Cooperative Robot Teleoperation through Virtual Reality Interfaces

***Monferrer, Alexandre** & ****Bonyuet, David**

** Facultat de Nàutica.*
Depart. Enginyeria de Sistemes, Automàtica i Informàtica Industrial.
***Universitat Politècnica de Catalunya**.*
Pla de Palau #18. 08003. Barcelona. Spain.
E-mail: <amonferrer@esaii.fnb.upc.es>

*** **Delta Search Labs***
400 Technology Square
Cambridge, MA 02472
USA
E-mail: <dbonyuet@deltasearchlabs.com>

Abstract

Robots are employed to do exacting routines, ranging from the common place to the difficult and from the relatively safe to the highly dangerous. Remote-controlled robots -or teleoperation- is one way to combine the intelligence and maneuverability of human beings with the precision and durability of robots. Teleoperation can be difficult, due to the complexity both of the system and of information management –and more difficult still in a cooperative environment in which multiple teams are working together in different locations. To facilitate teleoperation, information visualization and a clear communication reference must be deployed in conjunction with an enhanced human machine interface (HMI) among all participating teams.

The aim of this paper is to present a set of guidelines defining an ideal user interface utilizing virtual reality desktop for collaborative robot teleoperation in unknown environments. Enhancements in information visualization are discussed, and the case of an underwater robot is presented, because of the special challenges they present: a slow response system and six degrees of movement.

1. Introduction

Teleoperation is the manipulation of an object (in this case a robot), in such a way as to allow an operator to perform a task at a distance. This is usually done because of a hostile environment where human access is difficult, but human intelligence is necessary [11]. Teleoperated robots use different sensors to let the user operate them safely. In the Fig. 1, a schematic of **GARBÍ** (the UPC underwater robot) is presented, describing the different elements that interact in the robot control. To work more efficiently in an unknown environment robots need enough *sensors* to emulate human *senses* [1, 12]. Multiple thrusters are also required to move robots in the desirable direction (T1–T4, in Fig. 1). Additional sensors are required to measure the motor's performance. Devices that provide outputs and require inputs also serve to enhance control [8, 9]. Each technical improvement demands an additional effort in control and data presentation.

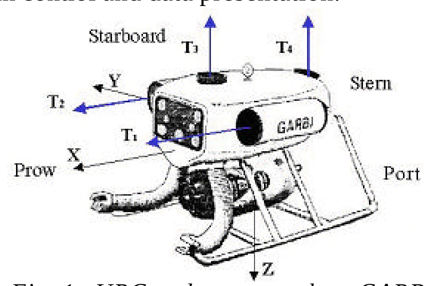

Fig. 1.- UPC underwater robot: GARBÍ

Fig. 2.- Interface for teleoperated robot from [8]

User interfaces for teleoperated robot started basically with video images [8] coming from cameras installed in the remote robot (Fig. 2); additional data in multiple fomats (numbers, characters, etc) were added. This was an easy start to develop the user interface; however, the operator of such system required extensive training and broad experience in multiple fields [12, 13].

Virtual reality (VR) was added as a tool to enhance the plane camera images [2, 5, 9, 14]. VR helps to solve some of those problems -like the spatial

Proceedings of the Sixth International Conference on Information Visualisation (IV'02)
1093-9547/02 $17.00 © 2002 **IEEE**

representation and object programming, for example-but it also introduce some new issues: viewpoint control and spatial location (i.e., where the robot is in relation to the environment) [4]. Bejczy *et al* used VR to teleoperate robotic arms in the space [2]; Fong *et al* used it in robot teleoperation using PDAs [9]; Nguyen *et al* are working VR in remote robot control for planetary surface exploration [11]. Further applications in VR and robotics can be found on Burdea's paper [6].

