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Simulation of an Autonomous Robot Independently Lifting a Person in a Home Setting

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ABSTRACT

Although different modifications have been added to enhance the quality of wheelchairs, the process of transferring in and out of a wheelchair can be exhausting and harmful: caregivers face a higher risk of injury when aiding their patients in doing so, and any slight change in lifting can cause severe injury for the patient. Other human-dependent robots for hospital use have been designed, but not independent or for home use. This paper outlines the simulation of an autonomous robot that can safely lift and carry a physically disabled person at home without depending on or risking the health of the caregiver. Upon the person requesting assistance by raising their hand, the robot travels to them. The robot determines the safest locations to place its arms in order to lift the person before carrying them to their destination. This autonomous robot thus serves as a personal assistant to provide wheelchair users a more comfortable transfer in and out of a wheelchair and throughout the house.

Keywords: *Assistive Technology, Wheelchair, Human-Computer Interaction*

I. INTRODUCTION

Over 65 million people worldwide use wheelchairs on a daily basis. Wheelchairs provide its users with comfort, self-confidence, and the autonomy to freely move and perform certain activities[1]. Thus, ensuring that wheelchair users can easily and safely access wheelchairs is critical to improving their quality of life and bridging the accessibility gap via equality. However, transferring in and out of these wheelchairs still poses a significant hurdle, often necessitating the help of a caregiver or limiting the autonomy of the patient. This physical strain on both the caregiver and patient results in high rates of injury and pain[2]. Specifically in a home setting, this strain is amplified as the burden of aiding the patient is often solely on the caregiver, whereas multiple medical professionals can be of assistance in a hospital setting. Robotic assistants thus emerge as a potential solution in order to increase the quality of life of wheelchair users and other physically disabled people in a safe and cautious manner.

Previous Works

In 2017, a Robotic-Assisted Transfer Device (RATD) was developed and tested at the University of Pittsburgh, where the safety of the device was improved through brakes and error-checking. This device is attached solely to electric-powered wheelchairs and must be severely redesigned in order to do so. RATD is currently undergoing development for eventual market deployment[3].

Furthermore, a transfer robot called RIBA (Robot for Interactive Body Assistance) was previously developed in 2010 by researchers at RIKEN-TRI Collaboration Center for Human-Interactive Robot Research (RTC) in central Japan. RIBA is capable of lifting a person off a bed and onto a wheelchair and vice versa. However, RIBA depends heavily on another caregiver to start running RIBA and guide RIBA's human-like arms in the correct positions to safely carry the person. RIBA also functions primarily in a hospital setting[4].

Although a caregiver is required to supervise in case the robot misperforms, this research is focused on developing a robot that is more autonomous and independent in recognizing when the person requests assistance and identifying how to safely lift the person, particularly in a home setting.

II. METHODOLOGY

Robot Simulation

Due to financial constraints and required verification of the software's accuracy, the developed algorithm was implemented in a robotic simulation. Webots was the selected platform for this robotic simulation due to its compatibility with Robot Operating System (ROS), robust robot and environment catalog, and realistic application of physics[5]. Different environments, representing the different home settings where this robot could be used, were created and employed in this simulation. The robot's actions and movements, from traveling to the person to lifting them, on Webots most accurately reflect its resultant actions and movements in real-life because Webots accounts for friction, inertia, gravity, etc. when simulating the robot.

Clearpath Robotics' PR2 was the selected robot for this research and simulation. PR2 is a four-wheeled robot with two human-like arms with grippers attached at the ends. Equipped with multiple cameras, position sensors, and touch sensors along its face and arms, PR2 possesses a high level of both dexterity and capability to manipulate[6]. Although a bipedal robot would allow for more movement, particularly up flights of stairs, PR2 is ultimately safer and more stable, thus proving a better option for physically disabled people.

