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Determining Range of Motion of StrongArm Transfer Technology

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Abstract

The objective of this research is to quantitatively characterize the capabilities and limitations of the robotic StrongArm through theoretical equations. Current transfer technology subjects the caregiver to high physical stress and often results in injury/pain, usually in the lower back. The arm can be used to assist wheelchair users in completing transfers with lessened risk of injury to the user and to the assisting caregiver. The purpose of this study was to determine the tipping point of a power chair with attached StrongArm technology when a load is applied to increase the safety during a transfer and to minimize the chance of tips and falls. It was found that while supporting an 83.9 kg weight, the StrongArm had a maximum forward extension of 635.07 mm and a maximum transverse extension of 725.117 mm

Keywords: Wheelchair, transfer technology, range of motion

1. Background

For veterans with spinal cord injury (SCI), multiple sclerosis (MS), amputations, traumatic brain injury (TBI) and other disabilities who rely on wheelchairs for their independence, transfer devices are an integral component of their daily lives, allowing them to move between their wheelchairs and their beds, showers, and toilets. The over 3 million individuals who use wheelchairs in the United States perform these transfers 14-18 times per day[1], often with the assistance of a caregiver. This task is considered a hazardous activity for the aide as he is subjected to high amounts of physical stress while providing the required lifting force to complete the transfer.

In a study done by A. Garg, B. D. Owen and B. Carlson, 38 nursing assistants were studied in a nursing home setting. The researchers found that nursing assistants used assistive devices, like lifts, less than 2% of the time, while a majority of the assistants suffered from lower back pain directly associated from their work.[2 and 3] This paper describes the methodology of quantitatively finding the center of mass and the tipping point of the arm. Tipping of the wheelchair is a major source of injuries in wheelchair users, with the majority (65.7%) of all first power wheelchair accidents being tips and falls with one of the main self-perceived causes of wheelchair related accidents being transfers[4]. In a study done by C Calder and R Kirby, it was found that out of 770 fatal wheelchair accidents, the majority (77.4%) experienced a tip or fall from their chair and 10.2% of the accidents were linked with the person transferring to or from a wheelchair[5].

The StrongArm is robotic arm conceived and developed by the Human Engineering Research Laboratories (HERL) as a way to relieve strain on the caregiver who assists the person in the wheelchair in completing transfers in their daily lives. It was designed to increase the safety of both participants involved in a transfer, whether the transfer be fully dependent or a stand/pivot transfer.

The StrongArm has 5 degrees of freedom (figure 1): it can travel around a track attached to the power chair, allowing the attachment a larger area in which it can operate effectively while also allowing the arm to be stored in the rear of the power chair when not in use. The arm itself is made up of two joints, the shoulder and elbow joints, each of which may be independently rotated. The limbs of the robotic arm may each be individually extended[6].

Figure 1. The five degrees of freedom of the robotic StrongArm are indicated with red arrows.

The StrongArm attachment overcomes the shortcomings of current transfer technologies in use in that it is completely portable with a power chair while still lessening substantial amounts of strain on the caregiver. Figure 2 illustrates how the robotic StrongArm attachment can be used to carry out a fully dependent transfer.

Figure 2. Steps A through E illustrate how the StrongArm attachment can be used to transfer a humanoid test dummy from a power chair to a bed.

2. Methodology

2.1 Finding the centers of mass

To find the center of mass of the chair and StrongArm system, force plates were used in conjunction with the Vicon Motion Capture system. In the Vicon system, the movement and positions of the objects being recorded is sampled many times per second from multiple cameras so that a three dimensional image of the object may be calculated6. Due to its ability to accurately produce rapid and even real time results, it is often used in biomechanics and clinical medicine studies.

While on the force plate, the wheelchair-StrongArm system was tilted 1.5 inches and by 3 inches. The tilt was applied by lifting the back wheels up for 4 trials and the wheels on the right side of the chair for four additional trials. The total of ten trials was completed with two trials with the chair untilted. The centers of pressure, forces and moments about the x, y, and z directions and the location of the markers for the Vicon system were recorded for each trial.

The use of the force plate with the tilt table allows the researcher to obtain a reasonably precise estimation of the center of mass of the chair-arm system in three dimensions.

