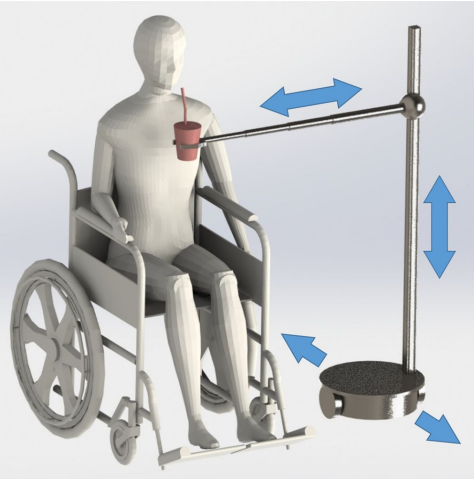
Problem #3 (33 points)



Mobile robots with arms have the potential to serve many roles in healthcare [1, 2]. Henry M. Clever and Prof. Kemp have been working on a new robot to provide physical assistance to people with disabilities (see figure). The robot's arm is a horizontal telescoping mechanism that can increase and decrease its length, such as when holding out an object for someone to use. This telescoping arm also moves up and down on a lift that is mounted to a cylindrical mobile base with wheels.

Since the telescoping arm can reach out a long distance and the robot is tall, a key concern is that the robot might fall over if it holds a heavy object with its arm extended. To better understand this issue, you will create a mathematical model.

When describing the robot, we will use the terms front and back. When the horizontal telescoping arm elongates, we describe the object as moving in the forward direction (i.e., out towards the person in the wheelchair in the figure). When the horizontal telescoping arm shortens, we describe the object as moving in the backward direction.

For your mathematical model, you may use the parameters in the following table:

symbol	*description*
t	height of the top of the cylindrical mobile base above the floor
r	radius of the cylindrical mobile base
h	height of the telescoping arm above the floor
l	length of the telescoping arm from the front of the robot to the held object's center of mass (i.e., how far the object is held out beyond the cylindrical mobile base)
m_r	mass of the robot
m_o	mass of the object held by the robot

Since the robot has heavy batteries in its cylindrical mobile base, you may consider the mass of the lightweight telescoping arm to be negligible. The center of mass of the robot is approximately located in the geometric center of the cylindrical mobile base. You may model the mobile base as only making contact with the ground with its two drive wheels, one at the front of the cylindrical mobile base and one at the back.

Your model should predict how far forward the robot can hold out an object before it is likely to tip over. More specifically, your model should predict the length, l, at which the robot would just be losing contact with the ground due to tipping over .

For full credit, you must simplify your equations, show your work, state your assumptions, and clearly communicate your reasoning using diagrams, equations, and text. Correct equations will result in no credit unless you also clearly communicate how you arrived at them.

[1] Older Adults Medication Management in the Home: How can Robots Help?, Akanksha Prakash, Jenay M. Beer, Travis Deyle, Cory-Ann Smarr, Tiffany L. Chen, Tracy L. Mitzner, Charles C. Kemp, and Wendy A. Rogers, 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2013.

[2] Assistive Mobile Manipulation for Self-Care Tasks Around the Head, Kelsey Hawkins, Phillip M. Grice, Tiffany L. Chen, Chih-Hung King, and Charles C. Kemp, 2014 IEEE Symposium on Computational Intelligence in Robotic Rehabilitation and Assistive Technologies, 2014.