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Robotics and Machine Perception

Guest Editorial

Remote control of physical systems by humans through the mediation of computers has been a fascinating topic for scientists and engineers for almost four decades. Depending on the field of application and the technology involved, different terms were coined to describe the process of controlling a system at a remote site: teleoperation, tele-robotics, tele-service or telepresence are just the most often repeated terms. In the early years the development was mainly driven by space, underwater, and automation applications for hazardous areas, but especially in the recent five years, different factors have led to an increasing number of applications. The first important factor was the exponentially growing computational power, enhanced control algorithms, and new mechatronic sensors and actuators which made it possible to actively enhance the operator's—visual, acoustical and haptic—perception of the remote location; new qualities of man–machine interfaces originated from these developments. The second important factor for the increasing number of applications is the broad availability of communication networks like the Internet. The Internet makes it a snap to access remote computers. It actually takes very little to deploy a remote system and make it available to many users over the Internet—not just for "fun and fame", but also for industrial, e.g., teleservice, applications.

All developments have the aim of introducing human perception, planning, and control into a technical process. Some people tend to consider this as just an intermediate step on the way to fully autonomous systems, but the contributions in this issue clearly show that the described technologies provide a new quality of cooperation and coexistence of humans and machines—where, of course, the human always keeps control. As we are now introducing the latest insights from the fields of human perception, sensing, and cognition into telepresence systems, we are not just making the automation part of such a system smarter but we are also laying the groundwork for a broad range of intuitively comprehensible man–machine interfaces. The articles in this issue cover this aspect from different viewpoints.

Multisensory feedback

To increase the sense of reality and presence in teleoperation systems is a major issue of current developments. Besides the stimulation of the visual sense by realistic computer graphical representations of virtual worlds, the stimulation of additional senses becomes very important—and the solutions become more and more effective. The paper by Schmidt/Kron/Kammermeier outlines the developments related to providing tactile feedback for the user's arm, hand, and fingers. Different devices are being used and versatile control strategies are being developed and implemented to allow users to "feel" virtual objects. Whereas this work aims at providing a realistic sensation of physical objects, Fong/Thorpe/Bauer use haptic feedback to teleoperate a vehicle. In this case, the forces felt are artificial force fields to support the precise driving of a vehicles; virtual forces here enhance the user's intuition. In a third paper on this topic, Kimura proposes to enhance teleoperation systems by a further sensual stimulation, by audio-feedback. Find out about the psychophysical background of his suggestion in this issue.

Projective Virtual Reality

Virtual reality used to be only about immersion and interaction; the papers by Hirzinger/Landzettel/Brunner and by Freund/Rossmann add the aspect of "projection." Allowing users to handle objects in the virtual world like they would do in the real world is just the basis; the key idea then is to automatically project these actions onto robots and other means of automation. This implies that robots make exactly the changes to the physical world that correspond to the changes the user made to the virtual world. The approaches presented in both papers are different, but the aims are the same: make the teleoperation of robots safe and easy!

The idea of controling a real-world device via a graphical user interface is also pursued by Tomatis/Moreau. They describe a comprehensive web interface used to control a mobile robot. The ideas presented are made complete by the work of Lane because he summarizes the results on the effect of time delay for the control of robot manipulators over long distances.

Space Exploration

The exploration of space has always been a driving force for the development of new ideas related to teleoperation. In their paper, Pirjanian/Huntsberger/Kennedy/Schenker look into the more distant future of planetary exploration where multiple rovers are to cooperate to explore planetary surfaces. Their ambitious plans are an inspiration and a driving force for the work in this field.

Teleoperated systems pioneered space, the planets, and the deep seas. The contributions to this newsletter show how the methods and tools are now evolving to make further pioneering more intuitive, more cost-effective, and also more fun. Please read and enjoy the authors' thoughts about the present and the future in this field.

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Active interfaces for vehicle teleoperation

Since 1997, the Robotics Institute of Carnegie Mellon University and the Virtual Reality and Active Interfaces (VRAI) Group[1] of the Swiss Federal Institute of Technology have been developing tools and technology for vehicle teleoperation. The goal of our collaboration is to make such teleoperation easier and more productive for all users, novices and experts alike. Thus, we have developed a variety of active interfaces incorporating sensor-fusion displays, gesture and haptic input, personal digital assistants, and the wwweb.[2,3]

Sensor fusion displays

Perhaps the most difficult aspect of vehicle teleoperation is that the operator is unable to directly perceive the remote environment. Instead, he is forced to rely on sensors, bandwidth-limited communications links, and an interface to provide him with information. As a result, the operator often fails to understand the remote environment and makes judgement errors. Thus, we need to make it easier for the operator to understand the remote environment, to assess the situation, and to make decisions.[4]

Our approach is to develop sensor fusion displays that combine information from multiple sensors or data sources to present a single, integrated view. These displays are important for applications in which the operator must rapidly interpret multispectral or dynamic data. Figure 1 shows an example in which lidar, stereo, and ultrasonic sonar range data are fused.[5] This display is designed to direct the operator's attention to close obstacles and to improve situational awareness in cluttered environments.

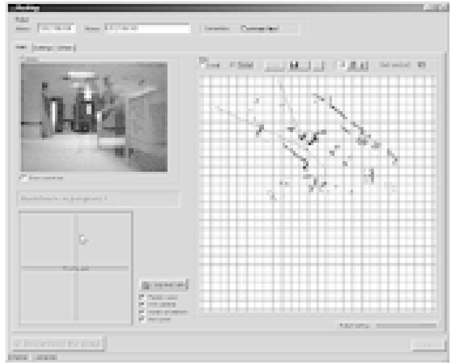

Figure 1. Sensor fusion display incorporating lidar, stereo vision, and sonar range data.

