ROBOTIC EXPERIMENT
WITH A FORCE REFLECTING HANDCONTROLLER
ONBOARD MIR SPACE STATION

N95- 23707

M. DELPECH, Y. MATZAKIS,
CNES
18 Avenue Edouard Belin
31055, TOULOUSE Cedex, France

E. ROUCHOUSE
Matra Marconi Space
31, rue des Cosmonautes
31077 TOULOUSE Cedex, France

ABSTRACT

During the French CASSIOPEE mission that will fly onboard MIR space station in 1996, ergonomic evaluations of a force reflecting handcontroller will be performed on a simulated robotic task. This handcontroller is a part of the COGNILAB payload that will be used also for experiments in neurophysiology. The purpose of the robotic experiment is the validation of a new control and design concept that would enable to enhance the task performances for telemanipulating space robots. Besides the handcontroller and its control unit, the experimental system includes a simulator of the slave robot dynamics for both free and constraints motions, a flat display screen and a seat with special fixtures for holding the astronaut.

INTRODUCTION

When robot manipulators are being used in unstructured environments, telemanipulation represents either the nominal or at least the contingency mode of operation. Kinesthetic force feedback constitutes then a classical feature to enhance task performances when time delay is not a problem.

Several constraints, however, limit the introduction of force reflecting devices for teleoperating robots in space:
- the device working area must remain small enough for accommodation reasons and this prevents the use of classical 6D anthropomorphic structures,
- the dynamics of large external manipulators such as the Shuttle RMS is much slower than the operator hand, this reduces the reflected force bandwidth and so the benefit of the device,
- the computing power necessary for achieving satisfactory performances has to be very high,
- the microgravity obliges to introduce special astronaut holding equipment.

Passive devices remain then the baseline specially after the success of the ROTEX control ball [1] which has brightly proven its efficiency when coupled to a shared control robot. Such facts force to reconsider the kinesthetic force reflecting technique from a different point of view. This paper introduces a new control and design approach that addresses some of these problems. It presents then the device developped according to this approach and the experiments that will be performed in space to evaluate the ergonomy of its utilization for robotics.

HAND CONTROLLER DESIGN APPROACH

The vast majority of robotic tasks can be represented by a sequence of elementary actions, each involving motions along at most 2 or 3 axes simultaneously.

It has been taken advantage of this property in advanced telemanipulation systems where the operator is offered a variety of control modes that allow mobility within only a subset of the cartesian space. To perform a drilling task for instance, after adjusting the orientation and position of the driller, the operator needs to keep control along the drilling axis only, the other axes are being blocked during the operation. In such a way, computer aided teleoperation enhances task performances since the operator can concentrate his perception and actuation abilities on the most rewarding part of the job. Those remarks can trigger a discussion about the necessity to provide operators with 6 d.o.f. hand controllers when half of them are supposed to be blocked most of the time.

The alternative we are proposing consists in using 3 d.o.f. force reflecting joysticks.
The advantages of such simpler mechanisms are numerous:
- the compacity of the structure makes its accomodation more realistic for space vehicles,
- the smaller envelope prevents the operator from reaching uncomfortable positions,
- the stiffness and the dynamics can be significantly increased, thus allowing better performances,
- the computational cost of forward / inverse kinematics is reduced and alleviates the implementation requirements.

For controlling 6 d.o.f. robots, the operator is provided with a set of two complementary 3 d.o.f. joysticks: one for the translations, the other for the rotations. This system being operated with both hands enables then to control a robot in free space like any classical 6 d.o.f. serial mechanism. The performances may be even better since translation and rotation motions are decoupled. When doing constrained motions, the coupling between the two joysticks appears however in a rather remarkable way. Let us consider an operator inserting a peg in a hole by moving only the translation joystick: if there is some orientation error a resistive force will be applied by the joystick to his controlling hand and at the same time he will feel some force in its idle hand generated by the rotation joystick. He may resist to this force and then block the peg or comply and allow the orientation correction. In this latter case, one hand is the "controller" and the other one is the "follower". Our opinion that needs to be confirmed by experimentation is that the operator, after some training, will better interpret multi component forces. For that purpose, a complete telemanipulation system involving such joysticks is under development and should be ready within months.

