A Handle Robot for Providing Bodily Support to Elderly Persons: Experimental and Simulation-Based Biomechanical Analysis of Assisted Postural Changes

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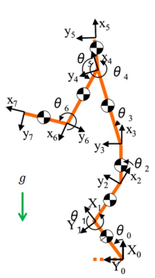
https://darbelofflab.mit.edu/handle-assist-robot-for-eldercare/

Abstract – Postural transitions can pose challenges for older adults or individuals with mobility impairments. We present a mobile robot that provides older adults with a handlebar located anywhere in space, mimicking and extending the functionality of grab bars. We further investigate the biomechanical effects of using a handlebar for assistance during sit-to-stand transitions and develop a methodology to optimally place the handle to provide the maximum support for the elderly user for different activities of daily living. An experimental pilot study suggested that, for the sit-to-stand transition, the use of a handlebar led to a shorter time to perform the motion, higher stability, higher symmetry, and reduced peak torques in the lower limbs.

Challenge Content

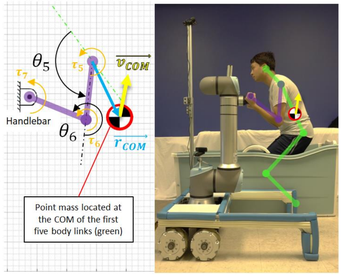
- ~25 million Americans use assistive devices such as canes, walkers, raised toilets or shower seats to perform essential daily activities.
- Existing elderly assistive devices have limited applications, and many require a caretaker to use.
  - Walkers may tip when the user's COM is outside of the base of support
  - Transfer slings require a human to operate
  - Hoyer lifts are expensive and narrowly tailored for specific tasks
  - Grab bar placement is constrained buy the room layout
- Transfers are associated with a risk of falls, particularly in individuals with neurological conditions. In one study, 40% of falls were caused by inappropriate sit-to-stand transfers.

Solution



Link	% of Body Mass
0	7.97%
1	13.54%
2	34.46%
3	25.93%
4	10.65%
5	4.19%
6	3.25%

joint 0 : ankle
joint 1 : knee
joint 2 : greater trochanter
joint 3 : iliac crest
joints 4 and 5 : acromion
joint 6 : elbow
joint 7 : wrist

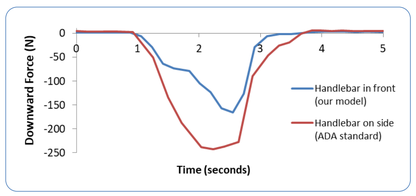


There is an inherent tradeoff between mechanical advantage and gear ratio. We desire to position the handlebar to maximize the mechanical advantage while applying a penalty for reduced gear ratio, since with a lower gear ratio, the patient will have difficulty in following their desired body trajectory. We therefore consider an index $L = MA \times GR = \frac{|W_{COM}|}{|\tau|} \cdot \frac{|\dot{v}_{COM}|}{|\dot{q}|}$.

This was evaluated to support the posture requiring the maximal muscle effort.

Discussion and Broader Impact

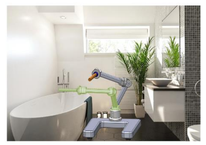
- The sit-to-stand transition exhibited a decreased time to complete the motion, as well as reduced peak velocity in both the horizontal and vertical directions. These findings suggest that a vertical handlebar results in improved control and smoother trajectories.
- The optimal L index handlebar location for getting up from a toilet resulted in more equally distributed muscle effort, outperforming the current ADA standard.
- The robot was teleoperated from Spaulding Rehabilitation Hospital as a proof-of-concept. A physical therapist was able to assist an older adult at MIT with toileting and bathing.
- By providing an anchor of support for diverse activities in a wide variety of environments, the robot presents a viable alternative to human caregivers in some contexts.



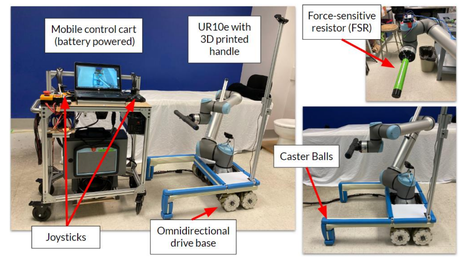
Scientific Impact

- This work is a step towards **pandemic-resilient eldercare devices**: teleoperated assistive tools caregivers can use for high-level care during periods of physical isolation.
- Prior research has examined the biomechanical advantages of utilizing a grab bar for assistance during sit-to-stand transfers. However, the configuration involving a bar placed vertically in front of the user remained unexplored, primarily due to its difficulty in implementation.
- Our methodology to place the handle requires only a sagittal plane video of the elderly user, and thus is rapid, scalable, and uniquely customizable to each user.
- Submitted paper to IROS '23 (under review)

In the bedroom: lie-to sit and sit-to-stand transitions



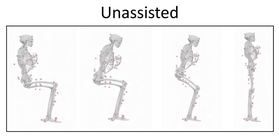
Entering or exiting a bathtub

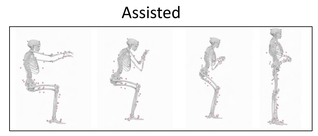


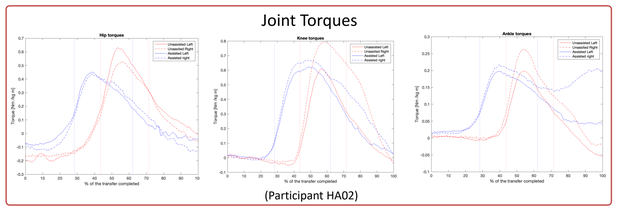
Results

The recorded sit-to-stand data was analyzed using an inverse simulation pipeline, which included scaling, inverse kinematics, inverse dynamics, and static optimization.

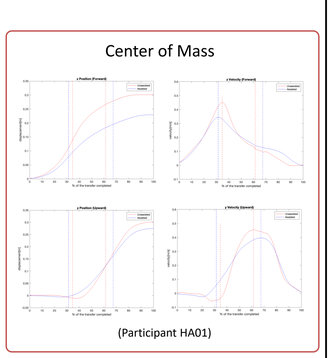
Sit-to-Stand (experimental data)







(Participant HA02)



(Participant HA01)

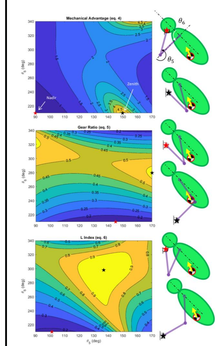
	Time to complete the Transfer	Peak COM Pos Forward	Peak COM Vel Forward	Peak COM Vel Upward
HA01	-21.50%	-26.80%	-1.02%	-20.53%
HA02	-12.39%	-26.59.	-9.01%	-16.22%
HA03	-15.03%	-11.60%	-11.73%	0.01%

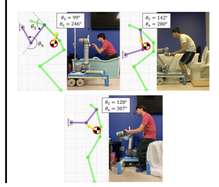
	Peak Hip Torque	Peak Knee Torque	Peak Ankle Torque	Sum of the Peak Values
HA01	-14,15%	7,79%	-4,62%	-3.59%
HA02	-24,63%	-12,04%	12,35%	-14.25%
HA03	5,11%	-22,50%	1,28%	-9.10%

		Path Length | cm |	Change
HA01	Unassisted	119.96	-23.49%
	Assisted	91.79	
HA02	Unassisted	51.21	2.23%
	Assisted	52.35	
HA03	Unassisted	98.59	-5.91%
	Assisted	92.76	

$$\frac{Unassisted - Assisted}{Assisted}$$

L Optimization (simulations)





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