Gesture and haptic input

Almost all teleoperation interfaces rely on input devices such as joysticks or two-dimensional computer pointers (mouse, pen, etc.). One problem with this approach is that the human-machine interaction is essentially static: the form and range of input is limited to physical device properties. With computer vision, however, we can create gesture-based interfaces that provide flexible, user-adaptive interaction. Moreover, since the interpretation is software-based, it is possible to customize input processing to minimize sensorimotor workload, to accommodate operator preferences, and to adapt to the task/operator in real-time.[3]

Figure 2. GestureDriver: a visual, gesture-based interface for vehicle teleoperation.

GestureDriver is a remote driving interface based on visual gesturing (see Figure 2). Hand motions are tracked with a color and stereo vision system and classified into gestures using a simple geometric model. The gestures are then mapped into motion commands that are transmitted to the remote vehicle. In our testing, we found that GestureDriver works well almost anywhere within the vision system's field of view. Thus, users were free to move about when they were not directly commanding the robot. Additionally, GestureDriver was able to easily accommodate users of different sizes and with different control preferences.

Figure 3. HapticDriver provides force feedback for precision driving tasks.

The most difficult aspect of remote driving, as with all teleoperation, is that the operator is separated from the point of action. As a result, he must rely on information from sensors (mediated by communication links and displays) to perceive the remote environment. Consequently, the operator often fails to understand the remote environment and makes judgement errors. This problem is most acute when precise motion is required, such as maneuvering in cluttered spaces or approaching a target.[3]

HapticDriver addresses this problem by providing force feedback to the operator (see Figure 3). Range-sensor information is transformed to spatial forces using a linear model and then displayed to the operator using a large-workspace haptic hand controller (the Delta Haptic Device). Thus, HapticDriver enables the operator to feel the remote environment and to achieve better performance in precise driving tasks.

Personal interfaces

For some remote driving applications, installing operator stations with multiple displays, bulky control devices and high-bandwidth/low-latency communication links is infeasible (or even impossible) due to environmental, monetary, or technical constraints. For other applications, a range of operators having diverse backgrounds and skills drive the vehicle. In these situations, extensive training is impractical and we need interfaces that require minimal infrastructure, can function with poor communications, and do not tightly couple performance to training.

PdaDriver is a PDA-based interface for vehicle teleoperation and is shown in Figure 4. PdaDriver uses multiple control modes, sensor-fusion displays, and safeguarded teleoperation to make remote driving fast and efficient. We designed the PdaDriver user interface to minimize the need for training, to enable rapid command generation, and to improve situational awareness. The current interface is has four interaction modes: video, map, command, and sensors (see Figure 4). We have conducted a number of field tests with the PdaDriver and found the interface to have high usability, robustness, and performance.[3]

To date, we have created two Web-based systems: WebPioneer and WebDriver. The WebPioneer (developed in collaboration with ActivMedia Inc.) enables novices to explore an indoor environment. The WebPioneer, however, requires significant network resources and only provides a limited command set. We designed our second system, WebDriver, to address these problems. In particular, WebDriver minimizes network bandwidth usage, provides a dynamic user interface, and uses waypoint-

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Intuitive haptic perception in virtual prototyping tasks

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the human fingertip. However, the ideal specification profile for such an array (which can be derived from physiological and biomechanical as well as task-oriented data) poses severe challenges in system design. The IACE has developed an actuator array with extraordinarily high pin forces and mechanical bandwidth[3] that is used for tactile representation of the interaction between the operator's fingertip and stiff objects in virtual prototyping tasks. Experiments have been performed with respect to detailed haptic exploration of an automobile engine (see Figure 2). In this scenario, the operator can examine the head of a screw to be fixed, judge the quality of workmanship at the edge of a workpiece, or localize a visually-occluded marker that indicates the assembly-rotation of a pulley.

Perspective

The benefits of including the proposed advanced haptic feedback technologies in virtual prototyping environments have been demonstrated in various laboratory experiments. Beyond the automobile industry, potential applications of this technique can be found in other industrial areas, as well as in medical simulation and education.

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based safeguarded teleoperation. WebDriver differs from other web-based driving because it is highly effective in unknown, unstructured, and dynamic environments.[6]

Future work

We believe that our tools and technologies are well-suited for tasks such as remote exploration. Thus, we are planning to apply our research to the exploration of planetary surfaces. In the next year, we intend to develop user interfaces that enable EVA crew members (e.g., suited geologists) and mobile robots to collaborate and jointly perform tasks such as surveying, sampling, and *in-situ* site characterization.

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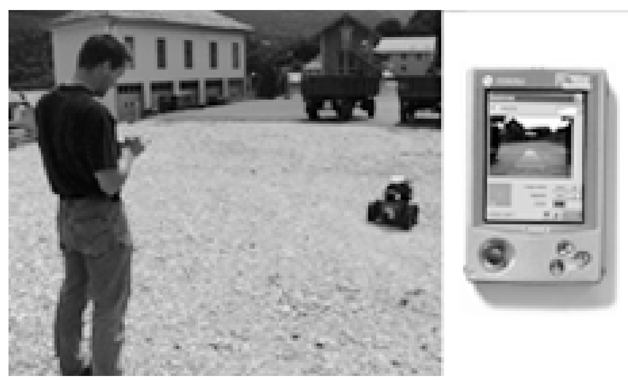

Figure 4. PdaDriver is a PDA-based interface for remote driving.

Figure 5. WebDriver enables safeguarded vehicle teleoperation via the wwweb.