ON-LINE ESTIMATION OF COMMUNICATION TIME DELAY IN A ROBOTIC TELEOPERATION SYSTEM

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Abstract–– **An estimation technique to compute on-line the communication time-delay in a robotic teleoperation system is presented. The proposed algorithm is based on the concept of correlation function and time-delay estimation. The estimation is obtained with an additional signal injected through the communication channel, that is correlated to another signal (of the same kind) generated at the remote station. This way, the correlation function is computed along with its maximum which, multiplied by the sampling time, will result in the desired time delay. Simulation results show the improvement of the teleoperation system performance when using both the communication time delay compensation structure and the time delay estimator. Finally, a comparison between the proposed algorithm and Matlab´s *xcorr* function to compute time delay is performed.**

Keywords–– **automatic control, time delay estimation, compensation structure, telerobotic system, hybrid position-force control.**

I. INTRODUCTION

In recent years, several experiments have proved that the execution time needed by a human operator to do a task with a robotic teleoperation system, is significantly dependent on the communication time delay, on the task complexity and on the control structure of the system. In 1965, Ferrel verified that the human operator can adapt his/her motions using a so called *"move and wait"* strategy so as to prevent destabilising the robot teleoperation system and other associated problems (Ferrel, 1965). With this control strategy, the operator performs a discrete motion command, then he/she stops and waits (round-trip delay time) for the confirmation that the control action has been followed by the remote robot manipulator or by the remote mobile robot. After this, the operator sends another discrete reference command, and the control cycle repeats itself. The control strategy thus keeps working.

Experimental results in the last two decades, have shown the problems of communication time delays in teleoperation systems (Sheridan, 1993). Hence, much effort has been put on designing control structures capable of compensating communication time delays, though, as for today, no approach can prevent their effects completely. *Predictor displays* is an alternative approach to solve some of the problems caused by time delay. With this technique, a cursor or other visual pointer is generated by a computer and they are forward time-extrapolated. This helps the human operator predict what will happen in the remote system upon sending a certain reference command from the local station.

If the force is backfed, when time delays are present, the problem is worsened. In 1963, Ferrel proved that it is unacceptable to backfeed continuously the remote sensed force to the same hand with which the operator is manipulating the local hand-controller in a robotic teleoperation system (Ferrel, 1963). This is due to the time delay in the feedback loop imposing a non-expected perturbation on the human operator´s hand, which he/she cannot ignore, thus provoking instability in the entire teleoperation process. If a visual display were available, the human operator could ignore the perturbation and, in this case, he/she could apply the *move and wait* strategy or some kind of supervision strategy to avoid system instability.

In previous works (García *et al.,* 2000a; García et. al. 2000b), a time delay compensation approach was presented. This approach was a Smith predictor based compensation method (Marshall, 1979). Smith predictor method calls for a good model of the system part that lacks a time delay, because this part of the model will be part of the control loop.

As mentioned above, the presence of time delay in data transmission between local and remote stations is a particularly important problem to solve in robotic teleoperation, for it can cause instability in the entire system. If this time delay is variable, this problem worsens up because the proposed control structures do not account for time-delay variation. Hence, aiming at ob-