HLPR Chair* – A Service Robot for the Healthcare Industry

** formerly RoboChair*

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Abstract — The National Institute of Standards and Technology (NIST) Intelligent Systems Division (ISD) has been working on a healthcare mobility system capable of mobilizing wheelchair dependents, providing patient lift and even rehabilitation. Targeted at the aging populations, stroke victims and wheelchair dependents, ISD is developing the "HLPR Chair" (Home Lift, Position, and Rehabilitation Chair) to provide independent (requiring little or no nurse or caregiver intervention depending on the patients status) patient mobility and lift for such tasks as moving a patient to the wheelchair, toilet, or other seats and the bed. While 1 in 3 nurses are expected to develop back injuries moving and lifting patients and half of non-ambulatory patients fall to the floor, all aspects of the HLPR Chair provide for independent patient mobility with emphasis on lifting and placing patients to eliminate or significantly reduce this back injury issue. The HLPR Chair, currently in the development stage, is designed to provide: powered mobility; patient lift to above current or previously researched and available off-the-shelf mobile patient lift devices; and the means to place people on beds, chairs, toilets, etc. while allowing access to areas of the home and business environments that are currently inaccessible to wheelchair dependents. Also, the HLPR Chair provides rehabilitation capability with a retractable seat and footrest and open base frame with future leg loading measurement to allow the patient to adjust the amount of load placed on legs as they again learn to walk. This paper will discuss the HLPR Chair in depth.

I. Introduction

[Pollack, 2005] says "today, approximately 10 percent of the world's population is over 60; by 2050 this proportion will have more than doubled" and "the greatest rate of increase is amongst the oldest old, people aged 85 and older." She follows by adding that this group is subject to both physical and cognitive impairments more than younger people. These facts have a profound impact on how the world will maintain the elderly independent as long as possible from caregivers. Both physical and cognitive diminishing abilities address the body and the mental process of knowing, including aspects such as awareness, perception, reasoning, intuition and judgment. Assistive technology for the mobility impaired includes the wheelchair, lift aids and other devices, all of which have been around for decades. However, the patient typically or eventually requires assistance to use the device; whether it's someone to push them in a wheelchair, to lift them from the bed to a chair or to the toilet or for guiding them through cluttered areas. With fewer caregivers and more elderly, there is a need for improving these devices to provide them independent assistance.

Wheelchairs

There has been an increasing need for wheelchairs over time. [van der Woude, 1999] states that mobility is fundamental to health, social integration and individual well-being of the humans. Henceforth, mobility must be viewed as being essential to the outcome of the rehabilitation process of wheelchair dependent persons and to their successful (re-)integration into society and to a productive and active life. [Thrun, 2005] said that, if possible, rehabilitation to relieve the dependence on the wheelchair is ideal for this type of patient to live a longer, healthier life. Van der Woude continues stating that many lower limb disabled subjects depend upon a wheelchair for their mobility. Estimated numbers for Europe and USA are respectively 2.5 million and 1.25 million. The quality of the wheelchair, the individual work capacity, the functionality of the wheelchair/user combination, and the effectiveness of the rehabilitation program do indeed determine the freedom of mobility.

Patient Lift

Just as important as wheelchairs are the lift devices and people who lift patients into wheelchairs and other seats, beds, automobiles, etc. The need for patient lift devices will also increase as generations get older. When considering if there is a need for patient lift devices, several references state the positive, for example:

- "The question is, what does it cost not to buy this equipment? A back injury can cost as much as $50,000, and that's not even including all the indirect costs. If a nursing home can buy these lifting devices for $1,000 to $2,000, and eliminate a back injury that costs tens of thousands of dollars, that's a good deal," [Marras, 1999]
- 1 in every 3 nurses become injured from the physical exertion put forth while moving non-ambulatory patients; costing their employers $35,000 per injured nurse. [Blevins]
- 1 in 2 non-ambulatory patients fall to the floor and become injured when being transferred from a bed to a wheelchair. - [U.S. Bureau of Labor Statistics, 1994]

