AN IMPLEMENTED OF A REAL-TIME EXPERIMENTAL SETUP FOR ROBOTIC TELEOERATION SYSTEM

TAFUR J.C.

Pontificia Universidad Católica del Perú. Departamento de Ingeniería.
Sección Electricidad y Electrónica
Centro de Tecnologías Avanzadas de Manufactura, CETAM.
Av. Universitaria No.1801, San Miguel Lima-32 PERU
Email: jtafur@pucp.edu.pe

PEÑA C., ARACIL R., GARCÍA C.
Universidad Politécnica de Madrid. Escuela Técnica Superior de Ingenieros Industriales
Departamento de Automática y Robótica, DISAM.
c/ José Gutierrez Abascal 2, E-28006, Madrid, ESPAÑA
Emails: caugusto@etsii.upm.es,rafael.aracil@upm.es, cecilia.garcia@upm.es

Abstract: The development of this work presents the implementation of an experimental platform, which will permit to investigate on a methodology for the design and analysis of a teleoperated system, considering the delay in the communication channel.
The project has been developed in partnership with the laboratory of Automatic and Robotics of the Universidad Politécnica de Madrid and the Laboratory at the Centro de Tecnologías Avanzadas de Manufactura at the Pontificia Universidad Católica del Perú.
The mechanical structure of the arm that is located in the remote side has been built and the electric servomechanism has been mounted to control their movement. The experimental test of the Teleoperation system has been developed. The PC104 card commands the power interface and sensors of the DC motor of each articulation of the arm.
Has developed the drives for the management of the operations of the master and the slave: send/reception of position, speed, acceleration and current data through a CAN network.
The programs for the interconnection through a LAN network, between the Windows Operating System and the Real-time Operating System (QNX), has been developed.
The utility of the developed platform (hardware and software) has been demonstrated.

Key Words: Teleoperation, Robotic, Real-Time, Embedded board, QNX.

1. Introduction

The teleoperator device allows the human operator mechanical actions that are usually performed by human hands and arms. Thus, the teleoperators or the act of teleoperation extend human capabilities handling of arms and hands in remote, physically hostile or hazardous environments.
Historically, teleoperation systems were developed in the middle of 1940 to create highly radioactive material handling capabilities.
The Teleoperator allowed the human operator to handle radioactive material from work environments separated by a wall of meter thick, concrete walls absorb radiation from the radioactive environment.

The teleoperator development for the nuclear industry culminated with the introduction of bilateral systems master-slave with reflection of force. In these successful systems, the master arm is mechanically or electrically coupled on the remote side to a geometrically identical arm or similar to the arm of the master, that is handled by an operator and follows the movement of the arm of the master. Subsequently the mechanical connections were replaced with electrical servo motors allowing a greater distance between the master and slave system, Goertz and Thompson (1954).

Robotics teleoperation involves interaction between a human operator and a remote robotic system through a communication channel. The Figure 1 can illustrate a teleoperated system, Hoyakem and Spong (2006). It consists of a local station where the human operator are, the local manipulator through which sends commands to the remote site and also has a set of devices such as TVs and monitors that let you see the remote task. In the remote site are located the robot, that performs the task itself. Both stations are communicated through a communication channel that allows the flow of information in both directions.

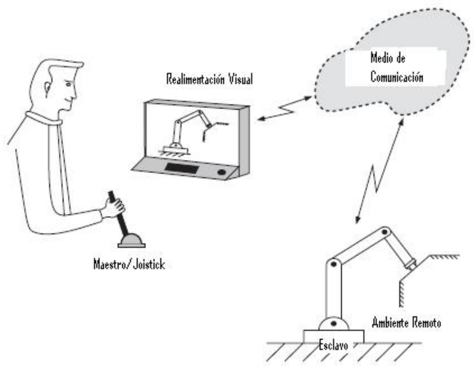

Figure 1. General Schematic of the Teleoperation System

The Figure 2 shows the block diagram of a typical teleoperated system. The diagram shows the major components of a teleoperation system; interaction with the human operator on the one hand and the environment by the other, the dynamics and drivers of the master and slave, and the communication channel is characterized through the delay transmission T.
Teleoperation systems are used in different areas that include: management of radioactive materials and space and underwater exploration, medicine, assistance to people with disabilities, the sector of electrical maintenance among other services. There is great interest in the field of Robotics in operation in remote environments using teleoperated systems.

