15th Triennial World Congress, Barcelona, Spain

INTEFACES FOR TELEROBOTICS STUDIES ON STEREOSCOPIC VISION

M. Ferre * and R. Aracil **.

(*) Dpto. Electrónica Automática e Informática Industrial (ELAI).
Universidad Politécnica de Madrid.
Ronda de Valencia 3, Madrid 28012, Spain.

(**)Div. Ingeniería de Sistemas y Automática (DISAM).
Universidad Politécnica de Madrid.
C/. José Gutiérrez Abascal, 2, Madrid 28006, Spain.

Abstract: This paper is focused on the study of telerobotic interfaces. The interface devices connect the operator to the remote environment. The aim of these devices is, therefore, to get a design that provides the highest degree of telepresence to the operator. In this paper, first a classification of interfaces is introduced according to the processed information: operator's commands and/or feedback remote information. Next, a deep study about stereoscopic vision is introduced by showing the results of experiments that evaluate stereoscopic versus monoscopic images. These results are applied to the ROBTET system, a prototype for live power lines. Finally a description of this implementation is given. *Copyright 2002© IFAC*

Key words: teleoperation, telerobots, stereoscopic vision.

1. INTRODUCTION

Interfaces are the way to connect the operator of the teleoperated system to the remote working site. Teleoperated tasks are normally carried out by manipulators using tools with different degree of automation.

Two data channels are required to implement a teleoperated system. The first channel shows the operator the working site and the second one sends the operator's commands to the different teleoperated elements. Once the operator and the remote working area have been connected, it is necessary to define the automation degree of the teleoperated system (Sheridan 92).

The performance of a teleoperated system can be improved in two ways: by increasing the automation degree of task or by improving the operator's telepresence. The first way, by improving the automation, requires a model of the working environment and a model of the task to be executed (Ferre 97). However, obtaining these models is a difficult task, since the element spatial localization is often unknown. It implies to previously define the corresponding mechanism that calibrates the computer model with the real working area. Many studies have been done trying to resolve the computer calibration with the remote area through computer vision techniques, like those of (Aracil 98, and Maruyama 96), or through increasing reality techniques (Ferre 96, Kotoku 91), and in many cases the operator's intervention to localize the objects has been used (Peñin 98a, 98b).

This article shows the works done in order to improve the execution of teleoperated tasks by increasing the operator's degree of telepresence. Improving the operator's telepresence can be complementary to increasing the automation, and it represents an effort to achieve better human-machine interfaces.

2. CLASSIFICATION OF TELEROBOT INTERFACE DEVICES

The following table shows a classification of the mechanisms that the operator can use to carry out teleoperated tasks. This classification has been designed according to its use: to send or to receive information. So three types of mechanisms have been found: operator's commands, feedback information and bilateral devices. The first one is used by the operator to issue commands to the teleoperated elements. The feedback information is used to know the remote environment. The operator's senses are excited by the remote environment information. And third, the bilateral devices are characterized by its double function: issue of commands and simultaneously the excitement of the operator's senses.

Operator's commands	**Low level** High level
Feedback information	Visual (sight) Haptic (touch) Sound (hearing)
Bilateral devices	Operator's commands & Feedback information

Table 1. Classification of interface devices

2.1 Operator's command devices

The issued commands by the operator can be divided up into two categories: low level and high level commands. Low level commands are related to the join movements of teleoperated robots. The devices normally used are masters, joysticks, buttons, etc. This kind of devices issues references to the servos, controlling the position and speed over the articulations of teleoperated elements. The process undertaken on low level commands is simple, usually an algorithm like a PD, sometimes a reference change takes also place.

High level commands are related to the task. These commands indicate, among others, the parameters of task to be carried out or and the used tools. These commands can be easily issued through a computer, i.e. by using the mouse, keyboard, or advanced tools like a voice or mimic recognition system. The power of these interfaces is much higher to the previous ones, but more information about the working remote area is needed, like the object spatial localization and dimensions, work procedure, etc. Handling with this information requires having the appropriate equipment to obtain and manage such information. It implies consequently sensors and a higher complexity of the teleoperated system. Fostering these systems means increasing the degree of automation of the teleoperated system. Such an increase should be valued against the complexity and costs of the equipment.

2.2 Feedback Information Devices

Feedback information shows to the operator the state of the teleoperated task by exciting the operator's senses with the information obtained from the remote environment. Table 2.1 shows the devices classification according to the excited sense: sight, touch, and hearing.

