Abstract
A significant need has been identified for an improved device to assist in transferring mobility
limited patients, particularly those who are heavier. Typical transfers include moving between a
bed, wheelchair, chair/couch, toileting chair or toilet, car, or the floor. We are developing a new,
cost effective, hydraulically actuated prototype patient transfer assist device; hydraulic actuation
has higher force density than electrical actuators that are typically used at this power scale. This
project aims to improve control of machines that collaborate with humans, and to investigate
hydraulic power application at the human power scale. It is necessary to overcome some control
challenges with these actuation systems, such as non-ideal characteristics of the low cost
hydraulic components and management of any undesirable environment interaction forces. A
first prototype patient transfer assist device has been developed, a simple and intuitive operator
interface has been implemented, and interaction controllers have been implemented and tested.

Introduction
As a result of a high incidence of orthopedic injuries to caregivers resulting from manual transfer
operations without a lift device, healthcare institutions are implementing "no lift" policies, which
require caretakers to use lift devices for all patient transfers. The Veterans Health Administration
and OSHA have issued guidelines for safe patient handling [1, 2]. We performed an informative
needs assessment, including input from users and a wide range of stakeholders for the current
patient lift industry. They indicated several key areas for needed improvements, including better
maneuverability in tight spaces and around obstacles, an intuitive caretaker interface that allows
for safe operation in a relatively delicate environment by a single caregiver (current transfers
often require multiple personnel, especially with heavier patients), and capability to lift and
maneuver the heaviest patients [3]. The machine requires large force capability and operates in a
relatively delicate home or clinical environment, with humans in its workspace. A first prototype
patient transfer assist device has been designed and fabricated, with four degrees of freedom
(DoFs) fully functional: a vertical lifting scissor mechanism, a horizontal boom extension, and
two differential drive wheels. Various forms of interaction controllers are being tested on the
boom extension and main lifting degrees of freedom, and obstacle avoidance is being
implemented on the wheeled base; both forms of control of interactions with the environment are
integrated with the operator input.

In order to allow for this powerful machine to operate safely in a relatively delicate environment
with humans in the workspace, and to reduce the caretaker mental workload, it is desirable to
manage any undesirable environment interaction forces. For the main lifting and boom
extension, close proximity and some interaction with the caretaker and patient are necessary.
Therefore, it is desirable to develop controllers which manage both force and motion. A
substantial literature study has been performed on various types of interaction controllers.
Considerable work on interaction control specifically applied to high stiffness and high force
actuators was done by Buerger [4]. The focus at this stage of the project is on the interaction
control; in this application, any external forces other than those required to lift the patient should
be minimized.
Theory

Control and Operator Interface

Three different interaction controllers are being tested on the boom extension: a type of impedance control, a type of admittance control, and a passivity based human power amplifier. The control input from the operator is from the force sensing handle. That command is mapped to a reference velocity for each actuator, based on the kinematics of the machine. So the operator pushes on the handle in the desired direction of motion of the patient; if the operator pushes harder, it moves faster. If the machine encounters an obstacle, the interaction controllers resist motion in that direction, providing a form of haptic feedback.

Impedance and Admittance Control

The first control strategy applied to this machine is known as impedance control, which is designed to provide low output impedance and compliant interaction with the environment. The basic concept is to add a virtual spring and damper between the end-effector position and a virtual reference position in the task space. Particularly with lightweight and low stiffness actuators, this approach can be very effective in achieving control with the desired low output impedance [4]. There are a number of variations on impedance control. This formulation is based on a low level force or pressure control. The required estimate of the external interaction force is estimated from pressure measurements and knowledge of the system dynamic properties, such as inertia and friction/damping.

![Figure 1. 1-DOF Impedance Control Block Diagram - Boom Extension](image)

The block diagram for the impedance control implementation is shown in Figure 1. A second type of interaction control, termed admittance control, uses a very similar approach but with a low level position control rather than force control. Both impedance controllers and admittance controllers have been implemented on the boom extension, and preliminary experiments have been performed.

Passivity Based Human Power Amplifier

The passivity based human power amplifier is a different approach to operator-machine collaborative manipulation, using force and velocity feedback. The formulation adds a virtual mass-spring system coupled with the physical system mass, and it uses the force balance on the virtual and actual masses to achieve both velocity and force coordination, according to the specified force amplification factor. Many types of controllers could be designed with the property of passivity. Power amplifier controllers are inherently prone to instability; the property of passivity is desirable because this system also physically interacts with humans.
Methods
This section discusses the hardware system for the patient transfer assist device, as well as models of the system, which are the basis for implementation and testing of the interaction controllers and the obstacle avoidance.

System Integration & Hardware
The first prototype patient transfer assist device is shown in Figure 2. It includes four actuated degrees of freedom, a main vertical lifting scissor, a horizontal boom extension, and two differential drive wheels. For the purpose of safety in testing controller designs, the wheels are currently mounted on a separate cart. The machine uses a form of electro-hydraulic pump control which eliminates the need for expensive valves and associated throttling losses, and it provides simple integration with onboard battery power. Each actuator has its own separate servo drive, reversible DC electric motor, and small bidirectional gear pump. The actuation and control system is fully untethered, with onboard battery power and a National Instruments CompactRIO for control.

Figure 2. First prototype patient transfer assist device; left: main lifting and boom extension, right: differential drive wheels on separate testing cart

The control input from the operator is from the force sensing handle. That command maps to a reference velocity for each actuator. The operator input force maps to a reference patient velocity, and the kinematics calculations for conversion from patient motion to wheel motion are performed on the controller. The cart is fully functional and ready for testing of more advanced control architectures, such as obstacle avoidance. A detailed description of the design of the patient transfer assist device is given in [5].

Dynamic System Modeling
A model has been created to simulate the mechanical dynamics of the main lifting scissor mechanism, boom extension, and actuation mechanisms, as well as a variable patient payload, in MATLAB [3]. For the actuation systems, a gray box model based on system identification by spectral analysis, roughly based on the form of a first principles based model, has been developed, with input reference motor current and output actuator motion. Further investigation is in process to capture significant nonlinear or non-ideal features of the actuation systems, such as stiction, deadband, and other characteristics.
Results and Discussion
This section discusses results for only one of the three interaction controller types implemented on the boom extension, as an example. The goal of this preliminary test on the impedance control formulation was to determine how the controller would respond with and without an external force applied at a human scale, from a human. In this case, a software generated reference position command was used, and the human applied an external or environment interaction force. This preliminary test demonstrates that it is feasible for an external force in a reasonable range for a human to significantly affect the machine motion as desired, with the impedance control implemented.

![Figure 3. Preliminary impedance control experiment and effect of applied force on boom motion](image)

One issue with impedance control in this system is that it includes a low level force control, rather than low level position or rate control; this actuation system is more inherently a flow or rate control system. This low level force control is also difficult to achieve with high static friction. Position based, or admittance type interaction control, has also been implemented and shows promising results. The passivity based human power amplifier has been implemented on an earlier valve-controlled pre-prototype machine, and it will also be implemented on the boom extension.

Conclusion
Preliminary experiments demonstrate that it is feasible for the controller to reduce external interaction forces with the environment, while maintaining sufficient tracking performance. Furthermore, preliminary operator experiments demonstrate the coordinated control from the operator force input, integrated with the interaction controllers. Further investigation and improvements will be added to the interaction control, and it will be implemented and tested on the main lifting. Obstacle avoidance is also being implemented on the wheeled base, using ultrasonic sensors.

References