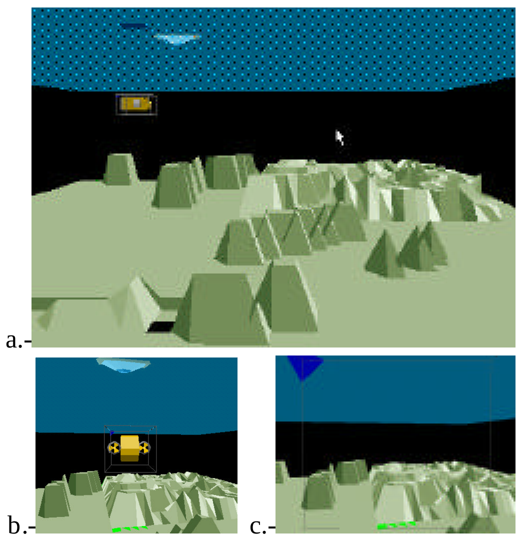

Fig 3.- Different viewpoints from a virtual world, using the interface developed in this project

A teleoperation task must display a great deal of information. Fig 3 shows three different perspectives using virtual reality. There is not real camera that allows these viewpoints. With virtual reality, one is able to figure out how to view a problem and complete a task in multiple ways. Fig. "a" shows the underwater robot from the left side; Fig. "b" from the backside; while Fig. "c" is inside the robot (as if the user were operating from inside the robot). Understanding the effects of information distribution and presentation in control and visualization of teleoperated robots is the key topic of research [6, 13] at the moment.

2. Information Sharing and Collaboration

While sensor technology has improved significantly, our ability to convey the information to the users with ease and precision has not [13]. This situation worsens when the data is shared among multiple users, each in a different location and, worse yet, working on different cooperative activities. A group of users in a one part of the world, for example, may be working the installation of an underwater pipe; another group, far away, may be bringing all the resources and tools from the cargo ship; a yet another group could be performing analysis of the data in a remote center. Such a project requires a common coordination: items must be brought, and if possible assembled, with high-level coordination among all the teams. The situation could also arise where a team might not directly control a robot, even though they must visualize all the information. Fig. 4 shows the various elements participating in robot teleoperation: users in different locations, each of whom works with his own human machine interfaces (databases, computers, etc) at point distant from wherever the real working activities are actually being developed.

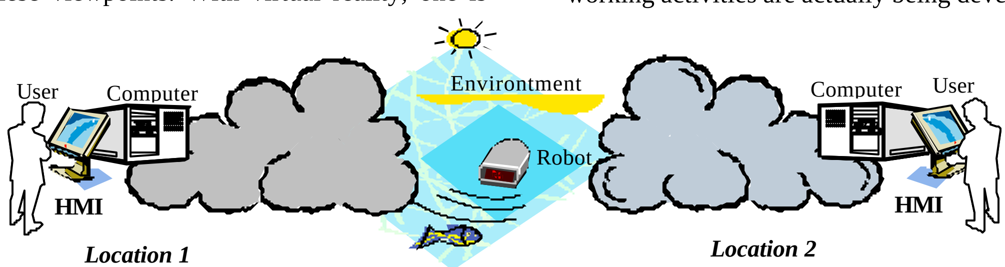

Fig. 4.- Elements in the user interaction in a collaborative robot teleoperation task

Fig. 5 describes the building blocks of a collaborative robot teleoperation. There are three groups: two controlling one robot apiece and a third one functioning as a supervision center. Each user group functions as a distinct entity with clear, independent objectives yet also with a common goal requiring them both to share information and to understand the entire process, in addition to their own particular role in or contribution to it. Collaboration is paramount, and human machine interfaces are the key to it. The common tool is that interface that allows collaborating user groups to communicate their objectives and tasks with one another. Obviously, social environments will influence different users differently and could lead them to various interpretations of the same information. Nor can the influence of the physical environment be discounted - where the team is located. Permanent communication and visibility through the interface would allow them to resolve any such issues that arise. Communication is based in a network link maintaining continuous flows of information among the participating teams.

