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ISSUES IN THE DESIGN OF HIGH DEXTERITY, FORCE REFLECTIVE TELEOPERATORS

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The Center for Engineering Design at the University of Utah is developing an anthropomorphic, hydraulically actuated, teleoperated arm. The system includes a sixteen degree-of-freedom slave manipulator controlled by a kinematically identical, sixteen degree-of-freedom force-reflective, exoskeletal master. The project has focused on four areas: (a) formulating a realistic set of **design objectives** which balance, against technical realities, the desire for performance, reliability and economy, (b) understanding **control issues**, (c) **designing and fabricating new subsystems** (presently unavailable) necessary for the construction of a successful machine and (d) integrating subsystems, through a series of prototype stages, into an operational teleoperation system.

Generating a comprehensive set of design objectives required the consideration of fundamental questions such as: (1) what should be the kinematic configuration of master and slave, hand and arm, (2) how many degrees of freedom will be necessary for the level of dexterity desired, (3) should the master be exoskeletal, or some other configuration, (4) what is the importance of force reflection and how can its fidelity be improved beyond current systems, (5) what are the realistic actuation alternatives considering active and passive performance requirements, (6) what performance is required of sensor systems, (7) when necessary, can tendons be successfully used to remotize actuators.

Our work in the control area focused on: (1) developing stable position and torque feedback approaches which result in desirable inter-system impedance (frequency dependent gain, stiffness and damping), (2) generating acceptable joint-torque compensation which removes undesirable effects of gravity, mass and viscous drag, (3) increasing system bandwidth to improve operator awareness of loads imposed on the slave.

Extensive efforts were expended in the design and fabrication of presently unavailable subsystems such as: (1) rotary and linear hydraulic actuators along with required servo valves, (2) joint-torque sensors capable of remote-axis-sensing, high stiffness, low stiction and minimal sensing of loads on other axes, (3) position sensors with acceptable accuracy, (4) computation systems which include digital and analog electronics for implementation of servo, intermediate and higher level control functions, (5) systems for long range communication between the master and slave systems. Designing subsystems such that they "package" into the available shaped volumes as well as satisfying other constraints was a problem of substantial magnitude. Packaging remains an underestimated problem which in fact dominates many design decisions.

Finally, work is proceeding towards integrating subsystems into a working machine which actually achieves its objectives with respect to performance, reliability and economy. The system must: (1) be capable of operating in sea environments which includes corrosion and substantial pressure, (2) survive substantial mechanical abuse and misuse, (3) include mechanical machine-operator interfaces which insure comfortable, nonfatiguing operation over long periods of time.

The presentation will address the issues mentioned above as well as include a video demonstration of the system executing selected dextrous tasks.