Video images and graphic simulations constitute the common way of visual feedback information from the remote working environment. The sight sense gives us essential information to manipulate elements, since it allows us to know which elements are involved in the working area, its dimensions and position. Section 3 handles in depth the use of video images for teleoperated tasks.

Haptic information is used to perceive the executed efforts by the manipulation of elements. This is the first information to be lost by remote tasks, since the elements are not directly manipulated by the operator. In teleoperated systems robots are in charge of the direct manipulation. The relevance of this information depends on the handled materials but generally maximal efforts cannot be exceeded, in order to avoid damaging the manipulated elements or the robots themselves. The haptic information is therefore necessary although it is only approximate to avoid damages. High quality haptic information requires a broad frequency band what allows recognizing textures, while a limited band allows only recognizing the presence of contacts, what in many cases should be sufficient.

The hearing information is hardly used in teleoperation and generally it is limited to the hearing of messages from the computers or alarms. The main advantage of this sense is that the operator does not need to pay constantly attention but can be informed at any time of any event occurred.

2.3 Bilateral Devices

Bilateral interfaces integrate in only one device the issued commands and the feedback information. These devices allow the operator to issue movement commands and simultaneously to receive the generated effort by his movements. The integration of issued commands and feedback information give to interfaces a high effectiveness while executing tasks.

An illustrative instance of this interface is the force feedback master-arms, which generates movement references and provides torque at the joins

3. STEOROSCOPIC VISION THROUGH BINOCULAR CAMERAS

Various mechanisms are involved in the spatial perception of depth (Barfield, 1995). The main factors are: binocular disparity, parallel movement, image perspective, real data like texture, reflexes and shadows.

The use of above mechanisms allows to operator the proper spatial perception. Stereoscopic video cameras are based on binocular disparity to provide information about the scene depth. Our Departments (DISAM and ELAI) have developed a stereoscopic video camera with two CCDs, with a 6 cm separation between them, similar to the human sight. Next figure shows an image of this stereoscopic camera.

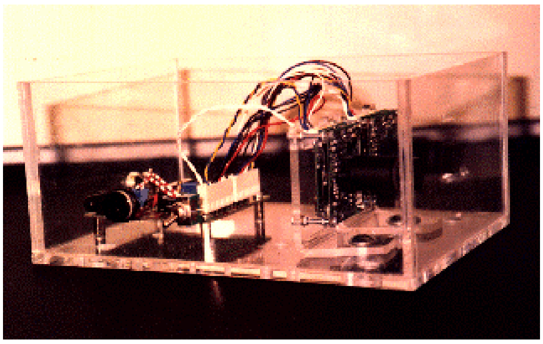

Fig. 1 Stereoscopic camera

Several works and experiments carried out with this stereoscopic camera highlight the behabiour of the binocular disparity. Image disparity is understood as the distance between the projection of an object on the two images. This disparity depends on the convergence angle of both CCDs and its distance to the visualized element.

Next figure shows a graphic where, for a given convergence angle, the stereoscopic image disparity in relation to the object is represented. As it can be seen, there is a point where disparity equals zero, it corresponds to the point where both CCDs axis cross.

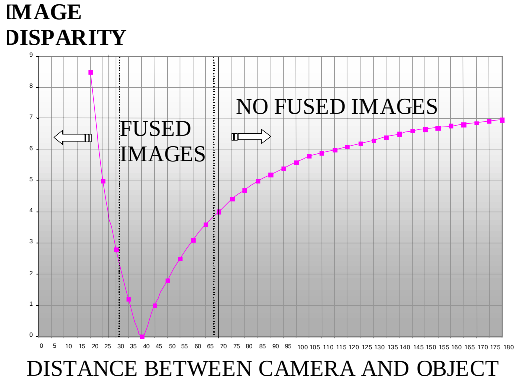

Fig 2 Image disparity versus distance

Different experiments show that binocular disparity should be found into a defined range in order to achieve a proper depth perception. With disparities inferior to 2 or 3 cm the operator fuses correctly both images together. It has been proved that sometimes when the disparity is higher the operator continues perceiving both images correctly. However it produces operator's tiredness when the limits are exceeded for a long time

Next graphic has been developed to calculate the best convergence for the binocular camera CCDs. In this graphic we can see the relation between different convergence angles.