- "Nursing and personal care facilities are a growing industry where hazards are known and effective controls are available," said OSHA Administrator John Henshaw. "The industry also ranks among the highest in terms of injuries and illnesses, with rates about 2 1⁄2 times that of all other general industries..." - [OSHA Website, 2005]
- "Already today there are over 400,000 unfilled nursing positions causing healthcare providers across the country to close wings or risk negative outcomes. Over the coming years, the declining ratio of working age adults to elderly will further exacerbate the shortage. In 1950 there were 8 adults available to support each elder 65+, today the ratio is 5:1 and by 2020 the ratio will drop to 3 working age adults per elder person." [Wasatch Digital IQ, 2003]

Recently, NIST ISD began the Healthcare Mobility Project to target this staggering healthcare issue of patient lift and mobility. ISD researchers looked at currently available technology through a survey of patient lift and mobility devices [Bostelman, 2006-1]. That report showed that there is need for technology that includes mobility devices that can lift and maneuver patients to other seats and technology that can provide for rehabilitation to help the patient become independent of the wheelchair. Therefore, NIST began developing the HLPR Chair to investigate these specific areas of mobility, lift and rehabilitation.

This paper includes an in depth review of the HLPR Chair design including sections covering the structure and mobility design, patient lift, placement on other seats, rehabilitation, and control. Conclusions, future work sections, and references close the paper.

II. HLPR Chair Structure and Mobility Design

The HLPR Chair prototype, shown in Figure 1, is based on a manual, steel, inexpensive, off-the-shelf, and sturdy forklift. The forklift includes a U-frame base with casters in the front and rear and a rectangular vertical frame. The lift frame measures 58 cm (23 in) wide by 109 cm (43 in) long by 193 cm (76 in) high (when not in the lift position) making it small enough to pass through even the smallest, typically 61 cm (24 in) wide x 203 cm (80 in) high, residential bathroom doors. The HLPR Chair frame could be made lighter with aluminum instead of steel.

The patient seat/stand mechanism is a double, nested and inverted L-shape where the outer L is a seat base frame that provides a lift and rotation point for the inner L seat frame. The L frames are made of square, aluminum tubing welded as shown in the photograph. The outer L is bolted to the lift device while the inner L rotates with respect to the seat base frame at the end of the L as shown in Figure 1. The frames rotation point is above the casters at the very front of the HLPR Chair frame to allow for outside wheelbase access when the seat is rotated π rad (180 deg.) and is the main reason access to other seats is available. Drive and steering motors, batteries and control electronics along with their aluminum support frame provide counterweight for the patient to rotate beyond the wheelbase. When not rotated, the center of gravity remains near the middle of the HLPR Chair. When rotated to π rad (180 deg.) with a 136 kg (300 Lb) patient on board, the center of gravity remains within the wheelbase for safe seat access. Heavier patients would require additional counterweight.