Besides this utilization, this kind of device is specially relevant for shared control modes already described by Hirzinger [2] or Hayati [3] since it will provide force feedback in the operator controlled subspace.

HANDCONTROLLER PRESENTATION

The 3 d.o.f. active joystick presented here-below has been developped to serve two purposes:
- analysis of human neuromuscular models,
- robot telemanipulation.

since the requirements were convergent in terms of kinematics and performances. Table 1 shows the joystick present characteristics.

Axes Features	X, Y	Z (Rotation)
Working envelope	+/- 120 mm	+/-120°
Maximum force	25 N	0.6 Nm
Residual Friction	< 1N	<0.03 Nm
Maximum speed	0.5 m/s	200 °/s
Maximum stiffness	10000 N/m	200 Nm/rad

Table 1

The selected kinematics with 3 rotations (Figure 1) enables no dynamic coupling between the axes. The actuation is provided by servo-motors through Harmonic Drive gears. To cancel the residual gear friction, active compliance is implemented on the joystick controller and relies on a 3 d.o.f. force/torque sensor located beneath the handle. Joystick control is based on a 68040 CPU board and runs at a high rate.

For doing force feedback evaluation experiments, the joystick system is linked via VME bus to a simulator running on a second 68040 board (Figure 2). The typical control

scheme being used for implementing force reflection is presented on Figure 3 (pure force feedback) and is achieved at a medium sampling rate for realistic simulations.
However, as long as simulation is concerned, it is possible to implement higher sampling rate systems and so increase the force signal bandwidth by running at high in the joystick controller a simple interaction model whose parameters are computed by the simulator and updated with the force at medium rate. This enables to emulate systems running at higher frequencies.
The stiffness characteristics from Table 1 have been obtained according to this method for an infinitely stiff and light robot interacting with a pure spring.

EXPERIMENT DESCRIPTION

Objective

The purpose of this space experiment involving a single 3 d.o.f. joystick is twofold:
- to evaluate the ergonomy of synthetic force reflection with and without shared control
- to assess its potential benefit w.r.t. other techniques (use of passive devices such as ROTEX control ball).

Harware description

The experimental system includes the following components accommodated inside one of the MIR modules (Figure 4):
- the astronaut seat that constitutes the structural part of the system and that is fixed in the present design to the module floor.
- the motorized joystick,
- the experiment calculator including the joystick controller, the simulator computer and a graphic board,
- a flat display screen and a optical tunnel to eliminate the visual distractions.
- a handle with switches to control the experiment.

The spaceflight model of the joystick is based on ground technology: except for specially developped power electronic boards, the other elements are only hardened to satisfy the mechanical, thermal and safety requirements.
The calculator is VME based and includes standard CPU boards (MVME 162 with mezzanine IO boards) for both joystick control and simulation/experiment management.)

Experiment protocol

Robotic task

The robotic task to be performed is a "peg in a hole insertion".that involves a simulated robot interacting with a virtual environment. The robot is a 3 d.o.f. mechanical system that enables to move its end effector within a plane (2 translations along the X, Y axes and a rotation for its orientation). Figure 5 presents the model of this task. Using the joystick, the operator has to displace the peg in front of the hole, adjust its orientation and insert it smoothly until it touches the bottom. He monitors the robot displacement by watching a 3D graphic display of the scene that is representative of an image coming from a global view camera (figure 6).

The simulation includes the following features:
- the robot dynamics is finite (represented by a second order transfer function on all axes),
- the tool (peg) is attached to the robot by some compliant interface (compliance along 3 axes),
- contact interactions such as jamming effects can be represented: the obstacle stiffness is considered infinite and the only structural deformations take place at the compliant interface.

The simulation process runs in 12 ms: the force reflecting loop is closed at 75 Hz but the joystick model based joystick control runs up to 750 Hz..

The operator is asked to insert the peg in the minimum time while keeping the contact forces as low as possible: the performance criterion is a combination of those two informations.

Modes of operation

Three modes of operation are considered:
- Velocity control with visual force reflection (Mode 1)
- Position control with kinesthetic force reflection along all axes (Mode 2)
- Position control with kinesthetic force reflection along translation axes only (Mode 3).

