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Issues on the Control of Robotic Systems Worn by Humans

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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. Extenders are defined as robot manipulators which extend (i.e., increase) the strength of the human arm in load maneuvering tasks, while the human maintains control of the task. Part of the extender motion is caused by physical power from the human; the rest of the extender motion results from force signals measured at the physical interfaces between the human and the extender, and the load and the extender. Therefore, the human wearing the extender exchanges both power and information signals with the extender. References 1-4 focus 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 not 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, and the load and the extender. These contact forces are 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 without a separate set of actuators. (Note that one requires two sets of actuators in a master-slave system: one set of actuators in the slave robot to perform the task, and one set of actuators in the master robot to simulate the force on the operator). 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

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

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.

In general our goal has been to determine the ground rules for a control system which lets us arbitrarily specify a relationship between the human force and the load force. In a simple case, the force the human feels is equal to a scaled-down version of the load forces described above. In another example, if the object being manipulated is a pneumatic jackhammer, we may want to both filter and decrease the jackhammer forces: then, the human feels only the low-frequency, scaled-down components of the forces that the extender experiences. Note that force reflection occurs naturally in the extender, so the human arm feels a scaled-down version of the actual forces on the extender <u>without</u> a separate set of actuators.

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 <u>not</u> 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 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. Some major applications for extenders include loading and unloading of missiles on aircraft; maneuvering of cargo in shipyards, foundries, and mines; or any application which requires precise and complex movement of heavy objects. Figure 1 shows a six-degree-of-freedom hydraulic powered extender being built at the University of Minnesota.

Human-Machine Interaction

Three elements contribute to the dynamics and control of this material handling system: the human operator, an extender to lift the load, and the load being maneuvered. The extender is in physical contact with both the human and the load, but the load and the human have no physical contact with each other. Figure 2 symbolically depicts the communication patterns between the human, extender, and load. With respect to Figure 2, the following statements characterize the fundamental features of the extender system.

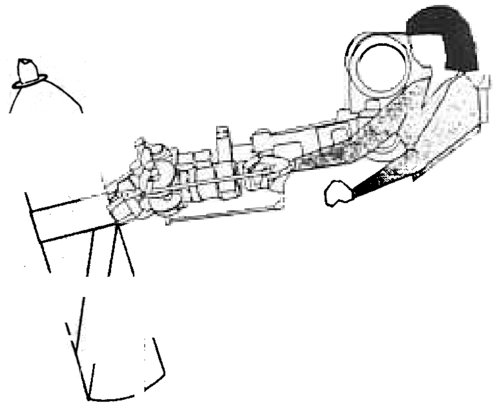

Figure 1: The six-degree-of-freedom hydraulic extender being built at the University of Minnesota.

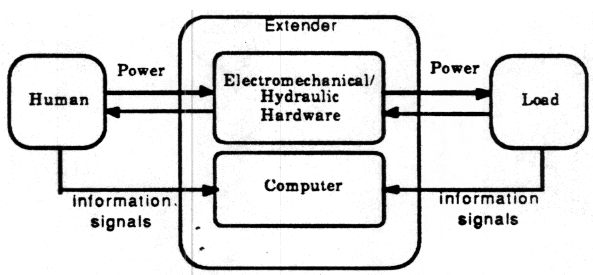

Figure 2: The extender motion is a function of the forces from the load and the human, in addition to the command signal from the computer.

1) The extender is a powered machine and consists of: 1) hardware (electromechanical or hydraulic), and 2) a computer for information processing and control.

2) The load position is the same as the extender endpoint position. The human arm position is related kinematically to the extender position.

3) The extender motion is subject to forces from the human and from the load. These forces create two paths for power transfer to the extender: one from the human and one from the load. No other forces from other sources are imposed on the extender.

4) Forces between the human and the extender and forces between the load and the extender are measured and processed to maneuver the extender properly. These measured signals create two paths of information transfer to the extender: one from the human and one from the load. No other external information signals from other sources (such as joysticks, pushbuttons or keyboards) are used to drive the extender.

The fourth characteristic emphasizes the fact that the human does not *drive* the extender via external signals. Instead, the human moves his/her hands naturally when maneuvering an object. Clarification of this natural control is found in the following. If "talking" is defined as a natural method of communication between two people, then we would like to communicate with a computer by talking rather than by using a keyboard. The same is true here: if "maneuvering the hands" is defined as a natural method of moving loads, then we would like to move a load by maneuvering the hands, rather than by using a keyboard or joystick.

Considering the above, human-machine interaction can be categorized into three types:

1) <u>Human-machine interaction via the transfer of power</u>
In this category, the machine is not powered and therefore cannot accept information signals (commands) from the human. A hand-operated carjack is an example of this type of machine; to lift a car, one imposes forces whose power is conserved by a transfer of all of that power to the car. This category of human-machine interaction includes screw-drivers, hammers, and all similar unpowered tools which do not accept information signals but interact with humans or objects through power transfer.

2) <u>Human-machine interaction via the transfer of information</u>
In this category, the machine is powered and therefore can accept command signals. An electric can opener is a machine which accepts command signals. No power is transferred between the can opener and the human; the machine function depends only on the command signals from the human.

3) <u>Human-machine interaction via the transfer of both power and information signals</u>
In this category, the machine is powered and therefore can accept command signals from the human. In addition, the structure of the machine is such that it also accepts power from the human. Extenders fall into this category. Their motions are the result not only of the information signals (commands), but also of the interaction force with the human.

Our research focuses on the dynamics and control of machines belonging to the third category of interaction involving the transfer of both information signals and power. The information signals sent to the extender computer must be compatible with the power transfer to the extender hardware. Our research efforts present this compatibility in terms of closed-loop stability. The detailed mathematical modeling and control issues and history of work of this nature have been discussed in references 1-4.

References

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