Fig. 1. Clearpath Robotics' PR2[7]

Hand Gesture Recognition

Next, PR2 needs to recognize when the person requires assistance, which is denoted by when the person raises their hand with an open palm. If raising their hand is not possible for the person, the algorithm can be altered to instead recognize a thumbs up or pointing gesture.

The assistance gesture is recognized via Google's MediaPipe Gesture Recognizer. This library applies hand landmark and a two step neural network in gesture classification models to a livestream video feed to recognize different hand gestures[8].

When PR2 is at least 55% confident that the assistance gesture has been signaled, the robot will travel to the person. However, if PR2 incorrectly assumes that the person needed help, the person can use a fist gesture to stop PR2 from continuing.

Obstacle Detection

To travel to the person (and to travel with the person after to their destination), PR2 must maneuver past obstacles that are obstructing its path.

OpenCV, a computer vision Python library, was utilized to detect these obstacles. Because the obstacles are often closer to the ground, the arm cameras' video feed is captured instead of the head camera's video feed. The captured frames are pre-processed by removing noise from filtering and converting it to grayscale. A threshold then creates a binary image that edge detection techniques can be applied to. Detected edges represent the boundaries of objects that block the robot's path. From there, bounding boxes are drawn around these objects.

Whenever PR2 comes into contact with such a bounding box, it turns slightly to the left or right, depending on which direction has the farthest next obstacle and which direction is still relatively close to the final destination.

When traveling with the person to the final destination, a similar technique is used to determine where the wheelchair is and placing the person into the wheelchair. The edges of the wheels, denoted by circles, as well as the seat are found through this method, and the distance between the robot and the wheelchair is continuously calculated as the robot slowly descends the person into the wheelchair.

Pose Estimation

PR2 must identify where the person is—in order to travel to them—and the safest positions to place its arms in order to lift the person. The lifting strategy implemented in this algorithm is a bridal style variation of the hip carry. When done by a caregiver, one arm would be under and below the person's hips and the other arm under the person's shoulder to lift the person onto the caregiver's back hip[9]. PR2 similarly detects the points under the person's shoulders and under the person's hips, placing one arm at each point to then lift the person. Rather than the person resting on the caregiver's hip, they instead rest on the front/chest of PR2.

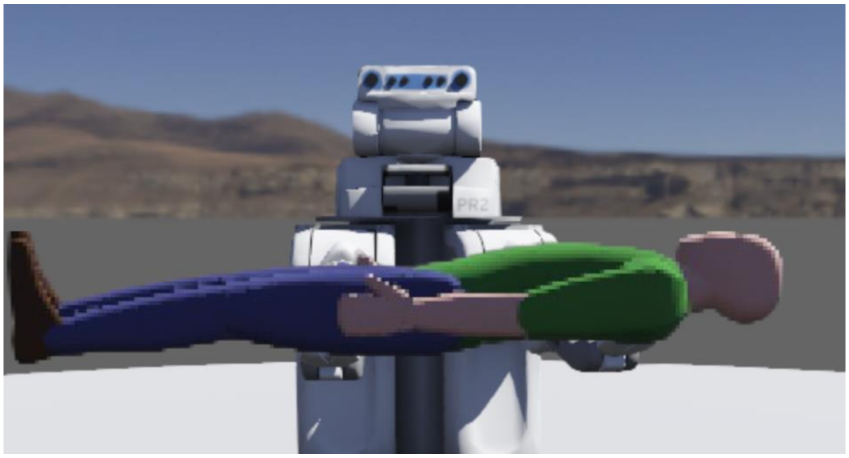


Fig. 2. PR2's lifting strategy. For a real person, the knees and hips would be bent for higher safety.

Pose estimation, a branch of computer vision concerning the location of people and objects, is utilized to detect where the person's shoulders and hips are via Google's MediaPipe Pose Landmarker. This library uses a convolutional neural network in a pose detection model to identify the presence/location of a person in the livestream and a pose landmarker model to identify the 33 three-dimensional points on the person's body that are outlined in Figure 3[10].