- Mode 1 simulates the way ROTEX manipulator was operated by the astronaut within the Spacelab module [1]. The joystick is blocked in a central position to emulate a 3 d.o.f. "control ball" and force information is displayed on the screen using 3 bars (Figure 5). The slave robot moves under shared control: active compliance is provided along the orientation axis when contact is achieved.
- Mode 2 represents classical kinesthetic force feedback where all axes are controlled by the operator.
- Mode 3 is an example of kinesthetic force reflection applied in a shared control scheme. The slave robot is controlled like in Mode 1 but now the operator feels the forces along 2 degrees of freedom (X, Y).

These 3 modes will be used for performing the insertion task with two types of simulated robots:
- a high dynamics structure corresponding to some small servicing manipulator
- a low dynamics structure representative of long external manipulators.

This will make a total of six different control configurations for the experiment.

Three astronauts will participate in the experiment during the 11 days flight mission. Each astronaut will perform a specified number of repetitions of the task in the different control configurations (a minimum of 10 repetitions is required to allow a valid statistical analysis). In order to compare the obtained results with a fair reference so that the influence of gravity can be identified, the astronauts will perform exactly the same tests on ground before the mission.

CONCLUSION

The experiment presented in this paper constitutes a first shot in the evaluation of kinesthetic force reflecting techniques for teleoperation in space. We expect to demonstrate that the technique is not only feasible but enables to improve task performances when implemented with small 3 d.o.f. joysticks. However, the main purpose is the collection of experimental data for performing ergonomic analysis. It will permit then to improve the design of a complete 6 d.o.f. system (two joysticks) and to get ready for a full scale demonstration with a real space robot.

[1] G.Hirzinger and als.
The sensory telerobotic aspects of the space technology experiment ROTEX. iSAIRAS, Toulouse, September 1992.

[2] G. Hirzinger 1989.
Multisensory shared autonomy - a key issue in the space robot technology experiment ROTEX, IEEE Conference on Intelligent Robots and Systems (IROS), Raleigh, USA, July 92.

[3] S. Hayati, S.T. Venkataraman
"Design and Implementation of a Robot Control System with Traded and Shared Control Capability". IEEE Conference on Robotics and Automation, Scottsdale, 1989.

