ROBTET: A NEW TELEOPERATED SYSTEM FOR LIVE-LINE MAINTENANCE

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Abstract

This paper presents a new teleoperated system for live-line maintenance developed for electrical utility IBERDROLA. Its aim is to increase the safety and confort of the workers and the overall efficiency, as well as to reduce labor requirements.
Its design is basicly like other similar systems already developed. It consists of a pair of hydraulic-driven master-slave teleoperated manipulators, placed on top of an insulated boom, which execute directly on the hot line the tasks commanded via master arms by an operator on the ground.
Telepresence of the operator is accomplished through a 3-D vision system, a multimedia interface and the force-feedback capabilities of the manipulators.
This paper describes in detail all these elements, as well as the teleoperation architecture that interlace them, with special attention to the telepresence issues which seem to lack in similar systems.

1. INTRODUCTION

As a consequence of today´s highly information oriented society and increasing demand of electricity, uninterrupted power supply has become a must. Outage-free maintenance techniques have been developed and used in Spain for more than 25 years to fulfill this objective, specially in overhead distribution lines.
In this conventional techniques workers have to do their job on a hot line indirectly with various kinds of hot-sticks or directly touching the line with rubber-insulated gloves. Therefore, workers are compelled to work in a hazardous environment with both the risk of electric shock and the danger of falling from a high place. In addition, workers have to be very skilled and work cooperatively under very demanding tasks.
In this context, since the first telerobotic developments for live-line maintenance back in the mid-eighties by EPRI (1) and KEPCO (2), several systems have been presented through the years (3-7). It also has been an issue of great interest for utilities around the world (8). IBERDROLA began back in 1990, in cooperation with COBRA Electric Co. and DISAM (Polytechnical University of Madrid), the first studies in order to introduce robotic techniques into high voltage distribution hot-lines work. These studies turned into a first laboratory prototype which showed the technical feasibility of the project and identified critical issues that needed a new approach. After dealing

with these problems, a new industrial prototype, called ROBTET (ROBot para Trabajos En Tensión) began development in 1994.

This paper presents a detailed description of the features of the system, making special emphasis in those features that are considered relevant and new with respect to similar systems in development or already developed.

2. OVERVIEW OF TELEROBOTIC LIVE-LINE MAINTENANCE SYSTEMS DESIGN ISSUES

Nowadays there are several different telerobotics systems for live-line maintenance being developed around the world. Each of these systems is specially designed to fulfill a series of requirements for the application they are suited for. In order to fulfill these requirements the designers had to cope with different solutions and approaches, some specific of their application and others of general relevance for all the systems (9). The solutions taken define the practical and efficient use of the telerobotic system, and have to be taken with care, being fairly conservative but always looking what would be needed in the future.

In first place, the type and location (accessibility) of the towers and the working voltage define in a great sense the type of system to be develop. The ROBTET has been designed to work for distributions lines of 46 kV, and in Spain the towers and lines are fairly accessible.

Working under bad weather conditions is one of the advantages of this kind of systems in relation to the conventional techniques, affecting the system isolation design. In the ROBTET this issue has been studied with special care.

Figure 1 presents a simulation of the ROBTET system: a telescopic boom with two slave manipulators, an additional lift arm to help perform some of the required tasks and the 3D camera torret on its top.