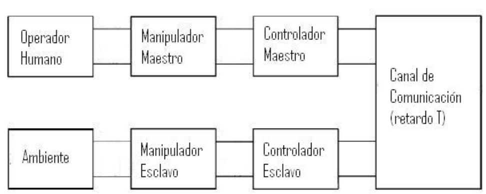

Figure. 2. Typical Block Diagram of Teleoperation System

There is several control schemes proposed in the literature to deal with specific problems in the field of robotics. In general the main objective of the system of teleoperation is run the task on a remote environment using the presence of a master manipulator and slave and regardless of the time delay in the communication channel between the master and slave.

The proposed control schemes use different non-linear control techniques such as; passivity, sliding modes and adaptive control, Arcara and Melchiorri (2002), Lee (2005), HO (2001) et al, which allow stabilize the master-slave system when the communication channel presents small delays and the environment is "soft". However, a linear dynamics for the teleoperator is considered in the design of control algorithms and the effect of the delay are analyzed using linear approximations, Hoyakem, Spong (2006), Yokokohji and Yoshikawa (1994).
The Automatic and Robotics Department of the ETSII at the Universidad Politécnica de Madrid has been developing for several years various robots which include several who have parallel structure. They include the underwater robots REMO I, the climbing robot CLIMBS I, II. These robots have favorable characteristics to move in their environments work, Almonacid et al. (2003).

The objective of this work is to development a real-time experimental platform, which will allow research methodology for the design and analysis of a teleoperator system, taken into account the nonlinear dynamics of the manipulator for the master and slave, as well as the delay in the communication channel.
The implemented robot arm will be located in the mobile ring a parallel platform (Stewart-Gough), allowing the teleoperated manipulation of the objects.
The work has been developed jointly between the laboratory of Automatic and Robotics (DISAM) of the Universidad Politécnica de Madrid (UPM) and the manufacturing laboratory of the Centro de Tecnologías Avanzadas de Manufactura (CETAM) at the Pontificia Universidad Católica del Perú (PUCP).
One take advantages significantly the movements of the platform with the purpose of obtaining minimum degrees of freedom in the arms, maintaining a specific workspace with the main orientation at the ends of the robots. The developed mechanical structure is compact and lightweight.

2. Methods and Materials

The experimental robotics teleoperation system platform elements are described below.

2.1 Embedded Board PC104
Hardware Characteristics

The TS-5600 is a compact, single Board Computer with all the features of a compatible computer, based on the AMD Elan520 processor. With a 133 MHz frequency, is approximately 10 times faster than products based on 386EX. The PC support allows rapid development, because you can use standard such as Turbo C or Power Basic computer development tools or tools based on Linux and QNX

Operative System

The PC of the *Technologic Systems Embedded* is compatible with a wide variety of operating systems. Some operating systems that supports embedded card are:

- TNT Embedded Toolsuite, Phar Lap Software
- UCos II
- RTKernel, On Time Software
- RTEMS, On-Line Applications Research Corporation
- DOS with WATTCP, public domain TCP/IP source code for DOS
- Linux
- QNX

2.2 Operative System Used: QNX

QNX is a real-time operative system based on the compatible microkernel POSIX-developed by QNX Systems in Canada. It is widely used in industrial control, media and other embedded applications which require a performance in real-time. QNX is a small operative system and can be configured to use a small amount of disk space and memory compared to other embedded operating systems for PCs. QNX microkernel developed an excellent performance in real-time via a configurable system user.

