Abstract

There are approximately 2.8 million wheelchair users in the United States and 65 million wheelchair users worldwide [1] (References in Appendix A). Almost all these individuals are limited in their reach due to the restrictions of sitting in a wheelchair. Every person in a wheelchair struggles to reach an item off the floor or grab a cup from a cabinet shelf. This limitation in reach considerably restricts an individual ability to perform basic, daily tasks and causes an increased dependence on a caregiver. As a result, individuals who are wheelchair dependent are actively seeking a solution to improve their independence.

To address this problem our team has developed the Robotic Assistive Reaching Mechanism (R-ARM), a low-cost wheelchair mounted robotic arm (WMRA) that allows wheelchair-dependent individuals to pick up objects up to 4.5 ft away and weighing up to 3 lbs.

While many individuals with disabilities are in direct need of a reaching aid, there are relatively few options that are commercially available. Indirect competitors of the R-ARM include devices such as trash grabbers and telescoping rods. While these are inexpensive reaching aids, they cannot pick up significant payloads, greatly limiting their utility. Our direct competition consists of two close competitors in the WMRA market, the JACO from Kinova and the iARM from Exact Dynamics. Both of these WMRAs are elegant solutions, but are complex and sell for an exorbitant price of greater than $40,000.

The R-ARM not only distinguishes itself by its more affordable price of $5,000, but also its transportability and safety features. The R-ARM was designed with the end user in mind. It can easily be removed and stowed without the use of any tools in less than 5 minutes. It also has a novel interference detection safety system, which can detect and halt the motion of the arm if an object impedes its path of motion, preserving the safety of the user.

Over the course of three years, our team has developed a fully functional prototype of the R-ARM for our first customer, which has proven to be able to reach and grasp many different types and shapes of objects. The R-ARM has been extensively tested for safety, and has been externally reviewed by six industry experts. Currently, the R-ARM is being beta-tested to further refine and improve the functionality of the device. We have partnered with the Texas Institute for Rehabilitation Research (TIRR) and will be progressing to clinical trials within the next 6 months.

Wheelchair users have varying degrees of limitations and disabilities. Customers of the R-ARM can range from elderly patients to individuals with neurological conditions. Our team has identified, based on a recent Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) report that individuals with muscular dystrophy, amyotrophic lateral sclerosis, multiple sclerosis, cerebral palsy, osteogenesis imperfecta, arthrogryposis and geriatric patients with lower back pain are in direct need and constitute an ideal initial target market [7].

Our future plans include making the R-ARM available to these individuals by partnering with existing major wheelchair manufactures. Customers will then be able to purchase the R-ARM as an accessory to either an existing or new wheelchair at a price of only $5,000.

Motivation for a Robotic Reaching Aid

The Problem

Currently, there are approximately 2.8 million wheelchair users in the United States and 65 million wheelchair users worldwide [1] (References in Appendix A). These users include individuals with varying degrees of disabilities, from geriatric patients with lower back pain to more extreme upper body extremity diseases such as osteogenesis imperfecta, spina bifida, muscular dystrophy, cerebral palsy, and paraplegia. Almost all these individuals are limited in their reach due to the restrictions of sitting in a wheelchair. Every person in a wheelchair struggles to reach an item off the floor or grab a cup from a cabinet shelf. This limitation in reach considerably curtails an individual's independence. For individuals with additional upper-body musculoskeletal limitations interacting with the environment is even more constrained. Many of these individuals cannot turn on/off a wall-mounted light switch, grab a pencil from a table, or pick up the remote from a coffee table. Over 1.5 million individuals in the United States have conditions like these and rely on others for basic tasks [2-6].

A recent article cited that 150,000 individuals could directly benefit specifically from a wheelchair-mounted robotic arm [7]. Additionally, another recent study showed that 84% of surveyed individuals with disabling conditions would consider buying a robotic reaching aid if it were affordable. This highlights the pressing need for a more affordable and effective solution to these individual's needs [9].

Limitations of Current Solutions

Unfortunately, for many of these individuals, current solutions are simply inadequate. Individuals who are wheelchair bound with strength or reach related limitations have only a few different types of options. These include devices in the three broad categories of trash grabbers, telescoping rods, and wheelchair mounted robotic arms (WMRAs).

Trash grabbers and telescoping rods, such as the Telestick 2000, which is simply a sticky pad on the end of a telescoping rod, are currently the most common solutions because of their extremely low cost and their commercial availability. However, they are severely limited in their effectiveness in aiding everyday tasks due to restrictions in payload capacity and reaching distance. For example, the Telestick 2000 lifts less than 1 lb and cannot conform to curved surfaces. Additionally, using a mechanical reaching aid requires lifting over an extended distance, which requires torque that many individuals cannot provide. For many, these devices are limited in their utility and do not provide a significant benefit.

