A New Dimension in Material Handling Systems

H. Kazerooni
Mechanical Engineering Department
University of California at Berkeley
Berkeley, CA 94720

The objective of our research at Berkeley is to determine the fundamentals for the design and control of computer-controlled assist devices that are operated directly by auto-assembly and warehouse workers. These assist devices are like virtual reality machines that can simulate forces on the worker's arms and trunk, forces which are different from and usually much less than the forces needed to maneuver a load.

In its simplest behavior, when a worker uses our assist device to move a load (e.g., a box in a warehouse), the assist device transfers to her/his arms, as natural feedback, a scaled-down value of the load's actual weight. For example, for every 40 pounds that a load weighs, the worker supports only 4 pounds while the device supports 36 pounds. The worker still "feels" the load's weight, but what he/she feels is less than what he/she would feel without the assist device. In another example, suppose the worker uses the device to maneuver a large rigid and bulky object, such as an exhaust pipe. Then, the device will let the worker feel the forces as if they were the forces of maneuvering a light, single-point mass. This masks the cross-coupled and centrifugal forces that increase the difficulty of maneuvering a rigid body and can produce injurious forces on the wrist. In a third example, suppose the worker uses the device to handle a powered torque wrench. Then, the device will decrease and filter the forces transferred from the torque wrench to the worker's arm, so the worker feels at most the low-frequency components of the wrench's vibratory forces and does not feel the high-frequency components that produce fatigue.

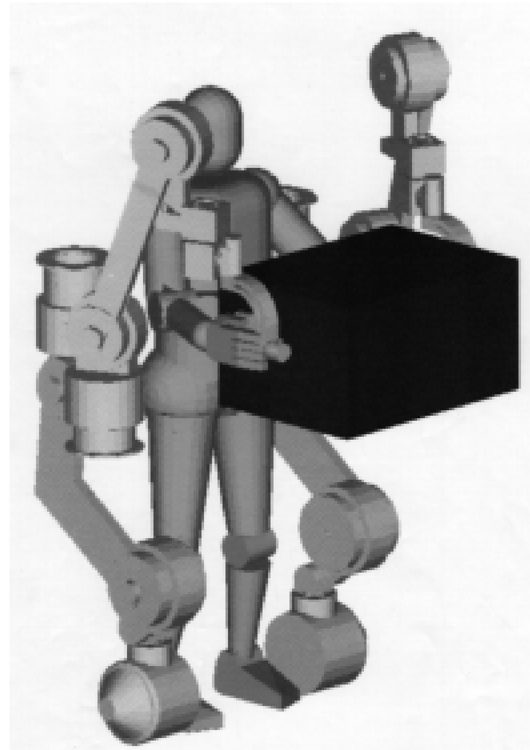
This assist device not only can mask unwanted forces on the worker, but also can be programmed to follow a particular trajectory regardless of the exact direction in which the worker manipulates the device. For example, suppose an auto-assembly worker is using the proposed assist device to move a seat into its final destination inside the car. In this situation the assist device can bring the seat to its final destination, moving the seat along a pre-programmed trajectory with a speed that is proportional to the magnitude (but not the exact direction) of the worker's force on the device. In other words, in a situation where the worker is paying little attention to the trajectory or to the final destination of the seat, the device will still bring the seat to its final destination.

In summary, the proposed device reflects on the worker's arm forces that are different from the forces needed to maneuver loads. Such a collaboration between human and machine benefits from the intellectual advantage of humans and the strength advantage of machines: the human provides a decision-making system for the assist device while the device actuators provide most of the strength necessary for performing the task. Thus, auto-assembly and warehouse workers can use the assist device to maneuver parts and boxes with greatly improved dexterity and precision. Our hypothesis is that these devices, when used by workers to maneuver parts, will greatly reduce the risk of back injuries in workers. This reduction in injury, in turn, will greatly reduce the national cost of treating back injuries.

The design of the assist device is different from the design of conventional automated systems because the system interfaces with a person on a physical level. The development of the assist device technology specifically for auto-assembly and warehouse workers demands advances in scientific knowledge and experience from both industry and academia. Thus, we carried out an interdisciplinary joint research effort involving the University of California-Berkeley and Caliber Technology.

As a part of research work, we focused on fundamental basic principles of human-machine interaction via the transfer of power and information signals. The aim was to establish methods for the design and control of machines that have stable dynamic interaction with humans via simultaneous exchange of both power and information signals. Assist devices are perfect examples of self-powered machines that should be built and controlled for the optimal exchange of both power and information signals with humans. The human operating the assist device is in physical contact with the machine, so power transfer is unavoidable, and information signals from the human help to control the machine. Our work explored methods for the design and control of machines that must interact with humans such as orthoses and assist devices. In particular our accomplishments include:

- Nonlinear stability analysis and the trade-offs between stability and performance.
- A nonlinear control algorithm that creates force amplification over a wide frequency range.
- The nature of device instability resulting from human-machine interaction.
- Understanding the human arm dynamics in horizontal and vertical planes.
- The role of human dynamics in Human Induced Instability of haptic devices
- A stabilizing control algorithm which creates any desired arbitrary force amplification and filtering.
- The trade-offs between stability and the size of the device impedance which are caused by the actuators' non-backdrivability.



The electric system, designed and built at UC, Berkeley, is composed of two arms and two legs and is used to maneuver boxes in warehouses. During operation, the extender transfers to the worker's arm, as feedback, a scaled-down value of the actual load which the extender is manipulating: the worker "feels" the load weight in the manipulations. For example, for every 50 pounds of weight, a worker supports 5 pounds and the extender supports 45 pounds. In this way, the extender minimizes the risk of back injuries to workers. Commands are transferred to the extender via the contact forces between the worker and the extender, eliminating the need for a joystick, pushbutton, or keyboard to transfer such commands.

Industrial Application

1. The Electric Human Power Extender

The Electric Human Power Extender is designed to be especially suitable for high-speed maneuvers: it produces smooth and stable behavior during high-speed tasks such as depalletizing. It offers two options in electric actuators: large and small. The controller is designed to be adaptive to all load variations and to produce force feedback on the worker. The ability of this electric extender to maneuver batteries (photo on far left) was evaluated at the General Motors Tech Center during the summers of 1996 and 1997.

2. The Pneumatic Human Power Extender Module

The Pneumatic Human Power Extender Module can be installed on all pneumatic manual material handling devices that are similar to those of Knight Industries, TDA Buddy, Zimmerman International, and Columbus McKinnon. This pneumatic material handling device can always be operated manually via its original up-down valves. This traditional mode of operation (i.e., up-down valves) is always available to the worker in case of failure of the electric power or failure of any device components or in situations where the worker does not wish to use the intelligent assist mode. The entire module is designed and the software is coded to be operable with all kinds of manual material handling devices. Thus, most pneumatic manual material handing devices can perform better than before when upgraded with this module. Many existing pneumatic material handling devices can be upgraded with this module.

Kazerooni, H., “The Human Power Amplifier Technology at the University of California, Berkeley”, *Journal of Robotics and Autonomous Systems*, Elsevier, V. 19, 1998.

Kazerooni, H., “The Human Power Amplifier Technology Applied to Material Handling”, *Progress in Material Handling Research: 1998*, The Material Handling Institute.

This research work was partially funded by NSF under grant number DMI-9941927