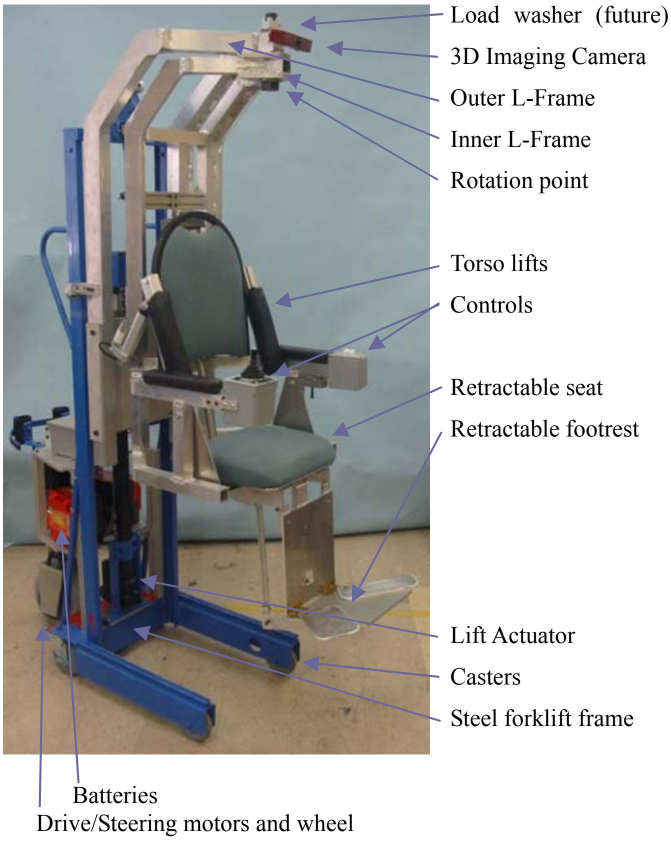


Figure 1 –Photograph of the HLPR Chair prototype.

The HLPR Chair is powered similarly to typical powered chairs on the market. Powered chairs include battery powered, drive and steer motors. However, the HLPR Chair has a tricycle design to simplify the need to provide steering and drive linkages and provide for a more vertical and compact drive system design. The drive motor is mounted perpendicular to the floor and above the drive wheel with chain drive to it. The steering motor is coupled to an end cap on the drive motor and provides approximately π rad (180 deg.) rotation of the drive wheel to steer the HLPR Chair. The front of the robot has two casters mounted to a U-shaped frame.

The prototype motors are 1/2 hp for drive and 1/17 hp for steering. The drive motor is geared such that its high speed drives a chain driven wheel providing further speed reduction. HLPR Chair speed is 0.7 m/s (27 in/s). While this is sufficient speed for typical eldercare needs, a more powerful motor can replace the drive motor for additional speed.

Steering is a novel single wheel design hard stopping the wheel at just beyond π rad (180 deg.) for safety of the steering system. Steering is reverse Ackerman controlled as joystick left rotates the drive wheel counterclockwise and joystick right rotates the drive wheel clockwise. The steering rotation amount can be limited by the amount of drive speed so as not to roll the frame during excessive speed with large steering rotation. The navigation and control of the vehicle under this novel rear wheel steer and drive is currently under study and will be described in later publications.

For access to the HLPR Chair and for mobility, the HLPR Chair is lowered as shown in Figure 2. A seat belt or harness will be required for eldercare occupant safety. For access/exit to/from the HLPR Chair, the footrest can be retracted beneath the seat. For mobility, the footrest is deployed to carry the feet. Also, manually rotated feet pads can be deployed to provide a wider footrest. When retracted, the footrest pads automatically rotate within the footrest volume.

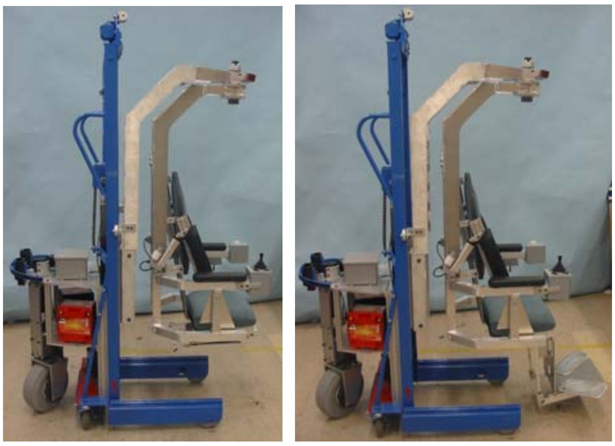


Figure 2 – Photographs of the HLPR Chair in patient access (left) and mobility (right) configurations. The left photo shows the footrest retracted to easy chair access and the right photo shows the footrest deployed for mobility.