1093-9547/02 $17.00 © 2002 **IEEE**

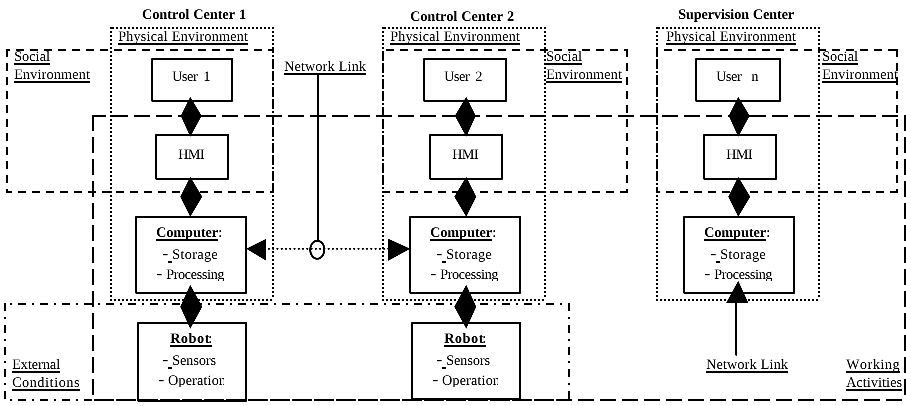

Fig. 5.- Block elements in the user interaction in a collaborative teleoperation

3. Information to show

Technological advancement produces a deluge of information the user risk drowning. The Internet, an infinite highway of data, for example, can easily become an infinite maze. When it comes to robots, the situation is still more complex. Now it is possible to fill any mechanical shell with literally thousands of electronic devices and make it function as a robot. Every one of the robot's individual sensors provides a minimum of data that must be processed and that should, at least in some cases, be shown. In fact, the sheer quantity of data available for any given situation amount to information overload (See Table 1).

Visualization:	***Control:***
▪ *Working area*. The users must be able to see what they are doing in the teleoperated robot. ▪ *Position information and spatial orientation information*. This provides information about where the robot is heading in relation to the north, the mother ship and to show to the user where they are. This information might come from Acoustic Transponder Networks, Doppler, Sonar, Inertial Navigation Systems, GPS, etc. ▪ *Navigation information*. Some parameters are needed while the user is driving the robot: · Where the north is. · Speed and depth. · Location of the robot in relation to the sea surface and the bottom. ▪ *Internal system information*. Information about the system status and other technical stuff. These include the visualization of equipment sensibility, threshold, communication parameters, data protocol etc. ▪ *Numerical information*. Show all the numerical data about the robot. By this function, the user would be able to show or hide –at convenience-, the task relevant information. ▪ *Enhanced displays*: Virtual image, compass and keymap. These functions enhance the robot controllability. A compass is a traditional orientation device to signal the north. A keymap is an intelligent map showing references about the user location, targets, origin and location of other virtual marks. ▪ *Help information*. On-line help is provided in three levels: active tags, medium information windows and advanced help. ▪ *Individual parameters*. Additional information helps the user to understand better the robot operation: · Underwater currents affecting the robot. · Power. The robot internal battery status. ▪ *Partners Visualization*. Location and movement direction of the other member of the team in the virtual environment should be clearly displayed. ▪ *Messages in Transit flag*. This indicator would warn users about delayed messages.	▪ *Vehicle control.* There are several motors to move the robot in the six axes of movement and rotational displacement (left and right). ▪ *Virtual reality control.* Due the virtual reality tool used, now the user has to deal with the power to change the point of view. ▪ *Interface control.* It includes the ability to perform file operations and other task related to the program and computer. ▪ *Arms control.* The robot is equipped with external arms to perform different task. This function activates the robot arms. ▪ *Speed control.* This function allows the user to increase the robot speed. ▪ *External system control.* External lights and specific sensors are activated by this set of controls. Stabilization (keep the robot statically in that place) icon is another example of external system service. ▪ *Route definition*. Specific routes in the workplace can be defined using this function. ▪ *Internal system configuration*. Using this function, which will open a window with all the configurable options, can set up the robot internal system. These include the sensors available to measure the motors performance and calibration of sonar system, range finder, communication parameters, data protocol, etc. ▪ *Bottom sea configuration*. The virtual bottom sea should be configured through this function, to allow the users to updated the working area map (according to new information). ▪ *Tracking Control.* This function would allow the user to track specific objects (pipeline, etc) or other robots in the working environment. ▪ *Message control.* Transmitting information to the other peers and to the master is fundamental in a collaborative scheme. ▪ *Flag mark control.* The user may decide to place a signal in the virtual environment visible for other teams working with other robots (tagging an area) or to signal places for direction purposes.

Table 1.- Requirements in teleoperation for visualization and control for underwater robots

But why, in fact, does all this data have to be shown? The operator of an automobile does not have to watch the meters and gauges on the dashboard at the same time while he/she is driving. Some gauges, in fact, are designed to be checked only when the car is in service (e.g. the oil meter, brake liquid meter, etc). In other words, the information while available need not be presented to the user unless he/she asks for it specifically. A robot's depth, for instance, is not always relevant, but can be useful in some cases, and, in others, indispensable. Information relevance depends on both user activities and context.

