HUMAN/ROBOT INTERACTION VIA THE TRANSFER OF POWER AND INFORMATION SIGNALS

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ABSTRACT

Through any reasonable observation and experience, the human's ability to perform a variety of physical tasks is limited not by his[1] intelligence, but by his physical strength. If, in the appropriate environment, we can more closely integrate the mechanical power of a machine with the human hand under the supervisory control of the human's intellect, we will then have a system which is superior to a loosely integrated combination of a human and his fully automated robot as in the present day robotic systems. We must, therefore, develop a fundamental approach to the problem of this "extending" human mechanical power in certain environments. The work presented here defines "Extenders" as a class of robot manipulators worn by humans to increase human mechanical strength, while the wearer's intellect remains the central intelligent control system for manipulating the extender. The human body, in physical contact with the extender, exchanges <u>information signals</u> and <u>power</u> with the extender. Reference 1 focuses on the issues of the dynamics and control of human machine interaction in the sense of the transfer power and information signals while this paper presents a summary of the research work.

CONCEPT

The ability of a robot manipulator to perform a task depends upon the available actuator torque. A relatively small hydraulic actuator can supply a large torque. In contrast, the muscular strength of the average human is quite limited. Extenders are defined as a class of robot manipulators which will extend the strength of the human arm while maintaining human supervisory control of the task. The extender is distinguished from conventional master-slave systems; the extender is worn by the human for the purpose of direct transfer of power. Consequently, there is actual physical contact between the extender and the human, allowing transfer of mechanical power in addition to information signals. Because of this unique interface, control of the extender trajectory can be accomplished without any type of joystick, keyboard, or master-slave system. The human provides an intelligent control system to the extender, while the actuators ensure most of the necessary strength to perform the task. The key point is the concept of "transmission of power and information signals". The human becomes a part of the extender, and "feels" some scaled-down version of the load that the extender is carrying. In contrast, in a conventional master-slave system, the human operator may be either at a remote location or close to the slave manipulator, but he is not in direct physical contact with the slave in the sense of transfer of power. Thus, the operator can exchange information signals with the slave, but mechanical power is <u>not</u> exchanged directly. In a typical master-slave system, natural force reflection does not occur because the human and the slave manipulator are not in direct physical contact. Instead, a separate set of actuators are required on the master to reflect forces felt by the slave back to the human operator.

In the extender system, the input to the extender will be derived from the set of contact forces resulting from the contact between the extender and the human. This set of contact forces is being used to manipulate an object in addition to generating information signals for the extender control. Note that force reflection occurs naturally in the extender, the human arm will feel a scaled-down version of the actual forces on the extender <u>without</u> a separate set of actuators. For example, if an extender is used to manipulate a 100 lbf object, the human may feel 10 lbf while the extender will carry the rest of the load. The 10 lbf contact force is used not only for manipulation of the object, but also for generating the appropriate signals to the extender controller. In other words, the contact force between the human and the extender is measured, appropriately modified (in the sense of control theory to satisfy the performance and stability), and used as an input to the extender control, in addition to being used for actual maneuvering.

The concept of a device to increase the strength of a human operator using a master-slave system has existed since the early 1960s. The concept was originally given the name "man-amplifier". In contrast with the previous man amplifiers, the extender is not a master-slave system. The human operator's commands to the extender are taken directly from the interaction force between the human and the extender. This interaction force is also used to help the extender manipulate an object. In other words, the power and information signals transfer simultaneously. The controller developed for the extender translates the signals representing the interaction force signals into a motion command for the extender. This allows the human to initiate tracking commands to the extender in a natural way. The controller also regulates the interaction force to be a "desired" force reflection on the human. The human operator <u>can feel</u> the scaled-down effect of loads and/or interaction forces on the extender because the forces acting on the extender are naturally reflected back. A master-slave system needs two sets of actuators for force reflection on the human.

Some of the major areas of application for the extender might include manufacturing, construction, loading and unloading aircraft, maneuvering cargo in shipyards, foundries, mining or any situation which requires precise and

[1] The pronouns "he" and "his" used throughout this article are not meant to be gender-specific.

complex movement of heavy objects. The extender also has the potential to become a useful upper limb orthosis for the physically impaired. The extender would be classified as an orthosis rather than a prosthesis, because it would enhance existing motor ability instead of replacing an absent segment.

Unstructured dynamic models for the human and extender have been developed in terms of nonlinear time domain mappings and linear transfer function matrices. The stability of the extender and human taken as a whole has been considered in this article. First, the Small Gain Theorem is used to determine a sufficient condition for stability in the completely general, unstructured, nonlinear system. Then, a sufficient condition for stability for the linear, time invariant, frequency domain model is determined. The condition for stability is determined using the multivariable Nyquist Criterion, with the "size" of the operators evaluated in terms of singular values. The equivalence of the conditions for stability when the Small Gain Theorem is extended to the linear system has been shown. The stability conditions can be given a physical interpretation, which shows the limit on the gain of the compensator is dependent upon the total compliance in the system, i.e., the physical compliance of the flesh along with the sensitivities of the human arm and extender. The effect of compensation on system performance has also been shown. Based on this result, it is desirable to have a large gain for the compensator. However, the stability condition places a limit on compensation, and thus there is a trade off between performance and stability.

References

[1] Kazerooni, H., "Human/Robot Interaction via the Transfer of Power and Information Signals", IEEE International Conference on Robotics and Automation, May 1989, Scottsdale, Arizona