A Double Claw Robotic End-Effector Design

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ABSTRACT

A new robotic gripper was designed and constructed for Activities of Daily Living (ADL) to be used with the new Wheelchair-Mounted Robotic Arm developed at USF. Two aspects of the new gripper made it unique; one is the design of the paddles, and the other is the design of the actuation mechanism that produces parallel motion for effective gripping. The paddles of the gripper were designed to grasp a wide variety objects with different shapes and sizes that are used in every day life. The driving mechanism was designed to be simple, light, effective, safe, self content, and independent of the robotic arm attached to it.

Keywords

Gripper, Robot, Rehabilitation, ADL, Assitive.

1. INTRODUCTION

Gripper design considerations are crucial in producing a functional and cost effective product for rehabilitation applications. This gripper is designed to be mounted to any robotic arm, and in particular, wheelchair mounted robotic arms that are used to enhance the manipulation capabilities of individuals with disabilities that are using power wheelchairs. Most grippers of similar objectives use two fingers for grasping, but the dexterity of these fingers limit the use of the gripper. This project attempts to provide a new design with enough dexterity to widen the range of grasping tasks that are used in the Activities of Daily Living (ADL) in an effort to improve performance and usability.

According to the latest data from the US Census Bureau Census Brief of 1997 [1], one of every five Americans had difficulty performing functional activities (about 53 million), half of them were considered to have severe disabilities (over 26 million). This work focuses on people who have limited or no upper extremity mobility due to spinal cord injury or dysfunction, or genetic predispositions. Robotic aides used in these applications vary from advanced limb orthosis to robotic arms [2]. Persons that can benefit from these devices are those with severe physical disabilities, which limit their ability to grasp and manipulate objects. These devices increase self-sufficiency, and reduce dependence on caregivers.

The main objective of this work is to design and fabricate a gripper that is capable of grasping various door handles and knobs, cylindrical and spherical objects, tapered and conical objects, rectangular and odd-shaped objects, sheets of paper, light switches and buttons, and other larger objects up to four inches in width that are commonly used for activities of daily living. As a criterion, the gripping force objective was set to roughly ten pounds of force. The gripper was to be mounted on the end of a robotic arm which was connected to a wheelchair. This factor limited the gripper's size and weight, so design ideas were kept simple but effective. 3-D models of the considered designs were created using Pro/E and then later printed out to scale using a Rapid Prototype printer for design adjustments before building the actual gripper.

2. BACKGROUND

There are many universal gripper designs available in the market today with pneumatic, hydraulic or electric actuation. The most important design consideration of grippers that are used for ADLs is the safety of the operator [3].

Kolluru et al [4] discussed the design of a reconfigurable gripper that consists of four fingers in a cross-bar configuration as shown in figure 1. A suction based gripper unit was mounted on each one of the fingers to handle limp material without causing any distortion or deformation.

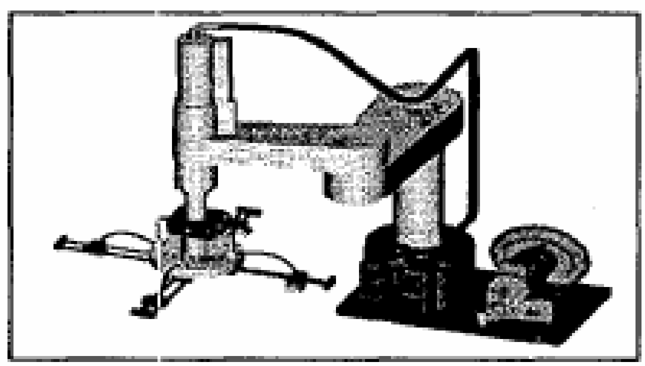

Figure 1. The reconfigurable gripper prototype

Figure 2 shows another design of a reconfigurable gripper that was conducted by Yeung et al [5] utilizing a wrench system and multi-finger configuration to handle parts of different geometry with different grasping points. This design was developed for robotic arms that are used for assembly of automotive body parts.

GertWillem et al [6] have redesigned the gripper of the Assistive Robotic Manipulator (ARM) or previously known as Manus to include a better and more efficient driving mechanism and adjustability by incorporating the drive mechanism into the base of the gripper independently from the robot's drive train as shown in figure 3.