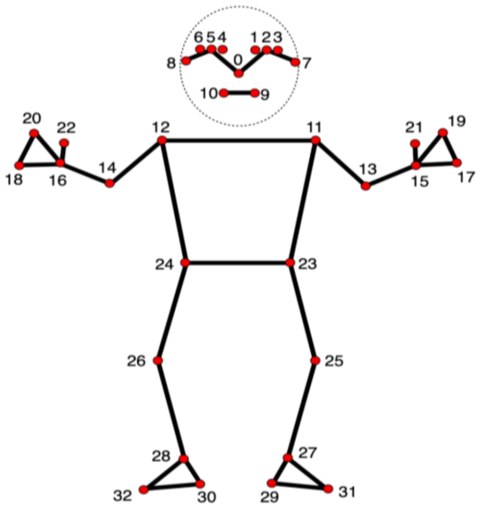


Fig. 3. Bodymark locations detected by MediaPipe Pose Landmarker[10]

Because PR2 will be using its arms for this operation, the arm cameras' video feed is used for the pose estimation. PR2 calculates the point under the person's shoulders by averaging the x- and y-coordinates of points 11 and 12 and subtracting the width of the body from the z-coordinate of these points. This process is replicated with points 23 and 24 to calculate the point under the person's hips. For both situations, the arm touches both points and the gripper wraps around the person's body in order to stabilize them.

III. RESULTS

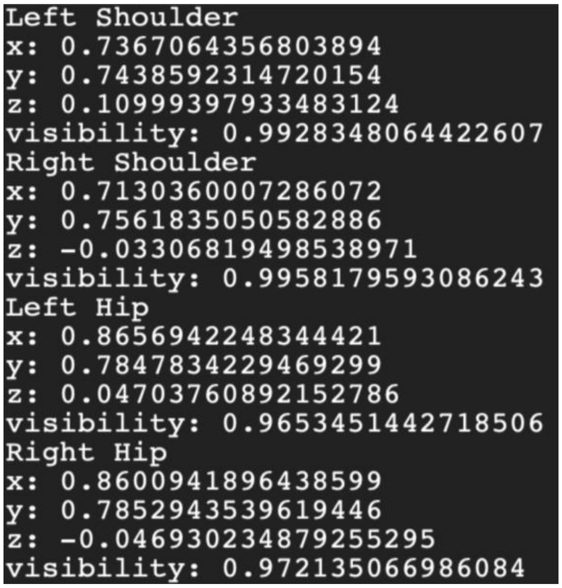
Thirty trials were conducted to test the robot's software. Of these thirty, ten trials addressed a person lying on the ground, ten trials addressed a person lying on a bed, and ten trials addressed a person sitting up in a wheelchair. For each trial, the person raised their hand, was lifted, and then carried to their destination.
Firstly, PR2 had to successfully recognize the person raising their hand, for which the results are outlined in Table 1.

	Person Lying on Ground	Person Lying on Bed	Person in Wheelchair	Total
Success of Recognizing Assistance Gesture	4 of 10 trials	8 of 10 trials	10 of 10 trials	22 of 30 trials

Table 1. Trial data for each of the three scenarios for which PR2 successfully recognized the person's **assistance gesture.**

Drawing a correlation from the data, the higher the person was from the ground—and thus the closer they were in height to the robot's head camera—the higher success rate of assistance gesture recognition. While lower height levels of the person resulted in 40% success, higher height levels of the person resulted in 100% success.