III. PATIENT LIFT

Patient lift is designed into the HLPR Chair to allow user access to high shelves or other tall objects while seated. The HLPR Chairs' patient lift (see Figure 3) is approximately 1 m (36 in) to reach what a typical, standing 2 m (6 ft) tall person could reach. This is a distinct advantage over marketed chairs and other concepts. [Bostelman, 2006]. The additional height comes at no additional cost of frame and only minimally for actuator cost.

Lift is achieved by a 227 kg (500 Lbs) max. lift actuator that can support 681 (1500 Lbs) statically on the HLPR Chair prototype. The actuator can be replaced with a higher capacity unit if needed. The actuator connects to a lift plate with a steel chain that is fix mounted at one end to the HLPR Chair frame and to the lift plate at the other end. The actuator pushes up on a sprocket of which the chain rolls over providing 1 m (36 in) lift with only a 0.5 m (18 in) stroke actuator. The outer L-frame is then bolted to the lift plate. Rollers mounted to the lift plate roll inside the HLPR Chair vertical C-channel frame.

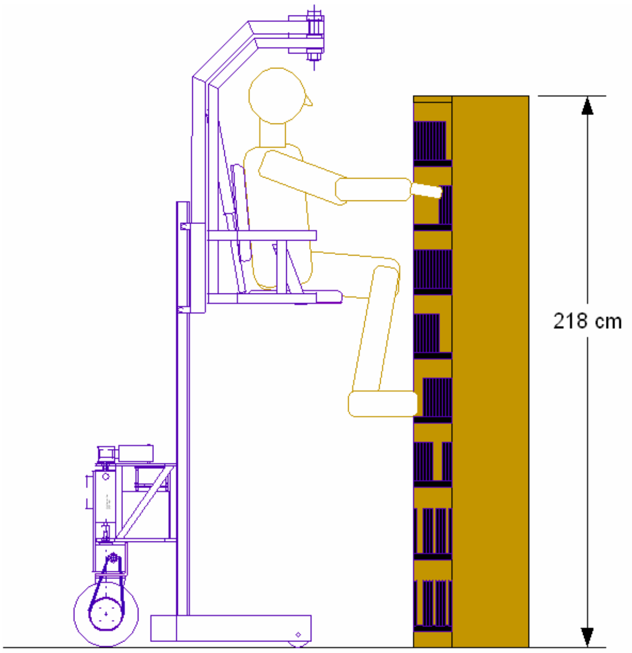


Figure 3 – HLPR Chair prototype (top) and graphic (bottom) shown in the patient lift position. Access to at least a 218 cm (86 in) shelf unit can be achieved while the patient is seated in the HLPR Chair.

IV. PLACEMENT ON OTHER SEATS

It is estimated that 1 in 3 nurses or caregivers will develop back injuries [Bostelman, 2006]. Most injuries occur because the patient is relatively heavy to lift and access to them is difficult when attempting to place the patient onto another seat. Wheelchair dependents have difficulty moving from a seat, to their wheelchair and back