2.3 Motion Control Board EPOS 24/1

Maxon motor EPOS 24/1 is a digital motion controller. Due to the flexibility and efficiency of the power stage 24/1 EPOS can command digital brush DC motors with position and speed (encoder) sensors, as well as also brushless motors with digital Hall effect sensors and sensor position and speed (encoders). The spatial vectorized control of sinusoidal current switching let to the EC motors a minimum ripple of the torque and low noise. It is specially designed to be commanded and controlled as a slave node in a CANopen network. In addition, the device can be operated from a RS-232 communication port.

Internally structured CANopen interface allows you to network multiple drivers and command line by a master CANopen device.
Because there are multiple devices EPOS, the CANopen Protocol is used. The individual devices in the network are commanded by the CANopen master.

3. Manipulator Arm

Implemented robot arm will be located in the mobile ring a parallel platform (Stewart-Gough), as shown in Figures 3 and 4 allowing teleoperated manipulation of objects.
The arm is three degrees of freedom serial manipulator vertically articulated, the actuator system consist of the electric DC motors, as shown in Figure 5.
One of the main disadvantages of serials with electrical actuators robots is their relationship load vs. weight.
Because of this a robot designed is one that the motors are located at the base. For this reason the arm is implemented with a series of transmissions leading the movement to each of the joints. Transmissions are performed using bearings and toothed belts polyurethane with steel fibers which provide the Sync feature which is essential for the control of the robot, Peña (2007).

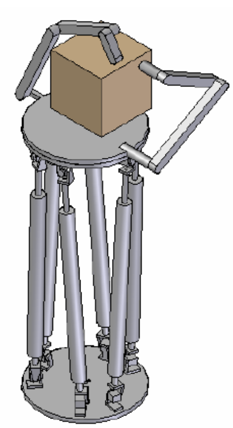

Figure 3. Simulated Structure in the software CAD

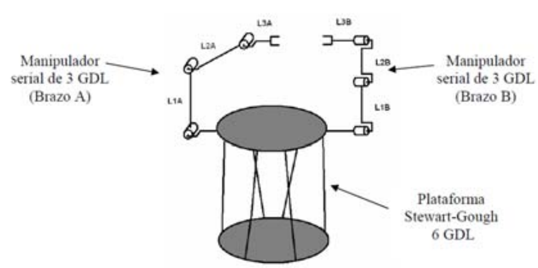

Figure 4. Robot Structure

Although there are many programs available for modeling and simulation of 3D motion, don’t exist a unique program that includes everything that evaluates the physical characteristics (features 3D) and functional description (motion planning) of the robot. The same simulation itself consists of the kinematics and dynamics depending on if is considered or not actuators torques or forces when generating motion paths.

Figure 5. Arm Structure

3.1 Manipulator Dynamic Model

Expressing the dynamic model arm by formulating Lagrange-Euler equation

$$\tau = D\ddot{q} + H + C \qquad (1)$$

Inertia Matrix D:

$$D = \begin{bmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \end{bmatrix} \qquad (2)$$

Where:

$$D_{11} = 0.60795\cdot 10^{-2}\cos(q_3+q_2)+0.032163\cos(q_2)+0.46029\cdot 10^{-2}\cos(q_3)+0.046869$$

$$D_{12} = 0.30397\cdot 10^{-2}\cos(q_3+q_2)+0.016082\cos(q_2)+0.46029\cdot 10^{-2}\cos(q_3)+0.01342$$

$$D_{13} = 0.30397\cdot 10^{-2}\cos(q_3+q_2)+0.19746\cdot 10^{-2}+0.23014\cdot 10^{-2}\cos(q_3)$$