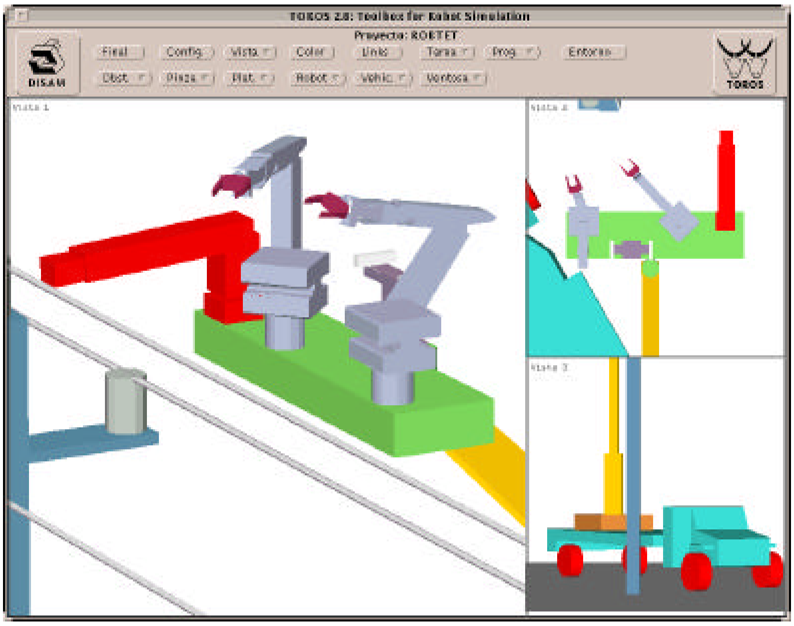

Figure 1 Simulation of the ROBTET

In first place, except for one system (10), all recent developments have considered the more basic approach of teleoperation with the operator on top of the boom. We have considered to place the operator on the ground because of safety, compactness and control reasons. Safety of the operator is a crucial matter, and as the regulations get tighter new solutions have to be met.

The system as a whole also gains compactness and simplicity, having separate operation and control zones, so that they can be upgraded or modified independently. It is finally a way of approaching what will be the future of everyday hazardous work.
In a first stage supervisory control (11) in some degree is expected, while the final objective is to reach supervisory control next to fully automatic control. The interface of the operator situated on a cabin on the ground it is being design as a multimedia interface, simple for the operator to use but powerful enough to control all the system capabilities. Telepresence and supervisory control are accomplished through the multimedia interface, an updated 3D model of the working environment through vision, real-time collision checking, voice processing features and force-feedback capabilities of the manipulators.
The system architecture is described in the following section.

3. SYSTEM DESCRIPTION AND ARCHITECTURE

Figure 2 presents a schematic view of the ROBTET architecture. Everything except the two slave manipulators and the vision system, represented by two cameras, are placed on a cabin on the truck. There are three different units: the operator post, the manipulators control station and the image processing system. These last two are connected in-between via VME bus, and via ethernet to the operator post. Communication between the boom top and the cabin is via fiber optic to maintain isolation between the zones. Two electrically driven master arms with force-feedback are also in the operator post.
All these elements, except the voice processing, the multimedia interface and the master arms are transparent for the operator, but their fundamental job is to make him feel like working on top of the boom with his hands and to help perform the tasks more efficiently. The bottom line is to achieve telepresence through simplicity in the operation of the system.
The division of the different modules that perform this telepresence is slightly different to the physical one: vision module, multimedia interface, master-slave manipulator system and working zone, which
are described on the following sections.

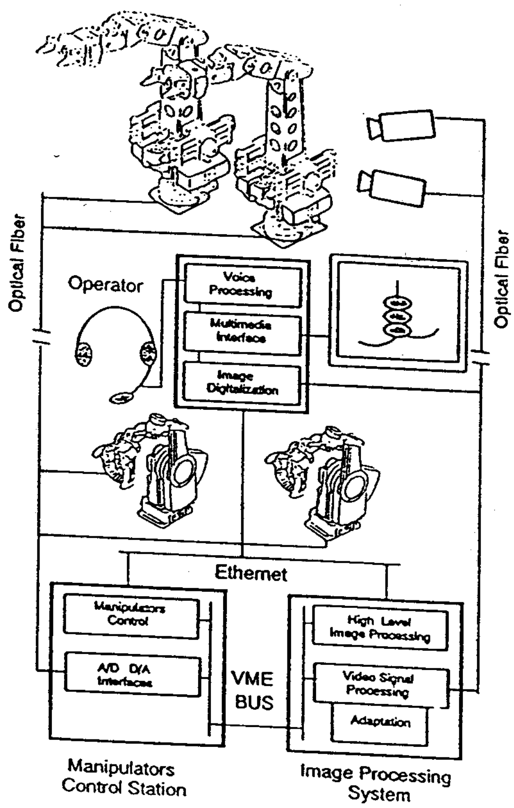

Figure 2 System architecture

3.1. Manipulators

Two hydraulic driven 6 dof manipulators placed on top of the boom are used as the ROBTET arms. Basic features of these manipulators are:

Maximum reach: 1.3 m
Lift capacity at full extension: 45 kg
Weight: 59 kg
Gripper Close Force: 90 kg
Degrees of freedom: 6 + grip

An Hydraulic manipulator is favorable in general over an electrical one because of its high load/weight ratio and isolation implicit

features, although its response an accuracy in operation are slightly lower. Similar live-line maintenance systems justify 7 dof manipulators because of better maneuverability (11) but simulations made in our typical tower designs show that 6 dof are enough and that adding one more would complicate the control without adding much advantages.
Both arms are commanded by the operator through a pair of master arms with force-feedback capabilities connected with the slaves through optic fiber. Every move of the slave arms in the modeled environment is monitored by the manipulator control station in order to prevent any possible unexpected collision (12). Path planning techniques (13) are also used to help the operator perform certain tasks. Future work trends are automating specific operations.

