the robot's environment. These operational challenges are further exacerbated by energy and information bandwidth limitations that force interface designers and robot operators to carefully consider each robot movement and prioritize the information to be collected. These constraints would be challenging enough if the system only needed to perform one task, but most mobile robot systems are designed for at least the task of navigation plus some other operational task. A single interface system might be required to handle navigation, obstacle avoidance, search, and manipulation, for example. The optimal interface design is different for each of these tasks, presenting even more tradeoffs for the interface designer.

In many ways, the challenges of designing an effective mobile robot interface parallel the challenges of designing an effective interface for exploring a virtual environment, such as a battle simulation system for training war fighters. In both cases the interface must convey an accurate sense of a remote, three-dimensional scene and the users must be able to both navigate and effectively perform tasks in this remote world. In both cases system cost and complexity increases with the imagery resolution and update rate. In both cases the need for global, large-scale information for effective navigation must be balanced with the need for local, focused information for effective task performance. There are also important differences. For example, the designer of a virtual environment for training is omniscient with respect to the environment and can design and test for all training conditions, whereas the robot interface designer often can make very few assumptions about the environment. Another difference is that a virtual environment is effectively finite in spatial extent and resolution whereas a robot's environment is effectively infinite in both spatial extent and resolution. Because of these similarities and differences, advancements in one field are likely to trigger advancements in the other.

Researchers have proposed that the ultimate goal for both virtual environment and mobile robot interfaces may be telepresence: developing the illusion that the operator is physically in the remote environment. Is this the best approach? Perhaps it would be better to pursue a more practical, performance-based goal—developing an engineering model—striving not to manipulate subjective perception, but to maximize system performance. Very few tools and models are currently available to help a robot interface designer make important design choices or predict a system's performance before it is built. Hopefully this special issue will motivate other researchers, like you, to explore this design space and guide the development of the next generation of robot interfaces. To facilitate the connections among different disciplines, it may be helpful to describe the robot interface design space in somewhat greater detail.

A natural way to organize the great diversity in mobile robot hardware is according to the robot's communication and power constraints. A physical connection between the operator and the machine (a tether) greatly enhances the speed and quantity of information that may be communicated. Without the tether, the information must be communicated over relatively slow radio links. Durlach and Mavor (1995) define four major classes of mobile robots: power and data tethered, data tethered, non-tethered telemetry, and unsupervised.

In a power and data tethered system, the cable between the operator and robot is typically thick and heavy. The tethered power allows the robot to be operated continuously for long periods. The data link often supports several cameras that provide a continuous stream of images to an array of monitors at the operator's console. This type of mobile robot is often used for underwater exploration (e.g., the Hydrovision Venom, www.hydrovision.co.uk/prod1venom.html). Because power tethers are thick and heavy, the management of the cables themselves can become a significant issue for the robot operator. For submersible robots, the cables can be neutrally buoyant to reduce their drag. On land, power tethers can significantly limit a mobile robot's range.

By moving the power supply onboard the robot, data tethered systems can use lighter tethers, such as fiber optic cables. This allows the robot to provide the large communication bandwidth necessary to support rapid frame, high-resolution video, eliminating the bulky power cable. These systems were often used in the late 80's and early 90's (Aviles et al., 1990), but are becoming less common because of advances in high bandwidth, wireless communication.

The third class, non-tethered telemetry systems, puts the greatest demand on efficient acquisition and use of information. Most air vehicles, some undersea and land vehicles, and most planetary robots are of this type. Interface designers of these systems must be very selective in choosing which information should be transferred between the operator and the robot because the bandwidth is limited. Also when the robot is very distant from the operator, there is usually a delay between sending commands and receiving system responses. Often the bandwidth is too small to support live, full frame rate video, particularly when the transmitter does not have a line of sight connection with the receiver.

A fourth class, unsupervised, or completely autonomous robots, requires no connection to the operator. Useful, working systems of this type either require sophisticated artificial intelligence algorithms or very simple tasks. In any case, since they are unsupervised and autonomous, developing a sophisticated model for the operator interface seems to be a less compelling need than it does for the other three classes of robot.

The three papers in this special issue provide a broad range of perspectives regarding both robot types and interface designs. Lawson, Pretlove, Wheeler and Parker consider the problems of fusing the robot environment with a virtual environment through augmented reality. They use a calibrated, stereoscopic camera system mounted on a data and power tethered robot designed for pipe inspection and emphasize the problems of calibrating the system and using a virtual cursor to make accurate measurements of features on the pipes. Lathan and Tracey describe a glove-based interface designed to direct ground-based military robots and show that the benefit of the device depends in part on the operator's spatial skill level. Ruff, Narayanan and Draper base their work on the unmanned flying vehicle paradigm for military reconnaissance and consider the effect of different levels of automation on system reliability.

Taken together, these works illustrate the great diversity of issues encountered in designing an operator interface for a mobile robot, and how, with the barest squint, all these articles could be about the interface to a virtual environment. Each researcher presents creative, practical design solutions to the specific design constraints faced in their system. To grow stronger as a community of researchers, however, we need to develop a solid theoretical framework so that work on individual robots may be more easily generalized to other systems.

In conclusion, I would like to thank the authors for their hard work and dedication to their research, and the journal editors for their generosity in sharing the pages of this wonderful publication.

In keeping with the style of previous issues, articles marked with an "S" in the table of contents are part of the special section.

Geb Thomas
Department of Mechanical and Industrial Engineering
The University of Iowa

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