$$D_{22} = 0.46029\cdot 10^{-2}\cos(q_3)+0.01342$$

$$D_{23} = 0.19746\cdot 10^{-2}+0.23014\cdot 10^{-2}\cos(q_3)$$

$$D_{33} = 0.19746\cdot 10^{-2}$$

$$D_{21} = D_{12} \quad ; \quad D_{31} = D_{31} \quad ; \quad D_{32} = D_{23}$$

The forces of Coriolis and Centripetal H matrix are defined as:

$$H = \begin{bmatrix} H_1 \\ H_2 \\ H_3 \end{bmatrix} \qquad (3)$$

$$H_1 = -0.60795\cdot 10^{-2}\dot{q}_1\dot{q}_3\sin(q_3+q_2)-0.60795\cdot 10^{-2}\dot{q}_2\dot{q}_3\sin(q_3+q_2)-0.60795\cdot 10^{-2}\dot{q}_1\dot{q}_2\sin(q_3+q$$
$$0.30397\cdot 10^{-2}\dot{q}_3^2\sin(q_3+q_2)-0.032163\dot{q}_1\dot{q}_2\sin(q_2)-0.23014\cdot 10^{-2}\dot{q}_3^2\sin(q_3)-0.016082\dot{q}_2^2\sin(q_2)-$$
$$0.46029\cdot 10^{-2}\dot{q}_2\dot{q}_3\sin(q_3)-0.46029\cdot 10^{-2}\dot{q}_1\dot{q}_3\sin(q_3)-.30397\cdot 10^{-2}\dot{q}_2^2\sin(q_3+q_2)$$

$$H_2 = -0.23014\cdot 10^{-2}\dot{q}_3^2\sin(q_3)+0.30397\cdot 10^{-2}\dot{q}_1^2\sin(q_3+q_2)-0.016082\dot{q}_1^2\sin(q_2)-$$
$$0.46029\cdot 10^{-2}\dot{q}_2\dot{q}_3\sin(q_3)-0.46029\cdot 10^{-2}\dot{q}_1\dot{q}_3\sin(q_3)$$

$$H_3 = 0.23014\cdot 10^{-2}\dot{q}_1^2\sin(q_3)+0.23014\cdot 10^{-2}\dot{q}_2^2\sin(q_3)+0.46029\cdot 10^{-2}\dot{q}_2\dot{q}_3\sin(q_3)+$$
$$0.30397\dot{q}_1^2\sin(q_3+q_2)$$

The force of gravity matrix C is defined as:

$$C = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} \qquad (4)$$

$$C_1 = -0.14146\cos(q_1+q_2+q_3)-0.74839\cos(q_1+q_2)-1.653\cos(q_1)$$
$$C_2 = -0.14146\cos(q_1+q_2+q_3)-0.74839\cos(q_1+q_2)$$
$$C_3 = -0.14146\cos(q_1+q_2+q_3)$$

4. Calculation and Motor Selection

The first step in the selection of the motors is the parameterization of the robot, this is calculated mass, centre of gravity and inertia of the links referenced to each of the links coordinate systems.
These parameters are obtained through the use of a computer aided design program.
Once is obtained the robot parameters, are replaced in the dynamic model, for this is necessary to choose the position of the robot which motors require a higher torque (worst position) and putting specific profiles of speed and acceleration as data input, using the computer dynamic inverse get torque required for motors.
Figure 6 shows the simulation diagram implemented for the calculation of the torque of motors.
Speed and Acceleration profiles were calculated taking into account the maximum speed at which revolved joints along with times of acceleration and deceleration.
These parameters were taken as:

- Joint maximum speed: -pi/3 rad/s
- Acceleration time: 100ms
- Constant time: 400ms
- Deceleration time: 100ms

