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ON THE ROLE OF EXCHANGE OF POWER AND INFORMATION SIGNALS IN CONTROL AND STABILITY OF THE HUMAN-ROBOT INTERACTION

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A human's ability to perform physical tasks is limited, not only by his[1] intelligence, but by his physical strength. If, in an appropriate environment, a machine's mechanical power is closely integrated with a human arm's mechanical power under the control of the human intellect, the resulting system will be superior to a loosely integrated combination of a human and a fully automated robot. Therefore, we must develop a fundamental solution to the problem of "extending" human mechanical power. 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 control system for manipulating the extender. The human, in physical contact with the extender, exchanges **power** and **information signals** with the extender.

The aim is to determine the fundamental building blocks of an intelligent controller, a controller which allows interaction between humans and a broad class of computer-controlled machines via simultaneous exchange of both **power** and **information signals.** Traditionally, human interaction with active systems (self-powered machines) has been defined as the exchange of "information signals" only. For example, the human sends information signals to an electric mixer (an active system) by pushing a "start" button, but the human does not transfer power to the mixer and does not feel the actual load on the mixer blades. As in this example, the prevalent trend in automation has been to physically separated the human from the machine so the human must always send information signals via an intermediary device (e.g., joystick, pushbutton, lightswitch). Extenders, however are perfect examples of self-powered machines that are built and controlled for the optimal exchange of power and information signals with humans. The human wearing the extender is in physical contact with the machine, so power transfer is unavoidable and information signals from the human help to control the machine. Commands are transferred to the extender via the contact forces and the EMG signals between the wearer and the extender, thus eliminating the need for a joystick, pushbutton, lightswitch or keyboard. This allows the person to maneuver his hand more naturally. If "talking" is defined as a natural method of communication between two people, then we would like to communicate with a computer naturally by talking rather than by using a keyboard. The same is true here: if we define "maneuvering the hand" as a natural method of moving loads, then we would like to move only the hand to maneuver a load, as opposed to using a keyboard or joystick. The extender augments human motor ability without accepting any explicit commands: it accepts the EMG signals and the contact force between the person's arm and the extender, and the extender "translates" them into a desired position. In this unique configuration, mechanical power transfer between the human and the extender occurs because the human is pushing against the extender. The extender transfers to the human's hand, in feedback fashion, a scaled-down version of the actual

1. The pronouns "he," "his," and "him" used in this abstract are not meant to be gender-specific.

external load which the extender is manipulating. This natural feedback force on the human's hand allows him to "feel" a modified version of the external forces on the extender.

Further clarification of the concept of transfer of power and information signals follows. The information signals from the human (e.g., EMG signals) to the computer reflect human cognitive ability, and the power transfer between the human and the machine (e.g., physical interaction) reflects human physical ability. Thus the information transfer to the machine augments cognitive ability, and the power transfer augments motor ability. These two actions are coupled through the human cognitive/motor dynamic behavior. The goal is to derive the control rules for a class of computer-controlled machines that augment human physical and cognitive abilities in certain manipulative tasks.