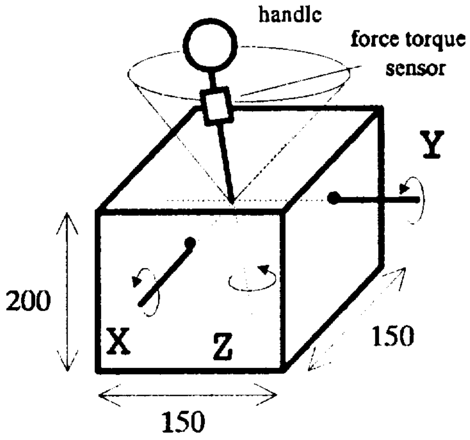

Figure 1

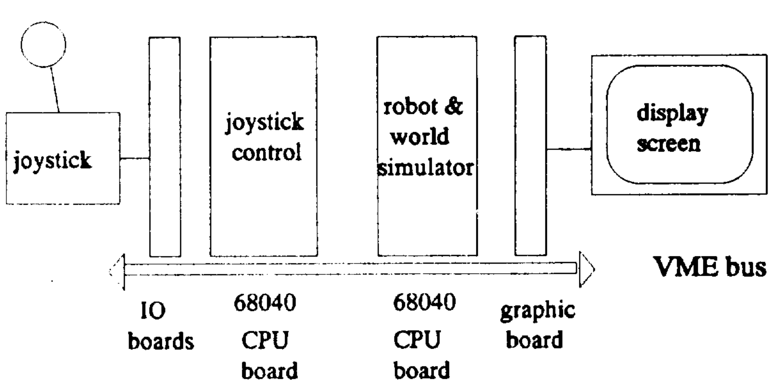

Figure 2

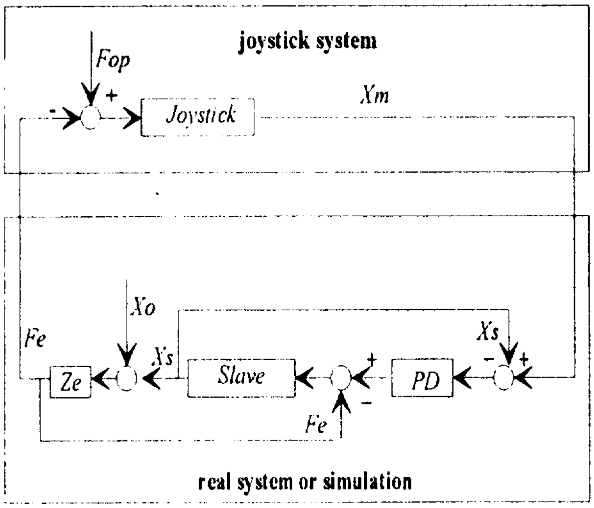

Figure 3

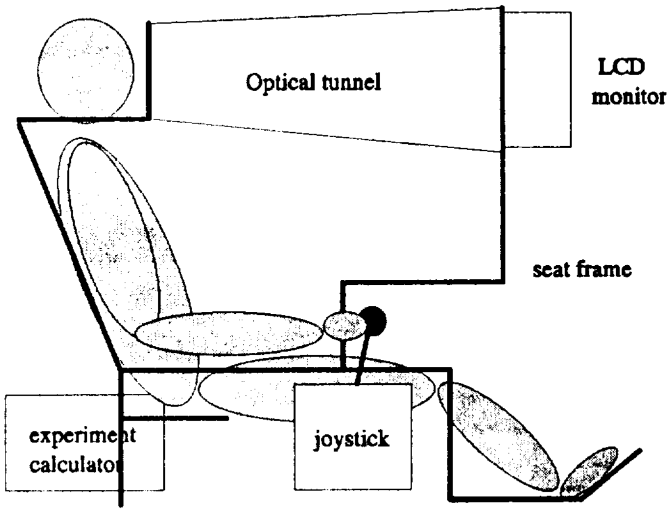

Figure 4

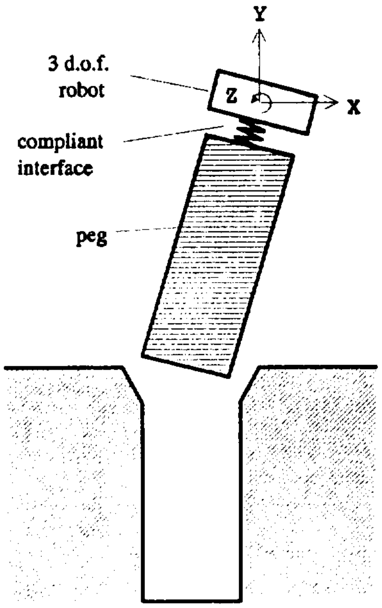

Figure 5

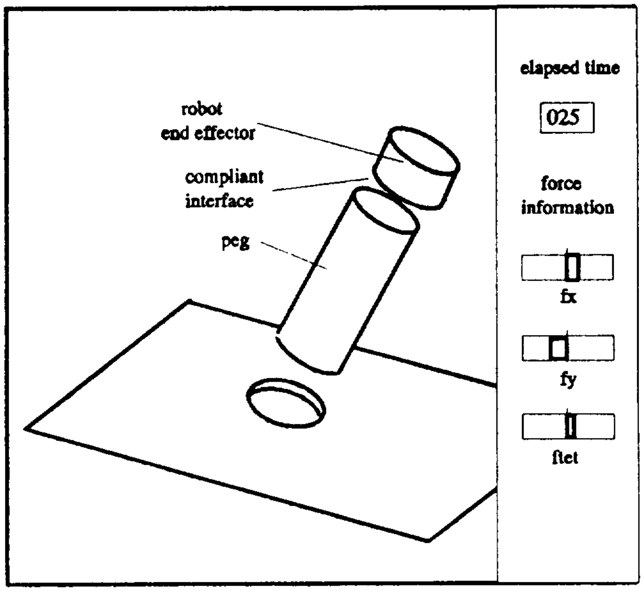

Figure 6