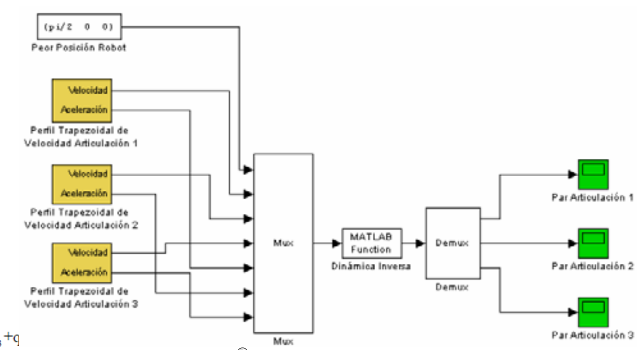

Figure 6. Simulink® Model for motors arms calculation

Table 1. Joint 1 Parameters

PARAMETER	VALUE
Length between axis	210.8 mm
Mass	0,429 kg
Centroid x	-82.337 mm
Centroid y	-1,026E-008 mm
Centroid z	-12,398 mm
I_{xx}	167,929 kg mm^2
I_{yy}	2,595E+003 kg mm^2
I_{zz}	2,583E+003 kg mm^2

Tables 1, 2 and 3 show the parameters for each joint.
Table 4 shows the torques that is required for each of the joints.
The following selections for the corresponding to each joint motor were made based on this.
The motors used are from Maxonmotor Company.
For joint 1 motor 200685 22 EC with a 143994 GP 22 C (316: 1 reduction ratio) gear and a control 302267 EPOS 24/1 unit was selected.
For joint 2 motor 283840 22 EC-max with a 143988 GP 22 C (128: 1 reduction ratio) gear and a control 280937 EPOS 24/1 unit was selected
For joint 3 motor 118459 RE 13 with a 110316 GP 13 A (275: 1 reduction ratio) gear and a control 280937 EPOS 24/1 unit was selected.

The material used for the manufacture of the links in the arm is stainless steel, aluminum has been considered for other elements.

Table 2. Joint 2 Parameter.

PARAMETER	VALUE
Length between axis	159.6 mm
Mass	0,214 kg
Centroid x	-70.7 mm
Centroid y	-1,743E-008 mm
Centroid z	-17,720 mm
I_{xx}	39,977 kg mm^2
I_{yy}	724,650 kg mm^2
I_{zz}	737,257 kg mm^2

Table 3. Joint 3 Parameter.

PARAMETER	VALUE
Length	40 mm
Mass	0,021kg
Centroid x	-14.42 mm
Centroid y	2,771E-005 mm
Centroid z	43,500 mm
I_{xx}	2,279 kg mm^2
I_{yy}	5,603kg mm^2
I_{zz}	6,236 kg mm^2

Table 4. Calculated Torques.

Joint	T_{peak}[Nm]	$T_{nominal}$[Nm]
1	-4.14	-2.7
2	-1.59	-0.96
3	-0.34	-0.19

5. Implementation

Figure 7 shows a real-time experimental setup for system.
The experimental test of the Teleoperation system has been developed. The PC104 card (embedded board) commands the power interface and sensors of the DC motor of each articulation of the arm.
Has developed the drives for the management of the operations of the master and the slave: send/reception of position, speed, acceleration and current data through a CAN network; 1. Sending data, 2. Receiving data, 3. Command speed, 4. Command position and 5. Command current.
The programs for the interconnection through a LAN network, between the Windows Operating System and the Real-time Operating System (QNX), has been developed.
Local side uses a haptic device PHANTOM Omni® from SensAble Technologies as local handle, remote arm reproduces the movements of the operator on this device.