PR2 was placed in different environments given by Webots in order to test the obstacle detection capabilities. In all cases, PR2 successfully navigated past obstacles to arrive in front of the person, only bumping twice into obstacles in two different trials. PR2 utilized pose estimation to gather the three-dimensional locations of the person's shoulders and hips, as seen in the example from Figure 4. The visibility index, a measure of how clear and accurate the calculated points are, is also displayed.



```
Left Shoulder
x: 0.7367064356803894
y: 0.7438592314720154
z: 0.10999397933483124
visibility: 0.9928348064422607
Right Shoulder
x: 0.7130360007286072
y: 0.7561835050582886
z: -0.033068194985389 71
visibility: 0.9958179593086243
Left Hip
x: 0.8656942248344421
y: 0.7847834229469299
z: 0.04703760892152786
visibility: 0.9653451442718506
Right Hip
x: 0.8600941896438599
y: 0.7852943539619446
z: -0.04693023487925529 5
visibility: 0.97213506698 6084
```

Fig. 4. Example coordinates of the person's shoulders and hips found from Trial #4

Using these data points, PR2 calculated the ideal, safest locations for its arms to be. The difference between the arms' locations and theoretical ideal locations for each trial was measured and outlined in Table 2.

Trials for Person Lying on Ground	Deviation from Ideal Position (inches)	Trials for Person Lying on Bed	Deviation from Ideal Position (inches)	Trials for Person Sitting in Wheelchair	Deviation from Ideal Position (inches)
1	2.3	1	2.4	1	4.8
2	2.5	2	2.2	2	5.3
3	2.4	3	2.1	3	5.1
4	2.8	4	2.2	4	5.1
5	2.7	5	2.3	5	5.0
6	3.1	6	2.9	6	4.9
7	2.8	7	2.0	7	5.3
8	2.9	8	1.8	8	5.2
9	2.4	9	2.2	9	4.8
10	2.5	10	2.3	10	5.0
Average	2.64	Average	2.24	Average	5.05

Table 2. Distance from the calculated arms' position to the theoretical ideal position in each of the thirty trials.

Overall, the algorithm was relatively consistent for the first two scenarios, with an average deviation of only 2.64 and 2.24 inches respectively from the ideal position. For the last scenario, the average deviation was much higher at 5.05 inches from the ideal position.

For all thirty trials, PR2 was then able to lift the person, travel across the room with the person in their arms, and place the person in the wheelchair, although as seen by the larger deviations for the wheelchair trials, sometimes it was not always the safest route.

IV. DISCUSSION AND CONCLUSION

Through this research, Clearpath Robotics' PR2 was simulated in a home setting through Webots to recognize when a physically disabled person raised their hand for assistance, travel to them while maneuvering past obstacles, determine the safest places to place its arms through pose estimation, and carry them to their end destination. Given that wheelchairs serve as a major source of autonomy and independence for millions of physically disabled people worldwide, it is critical that the transferring of the person in and out of the wheelchair is a smooth and safe process.
For this research, there was more success in recognizing the assistance gesture when the person was higher above the ground. This could be because a higher height allows more of the person and their gesture to be visible by the robot's head camera, which is roughly three feet off the ground. Utilizing the lower arm cameras to work in conjunction with the head camera to recognize the assistance gesture could result in higher levels of success.

Furthermore, the larger deviations between the calculated ideal position and the theoretical ideal position for the trials where the person was sitting up in a wheelchair can be attributed to visibility issues with sitting up as well as the differing heights between the shoulders and hips. For the first two scenarios, the shoulders and hips were the same distance from the ground, making it easier for the robot to slip its arms underneath and lift the person. Thus, transferring into the wheelchair worked smoothly. However, when the person is already sitting in the wheelchair, the hips are much lower than the shoulders and the hips are against the seat. The robot thus had to squeeze one arm from under the knees to under the hips to lift up the person from one direction until the hips and shoulders were aligned, before then putting the other arm under the shoulders.

For future extensions of this project, assistance gestures could be changed or personalized, possibly adding voice control for those who are paralyzed in their hands or are physically unable to use an assistance hand gesture. More cameras and touch sensors could also be incorporated from PR2 to ensure that the lifting of the person is as safe as possible.

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