Controlling a teleoperated underwater robot offers several challenges to the normal user. Depending on the project mission, the user group will have its own set of required skills: biologist, oceanographer, pipe inspector, etc. Additional knowledge is also required: robots are equipped with multiple sensors to measure internal and external conditions; and various motors to control their displacement and control several appliances. Every single device in the robot provides information that must be processed.

Cantoni *et al* said that "a GUI can display only a limited number of icons without cluttering the screen" [7]. Previous work developed by the authors has proven that interfaces design must be evaluated according to the target user, task and system [4 - 5]. Trading off these parameters on behalf of a unified interface represent a recursive process of design - evaluation - review [4]. Underwater teleoperated interfaces are not very common and as Table 1 shows, there are specific requirements in control and visualization for this robot; data for this table were gathered through extensive information collection from expert users and technical requirements in the system in authors' previous works [1, 4, 5]. As if not all this was enough, we must also consider the **redundancy factor** -only for critical, specific data. Some parameters must be present in different formats for different users as well as to increase the data's **visibility** (as the old saying goes: "It is better to be safe than sorry"). The double visibility of specific parameters is intended to double the user's awareness of information vital to the task. Knowing the point of origin can be essential, for example, for guiding the user in the working area and for returning to the mother ship. Displaying that information both in different formats and in different places (in the virtual working environment and the virtual compass) would help the user to correlate all the information clearly a concisely. For example, signaling the north is useful in the working screen, but that information should be repeated in the keymap (map with the working area); additionally, that information should be repated in any instrument that provide guidance, like the compass or gyroscope.

4. Enhanced Landmarks and Tools for Improved Visualization in Collaborative Environments

Taking in account the issues discussed so far, it is possible to group some VR design concerns in three sections: user interface, technical and VR issues. These points come from a review in similar works and the authors' previous research [1, 4, 5]. These issues should be considered in the development of man machine interfaces for teleoperated robots in collaborative environments:

4.1. User Interface Issues

a) **Visible Navigation Aids**: Presenting navigation aids in a physical way will allow users (especially novice ones) to drive the system better, these navigation elements should include true north and drift direction among others.
b) **Customized Reference Data**: whenever the user is around a specific point in the working area, the ability to mark some areas (and possibly to share that data with fellow users) would be highly advantageous.
c) **Chat Channels**: Special channels for message communication should allow members to share information about the environment, the target and other related data. Voice communication would be preferable for fast transaction; it can also be recorded for auditing purposes. For easy log verification and review, however, a text line chat would provide a more detailed history of the activities performed and help beginners to track down working instructions.
d) **Redundancy with <u>Critical Data</u>**. Informing users about critical data is fundamental [3]; it also underscores, for the novice user in particular, the importance of changes in that information. Distintive sounds can be used to signal critical data variation, however, users should be trained about the sounds meaning.
e) **Attractive Data Presentation**. Certainly there is more than one way to skin a cat, and some are more appealing than others to the general audience of your system. It is worthwhile, therefore, to take the time to find the best, user-friendly way to present your information.

4.2. Technical Issues

a) **Positional Targets**: Specific working location on the ocean floor should be marked as reference points to help guide users to that place.

b) **Obstacle Detection**: Presentation of possible obstacles in the working trajectory directly in the image would be a useful feature, especially for new users.
c) **Tracking Route**: Tracking activities would be better performed if the trajectory to be tracked were highlighted. In an automatic system, one can rely on the tracking algorithm; in some cases tracking is related to an inspection task -checking the status of underwater pipelines or communication lines.
d) **Reference Information about Other Users**: In a collaborative environment where other users are performing other activities, the presence and activities of all concerned should be clearly described to everyone both to facilitate communication and prevent misunderstanding.
e) **Data Fusion**. Information from multiple sensors like (sonar system, thermal image, and even the laser system) might be integrated in a single picture, showing the relevance of each information to the user. In some cases, multiple images in different windows may provide clues for specific tasks.
f) **Communication Latency**. Working with teleoperated system involves in some cases to work with delayed data, but when a collaborative group is considered, the latency worsen the communication (and robots' controllability) among the team and the robots. Information synchronization should be planned in the data exchange.