3.2. Multimedia interface

The multimedia interface objective is to help the operator perform remote tasks. It can be implemented following various different approaches, but telepresence has proven to be the best solution. Telepresence is achieved through quick and coherent feedback of the environment in response of an operator external stimuli, being the operator who closes the control loop.
Figure 3 shows the functional architecture of the multimedia interface being developed.
The working sequence is as follows:

1) Initialization: In first place the operator indicates the main features of the remote work site (isolator and tower type, etc.) This helps the vision system to localize the different elements and their spatial and geometrical relationships. As a result several images from the remote site are displayed and a wire model of the elements of work is overlaid on them (14), allowing a preliminary coherency check between the computer model and reality.

2) Tasks to perform: The operator commands the tasks to do i.e. changing an isolator. Every task is defined previously like a sequence of steps, called procedure, to follow. He will be obligated to do that procedure step by step.

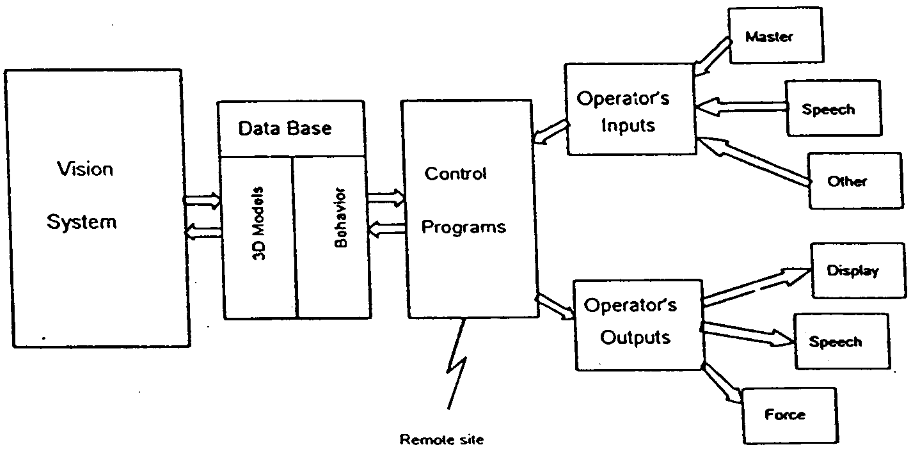

Figure 3 Functional architecture of the multimedia interface

3) Task supervision: The task execution control is shared by both operator and control system. The operator will determine how each step is done, if the control system can do this work it would be executed automatically; by other hand, if it is an unknown job it will be executed manually by the operator with the master arms.

The operator always communicates with the interface with his own voice through a limited set of commands according to the step which is being executed. The interface answers by voice and messages on display. Simultaneously a simulation is showed over the real images (video signals) to let the operator supervise the development of the task.
Learning of the way tasks are done by the operator is a crucial matter to achive full automatic control. When the operator performs a new operation, the control system learns it in order to be able to reproduce it on a similar environment in the future.