The deadweight dummy test subject being transferred can be considered a point mass and its center of mass can be assumed to be along the axis of the segment of the arm that it is resting on during the transfer.

2.2 The tipping point

When the arm is extended away from the wheelchair while supporting a mass, the arm and the mass on the arm create a moment about the front wheels. If the moment created by the protruding arm exceeds the moment produced by the chair, the wheelchair will tip about the pivot point on the chair. The pivot point is the front right wheel in the case where the arm is at the front right position on the track.

The tipping point was found theoretically by balancing the moments about a pivot point. To simplify the derivations to find the tipping point, several assumptions were taken into consideration. The two being studied were the chair with its StrongArm attachment, which was considered one body, and the dummy being transferred, a deadweight of 185 pounds, which was assumed to be a point mass. The arm attachment was considered to be a rigid static body with negligible deformation under the load. Furthermore, the mass of the upper limb of the StrongArm was negligible compared to the mass of the rest of the arm and the power chair, so that the center of mass of the StrongArm-power chair system can be assumed to remain constant, even with arm movement. To evaluate the stability of the chair-arm system while supporting the point mass, a series of three-dimensional moment balances in were used.

A Matlab script was used to automate the calculation of whether or not the chair will tip given a specific location of the center of mass coordinates of the test dummy. The inputs of the script are the center of mass (COM) position of the chair/arm system, COM of test dummy and the masses of chair system and the test dummy. All the coordinates of the COMs were found using a tilt table and then tracked the Vicon. The outputs from the program are the tipping point coordinates of the chair in the x and y directions, and whether these coordinates are within the range of motion of the arm.

In this experiment, the front right wheel of a Permobil C500, the model of power chair to which the StrongArm is attached. Two positions of the arm were taken into consideration in this study, the first with the arm in the front most position of the right side of the chair, extended straight out front, parallel to the side of the chair (figure 3a), and second with the arm in the same location but extended straight out to the right, perpendicular to the side of the chair (figure 3b).

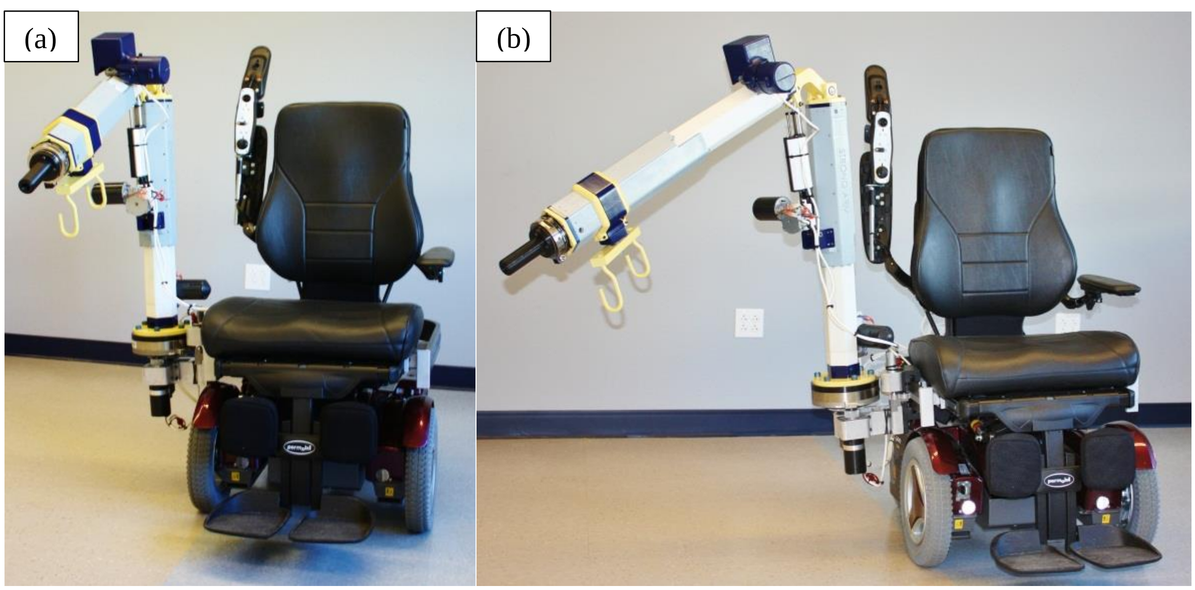

Figure 3. (a) Position 1 of the StrongArm, with the arm located on the front most right position of the track, extended straight out front from the chair. (b) Position 2 of the StrongArm, with the arm located on the front most right position of the track, extended straight out to the side of the chair.

