A Controller Design Framework for Telerobotic Systems

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ABSTRACT

This research work focuses on development of a framework for designing a telerobotic system controller. We define *telefunctioning* as a robotic manipulation method in which the dynamic behaviors of the slave robot and the master robot are functions of each other; these functions are the designer's choice and depend on the application. In a subclass of telefunctioning called telepresence, all of the relationships between the master and the slave are specified as "unity" so that all of the master and slave variables (e.g., position, velocity) are dynamically equal. To create telefunctioning, we arrive at a minimum number of functions relating the robots' variables. We then develop a control architecture which guarantees that the defined functions govern the dynamic behavior of the system. The stability of the closed-loop system (master robot, slave robot, human, and the load being manipulated) is analyzed and sufficient conditions for stability are derived.

1. ACCOMPLISHMENTS

1) We have introduced a new control architecture for telerobotic systems. This control architecture is different from the two most common telerobotic control architectures in present use: "position error architecture" and "forward flow architecture". The architecture proposed here is the most general extension of the two present architectures and allows a variety of performance specifications.

2) One important property of this new control architecture is that it can be formulated as an $H\infty$ problem after applying the exact linearization method to the robot dynamics. Our proposed control architecture has led to controllers which exhibit robustness in the presence of changes in the human and load dynamics.

3) The physical interface between a telerobotic system and a human has introduced a new concept: the exchange of <u>power</u> and <u>information signals</u> between the master robot and the human arm which is in physical contact with the master. The human wears the master robot, so power transfer is unavoidable and information signals from the human help to control the machine. We have studied such human-machine interaction when this new proposed control architecture governs the system behavior. Our study has led to an understanding of the role of human dynamics in the control of telerobotic systems.

4) We have experimentally verified the system performance when the system is subjected to changes in the human dynamics and the environment dynamics. We have evaluated both the system performance and the system stability experimentally. Figure 1 shows the experimental setup: a two-degree-of-freedom XY table was used as the master robot. A three-degree-of-freedom composite robot was used as the slave robot. Since the master robot operates only on a horizontal plane, one of the slave's robot actuators is physically locked so that the slave robot operates on the horizontal plane also. As shown in Figure 7, the operator's hand grasps a handle mounted on a force sensor. A piezoelectric force sensor between the handle and the XY table measures the human's force, f_m, along the X and Y directions.

2. TRANSFER OF TECHNOLOGY

The theoretical predictions for performance and stability were experimentally verified on the seven-degree-of freedom NASA Laboratory Telerobotic Manipulator (Figure2).

3. REFERENCES

H. Kazerooni, T.-I. Tsay, K. Hollerbach, "A Controller Design Framework for Telerobotic Systems' IEEE Control Systems Technology, Volume 1, Number 1, March 1993.

K. Hollerbach, H. Kazerooni, "Modeling Human Arm Movements Constrained by Robotic Systems", ASME Winter Annual Meeting, DSC Volume 42, December 1992.
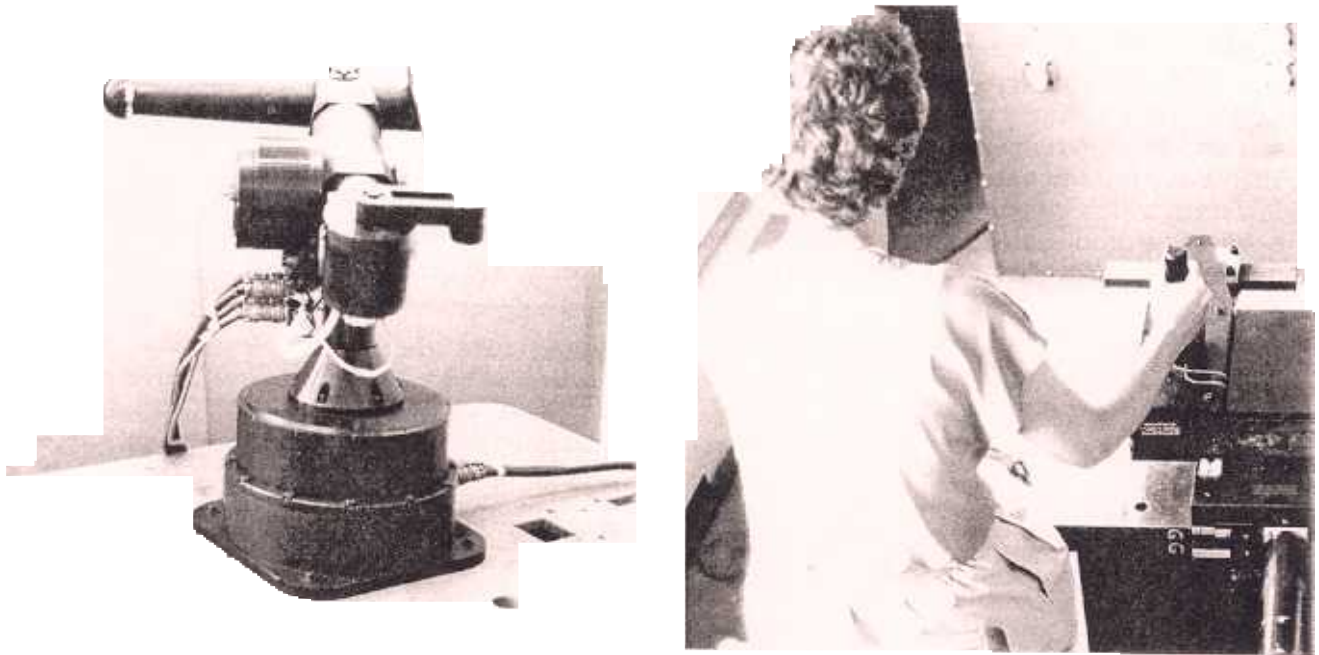
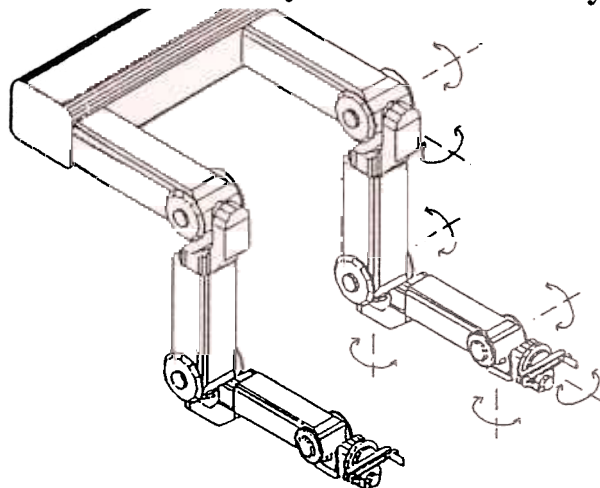Figure 1: Experimental Telerobotic System at the University of California.

Figure 2: The control method was experimentally verified on the NASA Laboratory Telerobotic Manipulator