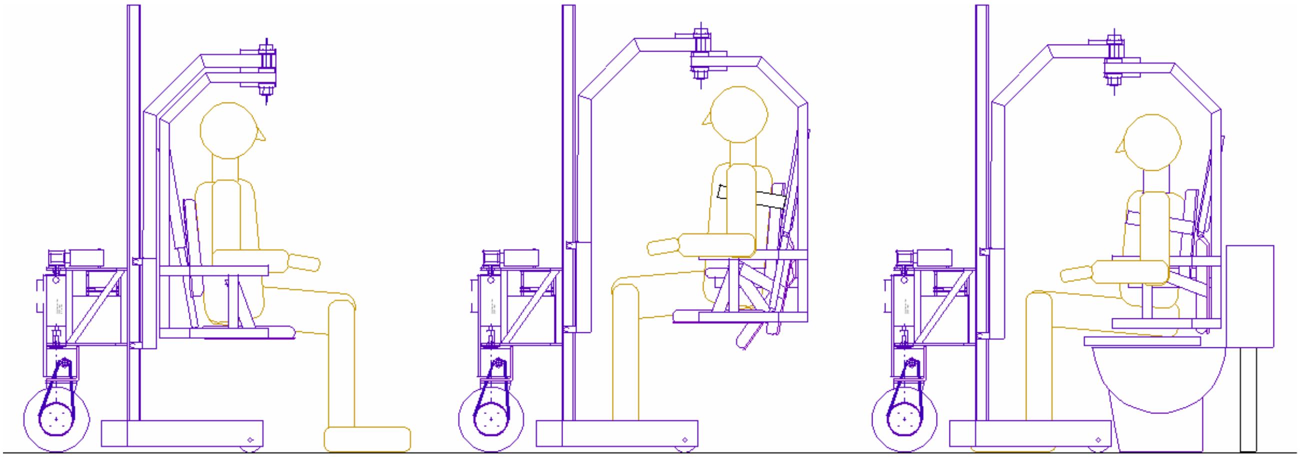


Figure 4 – Graphic showing the concept of placing a patient onto a toilet or chair with the RoboChair. *The patient drives to the target seat (left), manually rotates near or over the seat (middle) while the torso lifts support the patient and the seat retracts, and then is lowered onto the seat - toilet, chair or bed (right)*

without a caregivers help or other lift mechanisms. The HLPR Chair was designed with the patient lift, as explained previously, to not only access tall objects, but to also pick up and place the patient in other chairs, on toilets, and on beds.

Figure 4 shows the concept of placing a patient onto a toilet. Figure 5 shows the HLPR Chair prototype in the rotated and torso support position similar to the Figure 4 (right) graphic with the seat and footrest retracted as well.

Figure 5 – Photograph of the HLPR Chair in the same positions as in the Figure 4 (right) graphic placing a person on another seat.

To place a HLPR Chair user on another seat, they can drive to for example, a toilet, seat, or bed. Once there, the HLPR Chair rotates the footrest up and beneath the seat and the patients feet are placed on the floor personally or by a caregiver. The HLPR Chair inner L-frame can then be rotated manually with respect to the chair frame allowing the patient to be above the toilet. Padded torso lifts then lift the patient from beneath his/her arm joints similar to crutches. The seat, with the footrest beneath, then rotates from horizontal to vertical behind the patients back clearing the area beneath the patient to be placed on the toilet, seat, bed, etc.

Once the person is placed on a toilet, the HLPR Chair can remain in the same position to continue supporting them from potential side, back or front fall. However, when placing a person onto a chair, the HLPR Chair must lift the patient and the patient manually rotates the chair from around the patient and out of the patients space. The HLPR Chair could then be conceptually driven from the seat location, using radio frequency or through voice commands, to a charging or waiting location and out of the patients view. When requesting to be picked up again, the patient could conceptually call the HLPR Chair remotely and have it return to the same pick up location and reverse the seat placement procedure.

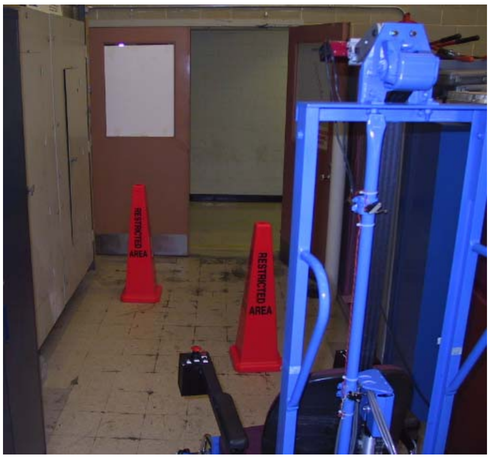
VI TOWARDS AUTONOMOUS CONTROL

A 3D imaging camera was mounted on an early version of the HLPR Chair and a control algorithm was developed and tested. [Bostelman, 2006-2] Given the large number of 3D data points, the data is too complex for direct conversion to a path planner. Our approach is to extract objects, find a safe path, and then guide the user to his or her destination.