The alternative, wheelchair-mounted robotic arms, is an extremely effective solution, but the cost prevents widespread adoption. Currently, there are two main WMRA's that are commercially available; the JACO from Kinova and the iARM from Exact Dynamics. Both of these WMRA's are elegant solutions and provide at least 6 degrees of freedom, allowing the user to perform a variety of activities. However,

because these devices are extremely complex and designed to be used by the most severely disabled individuals, they cost over $40,000. Additionally, these reaching aids are not covered by medical insurance, so consumers have to pay directly out-of-pocket. As a result, most customers who could benefit from WMRAs do not, because they cannot afford the devices. The R-ARM is designed to be much simpler, but still be effective at increasing independence during daily tasks for the majority of the individuals who need it. By simplifying the approach and focusing on cost as a barrier, we've created a device that can be retailed for only $5,000 which is over 800% more affordable for consumers.

The Design of the R-ARM

The Solution

The R-ARM is a two-joint robotic reaching aid that augments the current reach and strength capabilities of individuals confined to a wheelchair. The device consists of three main components: the base, the arm, and the gripper (Figure 1). The base consists of a semi-permanent mount that attaches to the back of the wheelchair and a removable gearbox component. It uses a 12V brushed DC motor to rotate the first joint of the arm through a worm drive reduction gearbox. The worm drive system is non-backdrivable and ensures the arm will not fall if a base component were to fail. The arm is composed of the upper and lower limb and is similarly driven by a 12V brushed DC planetary gearhead motor and an internal timing belt system. The base and the arm move in conjunction to rotate and extend the length of the arm with an operational range of 4.5 ft. The gripper is mounted at the distal end of the upper limb of the arm and provides actuated opening and closing in order to grab objects. It is made from ABS plastic and uses two 5V, high torque, servos to drive a four-bar linkage system. The four-bar linkage system allows for parallel gripping through its full 6 in grip range. High coefficient of friction rubber pads line the contact surface of the gripper in order to increase friction with the objects it is picking up.

Figure 1. The R-ARM

An external 12V battery, attached to the rear of the wheelchair, powers the R-ARM, while a Playstation3 (PS3) gaming controller controls the arm's movement. The controller acts as a friendly user interface, relaying motor commands to the R-ARM through an Arduino microcontroller. Once grabbed, objects can be retracted back within a 1 ft radius of the user. The user can release the object with either the controller or with a foot pedal. Using the foot pedal allows the user to use both hands to retrieve the object.

The modular design of the R-ARM allows it to be detached from the users' wheelchair. Individually, the base and arm weigh only 15 lbs and can be detached from the wheelchair in less than 5 minutes, without the use of any tools, allowing for quick and simple transportation of the device. The device utilizes a low power consumption microcontroller that allows for normal use of the R-ARM for up to 12 hours on a single charge.

Currently, the robotics and prosthetics market is focused on creating devices that are designed to mimic the vast capabilities of human limbs. This trend, while leading to phenomenal products and advancements in technology, has also lead to complex products that are too expensive for the majority of consumers. In contrast, the R-ARM was designed specifically with the customer base in mind, resulting in a simple and affordable, yet effective design.

Apart from price, the R-ARM differentiates itself in three ways: 1) The R-ARM does not use a wheelchair's integrated battery (uses external battery) thereby avoiding the possible loss of a wheelchair's valuable warranty and allows for use with manual wheelchairs. Additionally, an external power supply eliminates the possibility of the customer draining the main wheelchair battery due to device use. 2) The R-ARM is specifically designed for easy detachment and storage. Unlike other WMRAs, the R-ARM does not require separate tools to detach. Furthermore, the design is modular, allowing for the R-ARM to be broken up into manageable components and easily reconstructed. 3) Safety features on the R-ARM can detect interfering objects or human contact, halting the motion of the R-ARM, and preventing injury to humans as well as damage to the device.

Transportation

Individuals in a wheelchair often travel and must stow the wheelchair in a car, train, airplane, or other form of transportation. This becomes exceptionally difficult and cumbersome when the robotic arm is bulky and cannot be detached easily from the wheelchair or mobility device for stowing. Even when removal of the device is an option, current methods require specific tools and a considerable amount of time and effort, which is impractical for use on a regular basis.

Our device features a novel quick detachment mechanism that allows the base and arm component of the R-ARM to be removed. The design of the mechanism is completely self-contained and the process is intuitive; without any formal training, an individual can completely remove and stow the R-ARM in less than 5 minutes without the need for additional resources.

Safety

There is an inherent safety risk when dealing with wheelchair mounted robotic arms. They are powerful machines that have the potential to cause serious injury if used improperly. Existing wheelchair-mounted robotic arms that have been developed around rehabilitation do not have inherent safety features to protect the user. Two of the major concerns with regards to safety are that the movement of the arm could injure the operator and that the object being retrieved could fall on the operator.