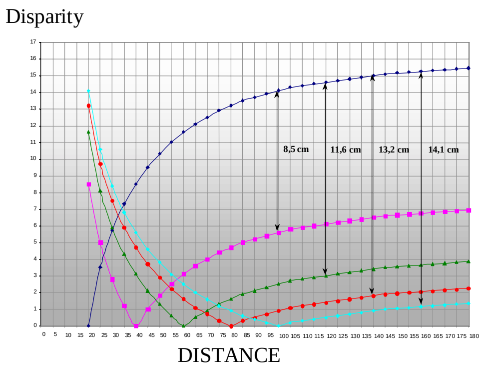

Fig 3 Disparity versus diseance for different convergence angles

It is important to take into account that during the execution of teleoperated tasks, the distance between camera and teleoperated objects varies. It will be therefore necessary to define the most adequate convergence corresponding to the executed task. It should be also taken into account that the disparity can sometimes be exceeded without preventing the visualization of stereoscopic images.

4. EFFECTIVENESS OF STEREOSCOPIC VERSUS MONOSCOPIC IMAGES

The use of a stereoscopic system, like the above described, should be used taken into account some factors for its correct functioning. First of all, it should be taken into account that the binocular disparity mechanism gains relevance in short distances, inferior to 1.5-2 m. In higher distances the binocular disparity effect decreases significantly and other mechanisms like parallel movements dominate. Other factor to be considered is the viewpoint under which the scene is captured. Depending on the executed task a monoscopic camera can provide all information needed, although it requires that the task is carried out on a perpendicular plane to the camera axis.

With the aim to know more about the use of stereoscopic systems, several experiments were carried out to evaluate the effectiveness of stereoscopic versus monoscopic images.

During the designed experiment a piece should be inserted into another one, the typical pin and hole experiment. This is a common operation in manipulation tasks and it permits to evaluate the depth perception achieved by the operator. The time taken for this inserting task was the index used to compare both visualization systems.

In the next figure can be observed an operator during the experiment. The operator has a joystick to guide the end of the robot. The robot guiding implements a speed control commanded by the joystick. As feedback the operator receives a video image from the remote working environment. The experiment is executed displaying a stereoscopic image and then it is repeated using a monoscopic image. Before measuring the execution times a training period is carried out in order to improve the operator dexterity guiding the robot with the joystick.

The experiment results are shown in next graphic. The x-axis represents the 34 participants involved at the experiment, and the y-axis represents the task execution time. Both curves show us that there are two types of operators, those that take so many time with monoscopic as with stereoscopic vision, and those who take more time with monoscopic vision. It can be explained by arguing that some operators reach enough depth perception regardless of the image mode. While in other cases enough spatial perception of the working remote area cannot be achieved using monoscopic images.

Fig 4 Opeartor executing the experiment

This conclusion is ratified if the trajectory is taken into account. Trajectories are fast a straight line when the spatial perception is satisfactory. Otherwise, the trajectory describes zig-zag lines. The last occurs by monoscopic vision since the operator cannot guide the robot to wished point and when he/she realizes the problem tries to correct the trajectory. Consequently the line is not straight.

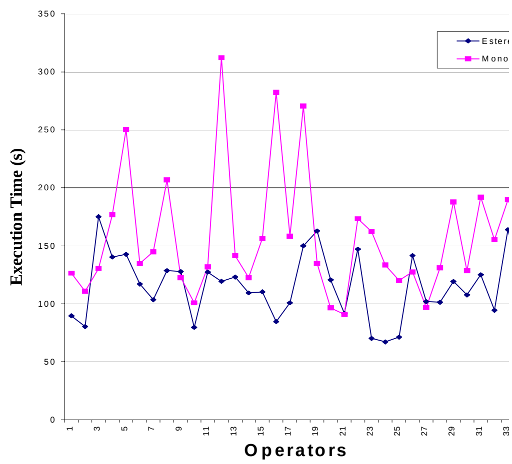

Fig 5 Execution time versus monoscopic and estereoscopic images

As conclusion of the experiment it can be drawn that the use of stereoscopic video images provides a higher depth perception of the elements in the remote environment. While with monoscopic images a vague idea is had about the real distance on the scene elements. It consequently decreases the teleoperation performance effectiveness in common tasks like guiding. In other tasks where the operator only supervises, without monitoring, could the monoscopic vision be sufficient.

5. APLICATION TO THE ROBTET SYSTEM

The Robtet system (Aracil 1995, 98) is a prototype for live power line maintenance tasks. It has been developed by the Universidad Politécnica de Madrid, Iberdrola a Spanish utility company, and Cobra a Spanish contractor.

Fig 6 The Robtet prototype

This system is shown in figure 6 and has two telemanipulators with force reflection, and other devices used by the operator to execute the teleoperated tasks (figure 7).