The initial path planner step removes the floor data so as to not mistake it as an obstacle. Since the height and vertical angle of the camera are known, the data can be rotated and a simple threshold can be used to extract the floor. The next step segments objects, which are tracked. This is performed using the 3D Connected Components Algorithm, an efficient adaptation of the Connected Components algorithm for grouping connected points together. We chose this approach because it is independent of the camera type from which the data originated as long as the data is registered and placed into the same coordinate system. The obstacles were then integrated into a local map centered on the HLPR Chair. The algorithm extends each obstacle to include the HLPR Chair volume to prevent the planner from attempting to steer the user through a space that is too small or clip the corner of objects as when moving past them. With the search graph built, the A* search is used to plot a path from the current location to the intended destination of the user. The Manhattan distance (distance between two points measured along axes at right angles) is used as the heuristic function. The algorithm suggests a path for the user to get from where he is to the camera's maximum measurement distance.

The method chosen for this algorithm is to only inform the user about what direction to take. In {Bostelman, 2006], a sound is played in each ear that seems to be coming from the suggested direction of travel. In the case of the HLPR Chair, a controller could instead steer the robot around obstacles to avoid collisions.

To test the algorithm, the 3D camera mounted on the HLPR Chair was placed in front of a doorway with obstacles blocking the path. Leading up to the door is a narrow hallway formed by a wall on the left and cabinet backs on the right. The doorway has two doors, one of which is closed and the other is open. Beyond the door is a hallway that runs perpendicular to the one in which the test was conducted. Figure 6 shows a picture of the scene and data obtained during the test. The camera was mounted 1.9 m (74 in) above the ground and angled 0.45 rad (26 deg) downwards. The rotation set the top of the camera field of view slightly above horizontal.



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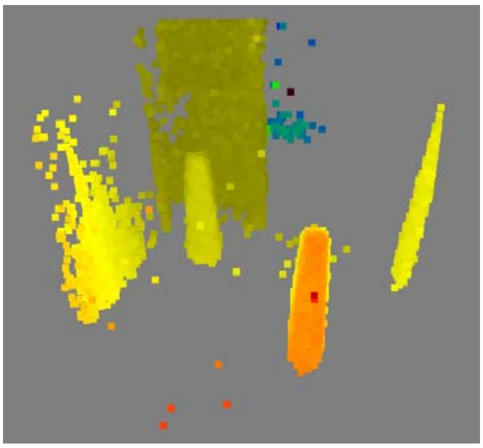

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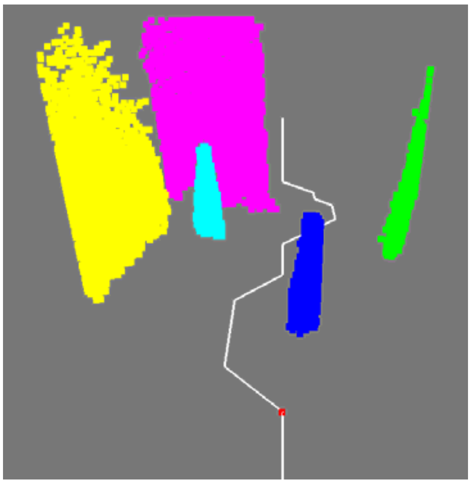


(c)

Figure 6 – (a) Photo of the test scene, (b) Input to the planner algorithm, (c) Range data, objects and path planned.