The R-ARM is designed specifically to address these concerns. The entire device is offset and operates in a plane outside the normal working area of the operator. This means that any dropped object will fall harmlessly to the side of the operator. Additionally, mechanically compliant clutch systems in each joint ensure that the arm cannot pick up objects heavier than desired prevents damage to its surroundings. The R-ARM also has novel interference detection mechanism that automatically stops movement of the arm when the device comes into contact with an interfering object, therefore preserving the safety of both the user and anyone nearby.

Development of a Minimum Viable Product

Over the course of three years, our team has developed a fully functional prototype of the R-ARM for our first customer, Dee (Figure 2). Dee is a 17-year-old male with osteogenesis imperfecta who receives care at Shriners Hospital under Dr. Gloria Gogola in Houston, TX. As shown in the video link (http://youtu.be/N1jbEvhFzQM), the R-ARM is able to reach and grasp many different sizes and shapes of objects. The R-ARM has been extensively tested for mechanical, electrical and software safety, and has been externally reviewed by six industry experts. In accordance with of our initial goals, the prototype is able to fully extend and grab objects 4.5 ft away and weighing up to 3 lbs. Additionally, Dee's parents were able to completely remove and stow the R-ARM from Dee's wheelchair in less than 5 minutes and without any formal training. The device has had tremendous success, not only in its ability to function, but in validating the need for a more affordable and user friendly WMRA. The Youtube video featuring Dee has reached almost 1 million views and has helped the R-ARM gain national media attention. Through exposure from major media sources such as Good Morning America, Fox News and CNN, our team has received strong, positive feedback for the commercial need of such a device. Doctors and universities across the country have requested the help of the R-ARM for their patients. Currently, the R-ARM is undergoing beta testing with Dee in order to further refine and improve the functionality of the device.

Figure 2. Dee picking up an orange

Figure 3. Dee Retrieving an Article of Clothing

The team has a working relationship with Dr. Gerard Francisco and Dr. Glendaliz Bosques, physicians at the Texas Institute for Rehabilitation and Research (TIRR), a world-renowned rehabilitation facility. Both Dr. Bosques and Dr. Francisco have several patients who they see as ideal users for the R-ARM. They have agreed to partner with us to identify at least five more patients who, as a group, have a wide range of disabilities. We are currently in the process of gaining IRB approval through the appropriate university and hospital channels. Once approved, we will begin clinically testing the R-ARM with these patients to quantitatively assess the degree to which the device can impact an individual's independence. The impact of the R-ARM will be assessed by its ability to improve the score of an individual on the Activities of Daily Living (ADL) scale, a commonly used and comparable measure between assistive devices.

In addition to Shriners and TIRR, we plan to leverage contacts within the Texas Medical Center, the largest medical center in the world, to gauge both need and interest in the R-ARM. Specifically, we will be conducting surveys this summer with more than 100 potential customers to test hypotheses regarding the initial market and the need for the R-ARM.

Appendix A. References

[1] World Health Organization, Disabilities and Rehabilitation. 2013. Guidelines on the provision of wheelchairs in less- resourced settings. http://www.who.int/disabilities/publications/technology/wheelchairguidelines/en/, Accessed 1 October 2013.

[2] Osteogenesis Imperfecta Foundation, 2012. http://www.oif.org/site/PageServer?pagename=InfChild, Accessed 1 October 2013.

[3] Joseph M. Lary, Larry D. Edmonds. Prevalence of Spina Bifida at Birth -- United States, 1983-1990: a Comparison of Two Surveillance Systems. Centers for Disease Control and Prevention, Department of Health and Human Services. Morbidity and Mortality Weekly Report – April 19, 1996 / 45(SS-2);15-26.

[4] National Institutes of Health, National Institute of Neurological Disorders and Stroke. Muscular dystrophy. http://www.cdc.gov/ncbddd/musculardystrophy/facts.html, Accessed 1 October 2013.

[5] Christopher and Dana Reeve Foundation, 2013.http://www.christopherreeve.org/site/c.mtKZKgMWKwG/ b.5184189/ k.5587/Paralysis_Facts__Figures.htm, Accessed 1 October 2013.

[6] “Data & Statistics for Cerebral Palsy." Centers for Disease Control and Prevention, 27 Dec. 2013. http://www.cdc.gov/ncbddd/cp/data.html Accessed 1 May 2014.

[7] Cheng-Shiu Chung, Rory A. Cooper. Literature Review of Wheelchair-Mounted Robotic Manipulation: User Interface and End-User Evaluation. 2012 RESNA Annual Conference, Arlington, VA.

[8] Persistence Market Research Inc., 2014. Prosthetic Robots, Exoskeletons and Assistive Rehabilitation Systems Market Assessment Report - Global Size, Share, Competitive Landscape, Future Prospects and Forecast from 2013-2019

[9] "Result Filters." *National Center for Biotechnology Information*. U.S. National Library of Medicine, n.d. Web. 29 May 2014.