Fig 7 The operator's cabin

The main operator interface elements are two force feedback master arms to command the manipulators, a voice recognition system for processing spoken commands, a monoscopic image, and a stereoscopic image. The biggest monitor (left figure 7) displays graphic task information and the monoscopic video image. The second monitor shows a stereoscopic image, coming from the stereoscopic cameras located above each telemanipulator.

This system uses a monoscopic camera located behind the robots. The camera has 4 degree of freedom. pan, tilt, zoom and focus. The 4 degree of freedom allow us to obtain panoramic images from the working site so that the operator knows the relative positions of the remote environment, and the zoom provides furthermore more detailed sights. The stereoscopic cameras are near of the manipulator grip with a fixed position and viewpoint. Convergence is calibrated so that object can be manipulated in a 50 cm distance, as obtained by graphic 4. The stereoscopic camera function is to facilitate the proper perception of depth in order to make efficiently the object manipulation. So that the operator by beginning the tasks can use the panoramic camera and later on concentrate him/herself on a stereoscopic one when the monitoring so requires.

7. CONCLUSIONS

According to the different works and experiments undertaken it can be concluded that: The teleoperation system interface should be design following the commands type that the operator sends to the remote working site. For a semi-automatic system, it can be sufficient with a common interface composed by a computer and a video image showing the working scene. In cases requiring higher operator intervention a more advanced interface is recommended, which can provides haptic information and precise object spatial location. So that it will be needed that the master has haptic information and stereoscopic cameras displaying the remote working environment. When the operator has a poor telepresence then the performance of teleoperated task decreases, that is a greater execution time and increasing the manipulation forces.

Acknowledgements

The electric utilities IBERDROLA, S.A. and COBRA, S.A., and the Spanish Ministry of

Industry through OCIDE (PIE No. 132.198) supported the work presented in this paper. Special thanks should be given to V. Trullenchs and A. Santamaría from IBERDROLA and M.A. Fernández, C. Ramiro, D. Nieto and C. González from COBRA. Also to F. M. Ferre for her invaluable support.

REFERENCES

Aracil, R. et al (1995). ROBTET: A New Teleoperated System for Live-Line Maintenance, *6th IEEE Int. Conf. on Transmission and Distribution Construction, Operation and Live-Line Maintenance, ESMO-95*, Ohio, USA.

Aracil, R., L.F. Peñín, M. Ferre and A. Barrientos (1996). ROBTET: Robot for live-line maintenance. *Int. Conf. on Live Maintenance (ICOLIM'96)*, Venice, Italy.

Aracil, R. et al (1998). Obstacle avoidance for teleoperated robots for live power lines maintenance, using artificial vision. *IFAC's Workshop on Intelligent Components for Vehicles, (ICV'98)*, Seville, Spain.

Barfield (1995). *Comparison of Human Sensory Capabilities with Technical Specifications of Virtual Environment Equipment*. Presence. Vol. 4, Nº 4.

Ferre, M., R. Aracil, L.F. Peñín and A. Barrientos (1996). Multimedia Interfaces for Teleoperated Robots. *3rd SPIE Conf. on Telemanipulator and Telepresence Technologies*, Boston, USA.

Ferre, M.(1997). Interfaz Diseño de interfaces para robots teleoperados. Desarrollo de un entorno de teleoperación con características multimedia *(in spanish) Ph.D. Thesis*. Universidad Politécnica de Madrid, Madrid.

Kotoku, T. et al (1991). Environment Modeling for the Interactive Display (EMID) used in Telerobotics Systems. *IEEE/RJS IROS'91*, Osaka, Japan.

Maruyama, Y. et al. (1993). A Hot-Line Manipulator Remotely Operated by the Operator on the Ground. *5th IEEE Int. Conf. on Transmission and Distribution Construction, Operation and Live-Line Maintenance ESMO-93*.

Maruyama, Y. et al (1996). MV overhead hot-line work robot. *3rd Int. Conference on Line Maintenance, ICOLiM-96*, Venice, Italy.

Peñín, L.F. et al (1997). Fundamentals of a master-slave teleoperation system with a force-position bilateral control scheme. *IFAC's Int. Symposium on Robot Control, SYROCO'97*, Nantes, France.

Peñín, L.F. et al (1998a). Telerobotic system for live power lines maintenance: ROBTET. *IEEE Int. Conference on Robotics & Automation*, Leuven.

Peñín, L.F. (1998b). Bilateral Control of Teleoperated Robots. Contributions on Force Reflection. *Ph.D. Thesis*. Universidad Politécnica de Madrid, Madrid.

Sheridan 92. (1992). "Telerobotics, Automation, and Human Supervisory Control". MIT Press.