Mounted on the top, front of the HLPR Chair it can also detect the top of the doorframe and could automatically adjust down to a passable height through the doorway. Another camera is mounted to the rear of the HLPR Chair to detect objects beyond 1 m behind and plan reverse direction paths. For obstacles within 1 m, a switch bumper with compliance is mounted to the rear to prevent continued drive in the reverse direction upon contact with an obstacle.

The algorithm was very successful at planning paths around obstacles placed in front of the 3D range imager. When the objects or camera were moved, the path replanned around the new object positions. For the study, audio played to each ear corresponding to how the path changed. For example, as the path shifted to go left around an object instead of previously to the right, the audio signal to the ears changed accordingly. The process operated properly whenever objects are within the operating limits of the camera.

VII. Control

The HLPR Chair controls include a joystick on the right side for drive and steering control and a rocker switch on the left for lift control, as shown in Figure 7. A lever switch to control seat and footrest retraction or deployment is also on the left side and under the armrest.

The joystick sends drive controls to 24Vdc power amplifiers that control the 90Vdc drive, steering. The patient lift actuator is also controlled with the same type power amplifier through a rocker switch. The footrest, seat and torso lift actuators are direct 12Vdc controlled switched forward and reverse from the battery through a single, momentary rocker switch soon to include built in delays between controls.

The HLPR Chair procedure for placing a patient on a chair will be as follows as the rocker switch is rotated to the retract position:

1. rotate footrest beneath seat
2. deploy torso lift actuator to lift patient beneath arm joints
3. retract seat with footrest beneath to behind patient.

Pushing the switch the opposite direction will cause the reverse delayed procedure.

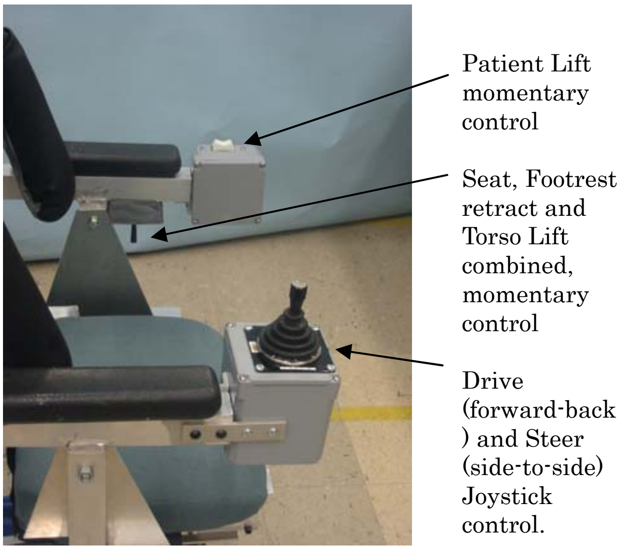


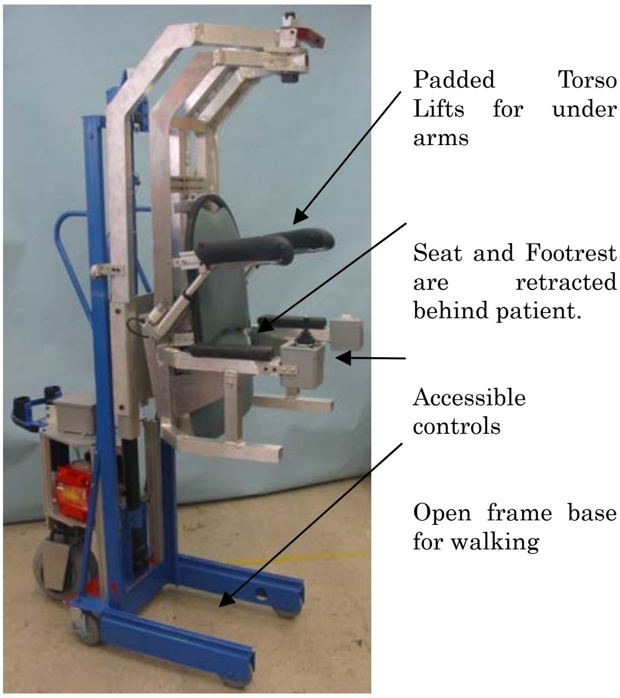
Figure 7 – Photograph of the HLPR Chair prototype controls.

