tors and collects the switch information. The software consists of a database, exercise procedures, a report-generating procedure and a pattern creation procedure. The software was written in Pascal and the RMS software was written in assembly language. The database contains the pertinent patient information. The pattern creation procedure allows the therapist to create individualized patterns for patients.

The patient is directed to perform a given movement or task as prompted by the end-effector and "home" switch indicator lights. The robot arm moves to a point in space and the indicator light on the end-effector switch illuminates, indicating to the patient to reach and touch the switch.

A formal evaluation of this system was performed, using 11 therapists and 22 patients. The study indicated that the system is safe, accepted by patients and therapists, and seen by the latter as having utility. However, a number of additions and modifications were suggested.

In Phase 2, additional software needed for two vocational assessment applications was produced.

Future Plans—Development of additional modules, constituting a system for upper extremity coordination testing/treatment, is under way. Five different tasks will be built and field-tested: tracing a pattern with a stylus, manipulating nuts and bolts, turning knobs and other devices, pushing switches and buttons, and independent finger manipulation. Task difficulty will be gradable in terms of speed of performance required, size of objects, distance of task to trunk, and orientation of task. Continuous feedback to therapist and patient will be provided. The tracing task, which is implemented on a Deeco touch-sensitive screen, is undergoing pilot testing. The upper extremity coordination system uses the UMI-RT100 robot, and instead of the custom-made RMS board, a commercially available microcomputer data acquisition and control board is used.

We also plan to redesign a robotic module for developing stroke patients' prehension skills, which was built earlier in the project. While the concept was very attractive to therapists, laboratory testing of the module indicated mechanical problems which made it impractical.

Recent Publications Resulting from This Research

A Robotic System to Provide Movement Therapy. Erlandson RF, et al. Proceedings of the Fifth International Service Robot Congress, Detroit, MI, 1990.

Patient and Staff Acceptance of Robotic Technology in Occupational Therapy: A Pilot Study. Dijkers M, et al. J Rehabil Res Dev 28(2):33-44, 1991.

[192] Human Machine Interaction via Transfer of Power and Information Signals

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Purpose—The aim of this project was to establish methods of design and control of machines that have stable dynamic interaction with humans via simultaneous exchange of both power and information signals. Orthoses are examples of self-powered machines that should be built and controlled for the optimal exchange of power and information signals with humans. The human wearing the orthosis is in physical contact with the machine, so power transfer is unavoidable and information signals from the computer help to control the machine.

Progress/Methodology—We have derived and experimentally verified the mathematical framework in controller design and human-machine physical interaction in the sense of transfer of power and information signals. General models for the human, the orthosis, and the interaction between the human and the orthosis are developed. The stability of the system of human, orthosis, and the object being manipulated is analyzed, and the conditions for stable maneuvers are derived. The trade-off between stability and performance is described.

To verify the theoretical analysis, we have designed and built a prototype orthosis (called extender in this research work). The input to the extender is derived from the contact forces between the extender and the human. The contact force is measured, appropriately modified (in the sense of control theory to satisfy performance and stability criteria), and used as an input to the extender control, in addition to being used for actual maneuvering. Because force reflection occurs naturally in the extender, the human arm feels a scaled-down version of the actual forces on the extender without a separate set of actuators. For example, if an extender is employed to manipulate a 10 lbf object, the human may feel 1 lbf, while the extender carries the rest of the load. The 1 lbf contact force is used not only to manipulate the object, but also to generate the appropriate signals to the extender controller.

Results/Implications—Our experiments show that the controllers derived by this research work are robust in the presence of significant variations in the human arm dynamics. Our research work will serve as the basis in design and control of intelligent prosthetic devices. The results of this research are being made public by the publications listed below. The publications have resulted in widespread exposure of these ideas to other researchers and engineers in industry.

Recent Publications Resulting from This Research

Human Machine Interaction via the Transfer of Power and Information Signals. Kazerooni H, IEEE Transactions on Systems, Man, and Cybernetics 20(2):450, 1990.

Stability and Performance of Robotic Systems Worn by Humans. Kazerooni H, IEEE International Conference on Robotics and Automation, Cincinnati, OH, 558, 1990.

Theory and Experiments on Robot Compliant Motion Control. Kazerooni H, Waibel BJ, Kim S, ASME Journal of Dynamic Systems Measurements and Control 112(3):417, 1990.

Dynamics and Control of Robotic Systems Worn by Humans. Kazerooni H, Mahoney SM, IEEE International Conference on Robotics and Automation, Sacramento, CA, 2399, 1991.

On the Stability of the Constrained Robotic Maneuvers in the Presence of Modeling Uncertainties. Waibel B, Kazerooni H, IEEE Transactions on Robotics and Automation 7(1):95, 1991.

Dynamics and Control of Robotic Systems Worn By Humans. Kazerooni H, ASME Journal of Dynamic Systems, Measurement and Control (in press).

[193] Robotics Simulation Research

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Purpose—Computer simulation is being employed as part of our research on robotic systems for use by physically disabled persons. The advantages of computer simulations over bench models are the increased safety of the investigator and the ability to change parameters without rebuilding the hardware.

Methodology—A major area of research on robots designed for use by physically disabled persons involves making them safe for the user, for attendants, and for others. Our basic approach is to improve safety by improving user control. We are investigating the improvement in user control which will be obtained by the use of the control strategy, "Extended Physiological Proprioception."

Progress—Work undertaken so far has involved the development of computer programs to give a 3-dimensional simulation of robotic systems. When this is completed, we will go on to the next phase which will involve performing several simulated tasks and evaluating the success.