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## **Teleoperation over IP Network : Virtual PUMA Robot**

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### **Abstract:**

We propose in this paper a stable remote position/force control scheme for manipulator robot via Internet based on Smith Predictor principle. In order to validate in real network situation our control method, we developed a real time Virtual Puma Robot based on *RTLinux Operating System*. This Virtual Robot contains a real time task which computes the differential non linear equation of the *PUMA* Robot including a virtual environment in order to perform a force control loop. Some interesting experimental results in the case of long distance (Mexico-France : ~7000 km) show the real improvement obtained with this method under some important mean time delay (~200ms). This addition enhances and secures the teleoperation through the *Internet*. The *Virtual PUMA Robot* server will be reachable on *Internet* and available for the conference to perform some real-time teleoperation experimentations via a Java HMI. Closing a loop through an IP network open some news application field such that a cooperated control for robotics systems via Internet.

## **Teleoperation over IP Network : Virtual PUMA Robot**

### **SUMMARY**

There are situations when firms or laboratories have to resort to remote manipulation. Such cases appear when dangerous objects have to be handled [1] or/and when the environment is too aggressive for humans. Typical applications belong to the nuclear domain (for instance in the dismantling of a nuclear plant), deep-sea domain (work on underwater structures of oil rigs) and spatial domain (exploration of distant planets). Teleoperation has the supplementary advantage of giving the possibility of sharing an experiment between several operators located in distinct places. This way, heavy outdoor experimentations could be easily shared between several laboratories and costs could be reduced as much.

However, long distance control of a remote system requires the use of different transmission media which causes two main technical problems in teleoperation : limited bandwidth and transmission delays due to the propagation, packetisation and many other events digital links may inflict on data [2]. Moreover bandwidth and delays may vary according to events occurring all along the transmission lines.

These technical constraints result in one hand in difficulties for the operator to securely control the remote system and, in the other hand, make classical controls unstable. Many researches have proposed solutions when delays are small or constant (for instance [3]), but when delays go beyond a few seconds and vary a lot as over long distances asynchronous links, solutions not based on teleprogramming [4] are fewer because such delays make master and slave asynchronous and the control unstable.

Since 1997, our team has begun a research project on teleoperation. At this time, publications about teleoperation methods when delays are small and/or constant were numerous but there was a lack in long distance teleoperation literature, when delays are prohibitive and variable such as through *Internet* channels. Starting from an initial experiment with our mobile manipulator, our first work consisted in highlighting practical difficulties inherent to teleoperation of mobile manipulator. We then began to develop a generic teleoperation model which we inserted in a simulation environment using *Matlab/Simulink*. Working with this tool, we proposed an architecture and a method [1] consisting in buffering data at its arrival in both master and slave. Associated with an adaptive predictor we could offer a real-time estimation of slave state over a virtual constant delay transmission link. In order to validate these results, we developed a software based on this model, which we applied on our mobile manipulator [5]. Experimentations permitted us to collect data on Internet network delays in 4 cases: very short (intranet), short (100km), medium (850km) and long distance (6000km). We tested our teleoperation method and we could draw conclusions about its advantages and drawbacks. The main drawback was that this buffering method induced a very high global constant delay in short distance teleoperation, due to an unsuitable transmission period. Therefore, we completed our model by a real-time network round-trip time delay measure and forward prediction in order to adapt the transmission period and buffer parameters to small frequency network behaviour. First results of the *Network Delay Regulator* (NDR) were presented in 2001 [6].

We propose in this paper a stable remote position/force control scheme for manipulator robot based on Smith Predictor principle including the NDR. The position/force control scheme [7] is both on local and remote site. The external force control loop is implemented on a TCP/IP client with the Smith Predictor (SP) by using the NDR to maintain the time delay constant. The position control loop is located on the remote site (TCP/IP server) and receives the desired position vector from the local site including the force error vector via a coordinate transformation (Inverse Kinematics) and sends back to the local site the force vector. This position control law is based on decentralised PID control law in the joint space.

In order to validate in real network situation our control method, we developed a real time Virtual Puma Robot (see Figure 1) based on *RTLinux Operating System*. This simulator contains a real time task which computes the differential non linear equation of the *PUMA Robot* including a virtual environment in order to perform a force control loop. The output vector is transmitted via a *FIFO* to the *TCP* server and the input control vector is received by the same way.

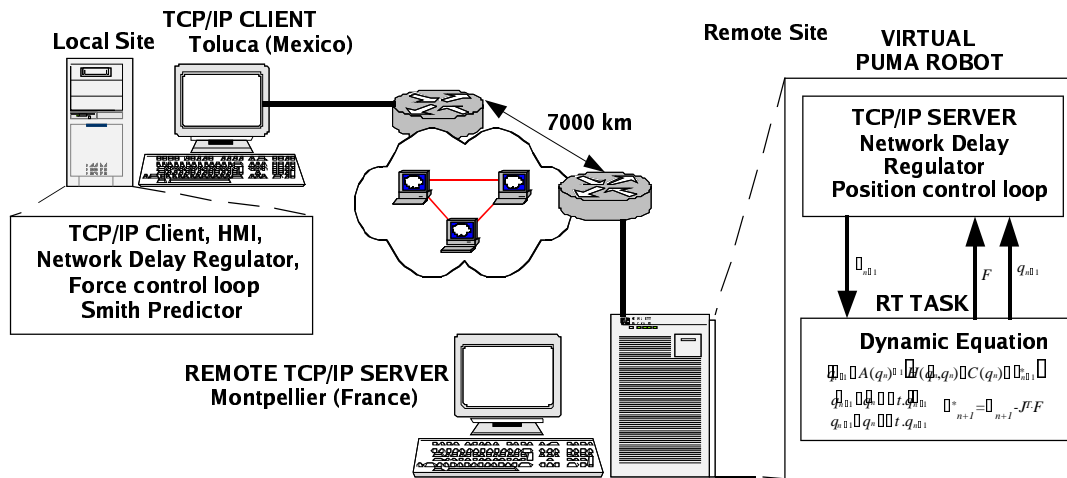


Figure 1 : Remote Position/Force Control of Virtual PUMA Robot

A specific protocol has been defined with the client/server connection including a timestamp word in order to compute the Round Trip Time (*RTT*). The simulator permits to detect instability cases without experimental constraints:

- no security problem,
- no damage possibility,
- 24h a day availability.

Some interesting experimental results in the case of long distance (Mexico-France : ~7000 km) show the real improvement obtained with this method under some important mean time delay (~200ms). This addition enhances and secures the teleoperation through the *Internet*. The *Virtual PUMA Robot* server will be reachable on *Internet* and available for the conference to perform some real-time teleoperation experimentations via a Java HMI. Closing a loop through an IP network open some news application field such that a cooperated control for robotics systems via Internet.

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