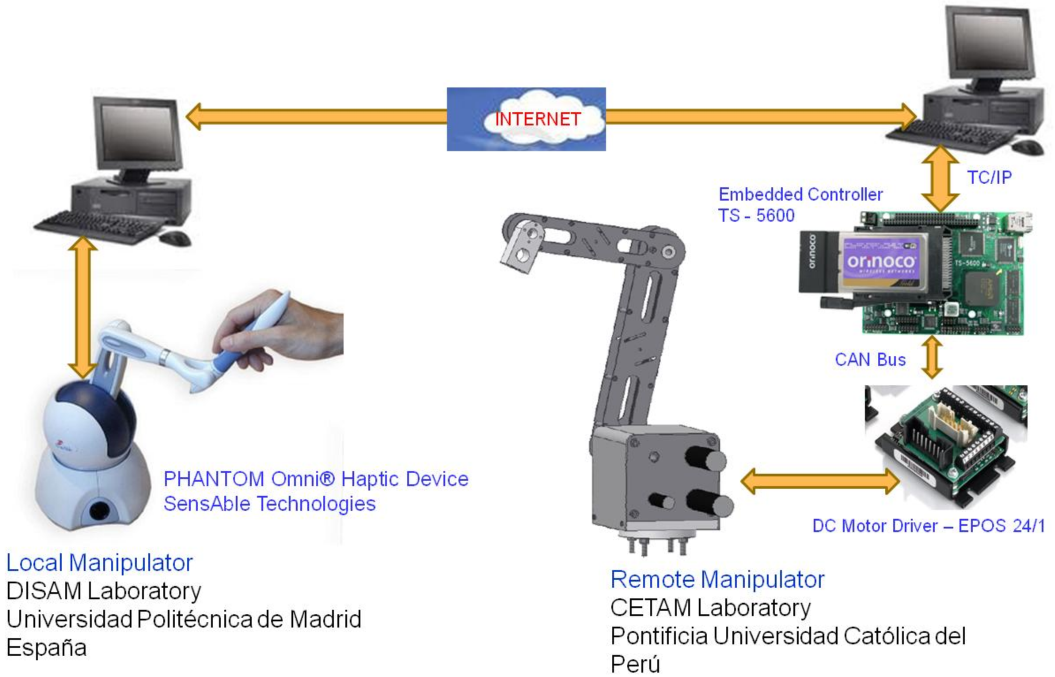

Figure. 7. A real-time experimental setup for Teleoperation System

6. Conclusions

Implemented structure will allow and facilitate implementation of nonlinear control algorithms in real-time ensuring the stability of the teleoperated system in the presence of delays in communication.

PC104 (embedded board), card commanded power interface and DC motors sensors and allows to run the control algorithm in real-time.

Transmission of rotational motion by toothed belts provides arms the ability to focus most of its weight on the basis allowing the use of lower power and size drives.

Acknowledgments

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References

Almonacid M., Saltaren R., Aracil R, and Reinoso O. "Motion planning of a climbing parallel robot," IEEE Trans. Robot. Automat., vol. 19, no. 3, pp. 485–489, 2003.

Arcara P., Melchiorri. "Control schemes for teleoperation with time delay: A comparative study", Robotics and Autonomous Systems 38 (2002) 49–64

Goertz, R.C. and Thompson, R.C. "Electronically controlled manipulator." Nucleonics, pages 46-47, 1954.

Ho S.A. et al. "A teleoperation position control for 2-DOF manipulators with control input saturation", Industrial Electronics, 2001. Proceedings. ISIE 2001. IEEE International Symposium on, Volume 3, 12-16 June 2001 Page(s):1520 - 1525 vol.3

Hokayem P.F., Spong M.W. Bilateral teleoperation: An historical survey, Automatica, (2006), doi:10.1016/j.automatica.2006.06.027

Lee D.; Li, P.Y. "Passive bilateral control and tool dynamics rendering for nonlinear mechanical teleoperators", Robotics, IEEE Transactions on [see also Robotics and Automation, IEEE Transactions on, Volume 21, Issue 5, Oct. 2005 Page(s):936 – 951.

Peña C. Trabajo Tutelado. Universidad Politécnica de Madrid. 2007.

Yokokohji Y. and Yoshikawa T. "Bilateral control of master-slave manipulators for ideal kinesthetic coupling—Formulation and experiment," *IEEE Trans. Robot. Autom.*, vol. 10, no. 5, pp. 605–620, Oct. 1994.