The 8 cm (3 in) stroke actuators for each of the footrest, torso lift and seat have a deploy time of approximately 5 sec. Therefore, a delay of 5 sec or less will be placed between the footrest and torso lift and the torso lift and seat rotate requests.

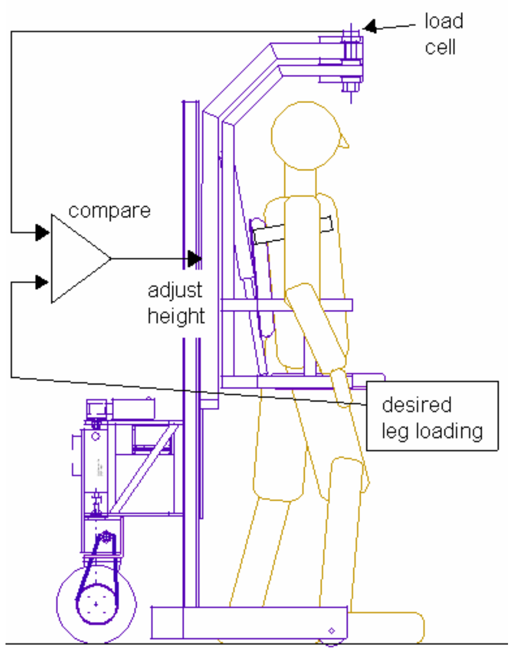
VI. Patient Rehabilitation

HLPR Chair enhances patient rehabilitation through a load sensor and control on the lift actuator, as described in [Banala, 2006]. The authors designed rehabilitation into the HLPR Chair to allow, for example, stroke patients to keep their legs active without supporting the entire load of the patients body weight. The patient, once lifted, could walk while supported by the HLPR Chair driving at a slow walking pace towards regaining leg control and eliminating the need for a wheelchair.

To accomplish rehabilitation, the HLPR Chair includes, as explained in the Placement on Other Seats section, footrest and seat rotate behind the patient while he/she is lifted with torso lifts. However, instead of being placed low on a seat, the patient lift continues to move up lifting the patient as they move their legs beneath them to standing position. The HLPR Chair's open U-frame base allows access to the floor directly beneath the patient for standing. Figure 8 shows a photograph of the prototype in this configuration and a concept of how the HLPR Chair can be used for patient rehabilitation.



(a)



(b)

Figure 8 –Photograph of the HLPR Chair prototype in the rehabilitation/walking configuration. (top) Graphic showing the concept of how the HLPR Chair can be used for patient rehabilitation and incorporate future legs load control. (bottom)

Additionally, the patient can be continuously monitored with a load washer at the L-frames rotation point. The patient could adjust the amount of load he/she wishes to place onto their legs and on the floor by rotating a dial on the controls from 0- 100 percent. Load control is a future concept to be applied to the HLPR Chair prototype in the next several months.

VII. CONCLUSIONS AND FUTURE RESEARCH

The HLPR Chair was designed to be a revolutionary patient lift and mobility system for wheelchair dependents, the elderly, stroke patients, and others desiring or even requiring personal mobility and lift access. The system shows promise for moving these groups of patients into the work force and removing the burden placed on the healthcare industry. The system has been prototyped to show the basic concept of such a patient lift and mobility system. The HLPR Chair was built to demonstrate its' relatively inexpensive capabilities to the healthcare industry and to build on it's capabilities with robust controls for mobility and rehabilitation in the near-term. Mobility control and force loading for rehabilitation of patient legs will be studies in the near term. Collaborations for proving the service capabilities and evaluating performance of the HLPR Chair to the healthcare industry are expected.

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