4.3. Virtual Reality Issues

a) **Natural Landmarks**: Certain natural landmarks are easily utilized as references for certain activities; not every underwater boulder, however, can be used to signal a specific point. Users must choose this option sparingly, considering other possible options in their immediate environment, and better yet, decide with the entire team about what would be the landmarks to be used.
b) **Virtual Route**: Virtual reality allows the interface to highlight specific sections with pale colors (transparent information), offering a clear and unmistakable path to the target. Obviously, the task must permit this feature: in the case of a random searching task, there is no route to illuminate.
c) **Special Marks**: Objects floating about in a virtual world have to provide additional information to the users. Imagine, for example, an object floating in the middle of a hall: what is its real position in relation to the ceiling? Since some users have difficulty with spatial problems, an additional object must be presented to simplify such inquiries. Our solution? <u>Virtual shadow</u> projection on both the surface and the bottom of the sea.
d) **Virtual – Reality Synchronization**. Objects in the virtual world must be synchronized with the one in the real world, to provide a meaning interaction. Communication latency should be taken in account to avoid data misinterpretation.

4.4. KISS: Keep it Simple and Short

Useless data can quickly clutter the user's screen. It is certainly tempting to present <u>everything</u> in <u>every</u> possible format. The data is there anyway, so why be stingy –or discriminating- with it? First of all, because distract the user. Nevertheless, there are other reasons as well:

a) The more unnecessary data on the screen, the less space available for important data.
b) Multiple formats, like alphanumerical data, can be hard to digest at critical moments.
c) Excess information requires a good amount of time to understand and to use the interface correctly.
d) If an element or graphic in the interface does not communicate anything meaning or significant, then delete it!

5. The Virtual Reality Interfaces

Two interfaces were developed using virtual reality desktop as a data visualization enhancement tool, one of them focusing on information (Fig 6), the other on controllability (Fig. 7).

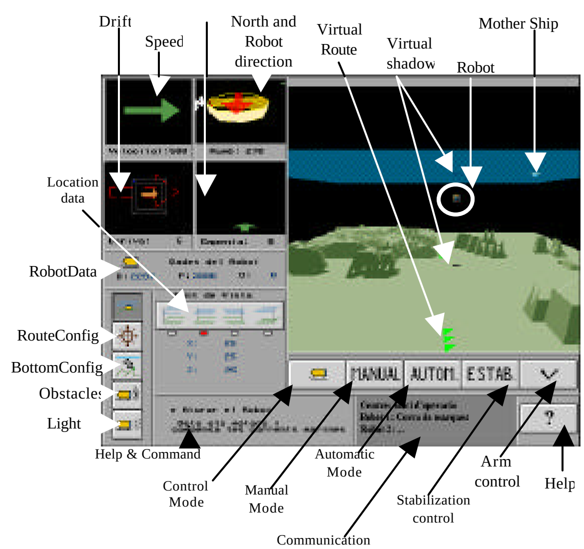

Fig. 6.- Interface for robot teleoperation with emphasis in information visualization

Proceedings of the Sixth International Conference on Information Visualisation (IV'02)
1093-9547/02 $17.00 © 2002 **IEEE**

The interface in the Fig. 6, emphasizing information visualization, provides all the basic information required for the specific task in separated windows, but offers minimum control. The interface in the Fig. 7, focusing on controllability, displays several icons to control all those possible elements needed to perform specific activity-related tasks. Both interfaces foster smooth team communication and a cooperative environment.

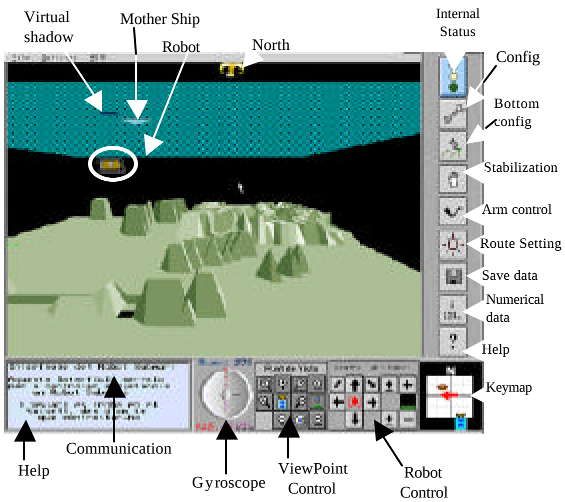

Fig. 7.- Interface for robot teleoperation with emphasis in controllability

6. Conclusions

Each new version of user interface will improve on previous performance standards and correct previous defects. The more logical its arrangement, the better, in all likelihood, the interface. Functionally purposes, logically, should be correlated to the user's activity; while attention paid to style and design insures not only greater efficiency but also aesthetic harmony. The best interface would consider the user to be the important input in its systemic operation. Collaborative environments, however, require an additional step in design and to improve information visualization should include unmistakably identified communication elements within the interface.