The calculations were repeated for both positions of the StrongArm and a range for the maximum extension of the arm was obtained based on the results.

3. Results

The equation describing the maximum distance of the weight supported by the arm from the origin in the x direction:

$$x_d < -\frac{M_{cy}}{D} \tag{1}$$

Or x subscript d is less than negative M subscript cy divided by D, where x subscript d represents the maximum extension of the arm in the x direction, M subscript cy represents the moment caused by the chair in the y direction and D represents the weight of the deadweight being supported by the robotic arm. M_{cy} was found for each trial from the data gathered from the Vicon Motion tracking system and D was given to be 83.9 Kg.

The equation describing the maximum distance of the weight supported by the arm from the origin in the y direction:

$$y_d < -\frac{M_{cx}}{D} \tag{2}$$

Or y subscript d is less than negative M subscript cx divided by D where y subscript d represents the maximum extension of the arm in the y direction, M subscript cy represents the moment caused by the chair in the x direction and D represents the weight of the deadweight being supported by the robotic arm. M_{cx} was found for each trial from the data gathered from the Vicon Motion tracking system and D was given to be 83.9 Kg.

The equations yielded two tipping points for the chair/arm system, one in the x direction and one in the y direction, but the results from the theoretical equations are limited by the actual range of motion of the StrongArm.

Table 1: Center of mass values, mm

Trial	Maximum Transverse Extension (mm)	Maximum Extension Forward (mm)
1	674.0623	623.3449
2	635.0732	654.0911
3	650.2211	607.2866
4	686.1399	576.9103
5	698.8881	696.5691
6	663.1160	725.1166
7	687.0804	721.0943
8	724.5692	692.1979

Table 1 shows the maximum extension distances in millimeters in the x (transverse) and y (forward) directions relative to the front right wheel that the StrongArm may take while supporting the deadweight for each tilted trial. These distances refer to the maximum extensions the arm can undergo without causing a moment that would unbalance the arm-chair system.

The smallest maximum extension length of the 8 trials was taken to be the maximum extension for the chair-arm system. In the transverse extension direction, the value of the maximum safe extension distance of the StrongArm was 635.0732 mm. The maximum extension in the forward direction was 725.11 66 mm.

4. Discussion of Results

The objective of this research is to quantitatively characterize the capabilities and limitations of the StrongArm through theoretical equations and bench testing. More specifically, the purpose of this study was to determine the tipping point of a power chair with attached StrongArm technology when a load is applied. The limits of movement of the robotic StrongArm will establish the greatest range over which a transfer can take place. In the calculations to find the maximum extension distances of the StrongArm, only the trials in which the chair was tilted were used as the two trials where the chair was level was used as a reference point.

This research is essential to ensure the safety of caregiver and individual being transferred as it will allow the user of the technology to prevent falls and injury during transfer. The maximum range of motion of the arm will allow any clinician or caregiver to safely gauge the maximum distance over which a transfer can occur when using the StrongArm attachment. If this range is exceeded, the chair-arm system is likely to tip over, making both the caregiver and the wheelchair user at risk for injury. However, if the movement of the arm as directed by the caregiver stays within the given range, the risk of injury or strain of both participants involved in the transfer can be decreased greatly.

With the base values found from this experiment, further testing can also be done to find ways to increase the range of motion of the StrongArm while maintaining stability of the system consisting of the Permobil C500 and the robotic StrongArm attachment. Additionally, stops in the arm will be put in place to prevent over extension of the arm. However, this study was limited in several ways. The study was carried out in a completely static set-up with a dummy weight that did not move instead of a human subject. Secondly, since there were only eight trials during this experiment, the number of data sets was limited. The equations found were mathematically derived and encompass a theoretical, static scenario. The next step in this study will be subject testing the system with caregivers transferring the deadweight dummy.

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