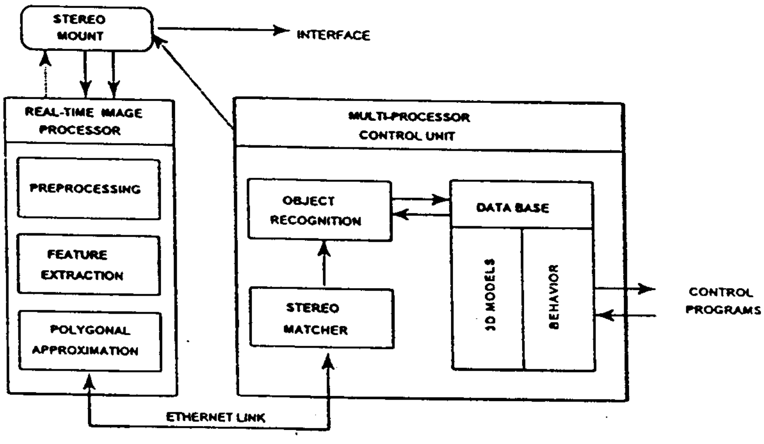

Figure 4 functional architecture of the vision system

3.3. Vision module

The task of updating the data base with the model of the environment needed for the path-planning, collision detection and the feedback of accurate visual data to the operator, is accomplished by a model-based computer vision system. Figure 4 presents a more detailed schematic view of the vision system which is made up of an acquisition subsystem integrated by a stereo mount with tilt and vengeance control for each camera equipped with zoom and focus control. There is also a laser illumination system to improve the segmentation of cables. This sensor feeds and image processing set of VME boards with pipeline architecture that implements the preprocessing, segmentation and feature extraction process. These selected features are a representation of the edge contours of the scene carried out by a linear segment approximation. The vision control CPU feeds the feature information by an Ethernet link to a multiprocessor system that holds the database of the environment, the vision process, and the path planning and collision tasks. The data base is updated by a stereo algorithm that recovers the three-dimensional information of the tower contours and match this information with a model data base in order to generate an accurate location of the tower and his elements such as insulators, stanchions, and cables.
The laser illumination system solves the epipolar collinear ambiguity of the stereo system. This allows an easier recovery of the exact parametric model with the location of the cables. For the tower location, a polyhedrical model was chosen. This model match the range of tower types used by Iberdrola, and allow to use a linear contour model. At the heart of the 3D reconstruction is a feature oriented stereo algorithm (15) based on a set of local, and global geometric constraints that solve the correspondence problem between primitives of both images. Figure 5. From the resulting matches and the calibration information, a 3D contour model of the tower is generated, that is treated as an obstacle. For some types of standard towers an additional recognition stage is introduced to improve his location accuracy and allow automatic maintenance tasks. The last

element to introduce in the data base is the insulator. Typical insulators used in electrical towers have a curved shape. In order to find his location it is handled by means a polygonal approximation of the external box contour. This approach allows to generate an excluding area for the robots. The maintenance of internal elements is carried out from the information of the model database for known types, and teleoperated for non standard isolators.

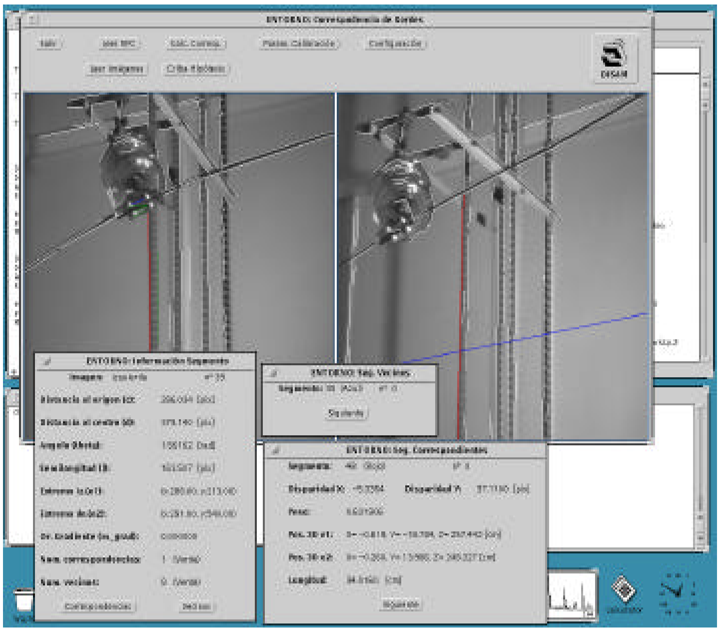

Figure 5 Example of the correspondence algorithm for an insulator

4. CONCLUSIONS

This paper has presented a new teleoperated system for live-line maintenance called ROBTET, being designed to fulfil all the requirements for live-line maintenance of the spanish power distribution (46 kV) network.

5. ACKNOWLEDGMENTS

The work presented in this paper is supported by electric utility IBERDROLA, S.A. and the Spanish Ministry of Industry through OCIDE under project PIE No. 132.198. Special thanks are also due to (in alphabetical order) F. Gallego, J. Gómez, C. González, E. Pinto and F. Val.

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