7. References

[1] Amat, J.; Batlle, J.; Casals, A. & Forest, J.; "GARBI: the UPC Low Cost Underwater Vehicle", Joint US / Portugal Workshop in: Undersea Robotics and Intelligent Control, march, 2 - 3 / 1995, Lisboa, Portugal, pp. 91 - 97.

[2] Bejczy, Antal; "Virtual Reality in Telerobotics", ICAR, Barcelona, Spain, 09/1996, pp 3 - 12.

[3] Bersen, N.O.. "Modality Theory. Supporting multimodal interface design." Proceedings of the workshop ERCIM on HMI, Nancy, Nov. 1993.

[4] Bonyuet, D & Monferrer, A. "Designing Virtual Interfaces for Teleoperated Robots". The 2nd World Multi-Conference on Systemics, Cybernetics and Informatics: ISAS' 98 – SCI'98, Orlando, 08/1998.

[5] Bonyuet, D.; "An Approach to Facilitate the Teleoperation of a Vehicle in the Space 3D", ERCIM Workshop: "Towards User Interfaces for All: Current Efforts and Future Trends", ICS-FORTH, Heraklion, Crecia, Grecia, 30 - 31 de octubre de 1.995.

[6] Burdea, Grigore. "Invited Review: The Synergy between Virtual Reality and Robotics". *IEEE Transactions on Robotics and Automation*. Vol 15, N 3, June 1999. pp 400 – 410.

[7] Cantoni, Virginio; Levialdi, Stefano and Roberto, Vito. *Artificial Vision. Image Description, Recognition and Communication*. Academic Press. GB. 1997.

[8] Fiorini, P; Bejczy, A. & Schenker, P., "Integrate Interface for Advanced Teleoperation", *IEEE Control Systems*, Vol. 13, N 5, 10/93, pp 15 - 19.

[9] Fong, T.W.; Grange, S.; Conti, F.; and Baur, C. "Advanced Interfaces for Vehicle Teleoperation: Collaborative Control, Sensor Fusion Displays, and Remote Driving Tools", *Autonomous Robots* 11. Vol. 1. July 2001. pp 77 – 85.

[10] Kotoku, T. "A predictive display with force feedback and its application to remote manipulation system with transmission time delay". Proc. 1992 IEEE. *RSJ Int. Conf. Intelligent Robots Systems*. pp 239 – 246.

[11] Nguyen, Laurent; Bualat, Maria; Edwards, Laurence; Flueckiger, Lorenzo; Neveu, Charles; Schwehr, Kurt & Zbinden, Eric. "Virtual Reality for Visualization and Control of Remote Vehicles". *Autonomous Robots*. Vol. 11. No 1. July 2001. pp 59 – 68.

[12] Rigaud, V.; Coste Manière, E.; Aldon, M.J.; Probet, P.; Amat, J.; Casals, A.; et al.; "Union: Underwater Intelligent Operation and Navigator"; *IEEE Robotics & Automation Magazine*; Vol.5 N.1, 03/98; pp 25-35.

[13] Stanney, K; Mourant, R & Kennedy, R. "Human Factors Issues in Virtual Environments: A review of the literature". *Presence: Teleoperators & Virtual Environments*. MIT. Vol.7. N 4. 08/98. pp 327 – 351.

[14] Stone, R., "Advanced Human-System Interface for Telerobotics using Virtual Reality and Telepresence Technologies", ICAR-91, Fifth International Conference on Advanced Robotics, Pisa, Italy, 19 – 22, 06/91, Vol. 1, pp 168 - 173.

Proceedings of the Sixth International Conference on Information Visualisation (IV'02)
1093-9547/02 $17.00 © 2002 **IEEE**