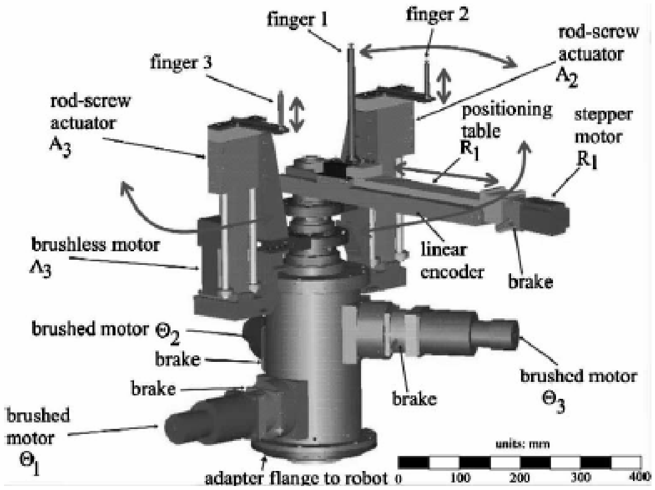

Figure 2. A 6-DoF reconfigurable gripper

The previous design used a tension cord that pulls the gripper to the closing position, and the driving motor was integrated to the arm, which means changing the gripper is very hard or impossible. The new design includes spring-loaded mechanism to build up the force on the parallel motion grip fingers, and the results were much versatile mechanism and more dexterous gripper.

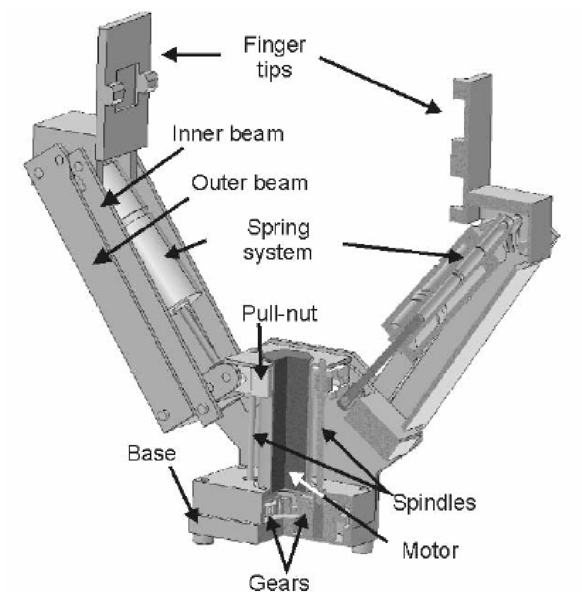

Figure 3. The redesigned gripper of Manus manipulator

3. GRIPPER HARDWARE DESIGN

In designing a gripper, functionality is very important, and it remains one of the main factors considered in most robotics applications. If the design has good functionality, minimal cost, high durability, and the aesthetic characteristics are met, a good product is likely to be produced. In order to decide on a good design for a gripper, several aspects have to be inspected, such as the tasks required by the mechanism, size and weight limitations, environment to be used in as well as material selection. Some of the ADL tasks that will be performed using the gripper are opening doors, grasping a glass to drink from, flipping on a light switch, pushing and turning buttons and knobs, holding books and similar objects, handling tiny objects such as a CD or loose sheets of paper, or holding a small ball.

3.1 Paddle Design

Specific considerations were taken in the attempt to optimize the functionality of the gripper. It was decided early on that the gripper would utilize parallel motion generated from a dual four bar mechanism attached to each side of the two fingers creating 8 links between the gripper surfaces and the driving mechanism itself. As a start, the gripper's fingers (paddles) were first put into consideration. Through the required tasks expected out of the overall device the gripper's surfaces were designed to be varied for the adequate handling and use of household objects mentioned. For those items, the profile was decided initially to be angled as shown in figure 4. The angled surface was designed to constrain and secure handled objects, and the middle opening was meant to secure spherical objects. When opening a spring-loaded door, the two teeth at the tip of the paddles can secure the handle during the robot motion, and make the grasping force independent of the closing force of the gripper.

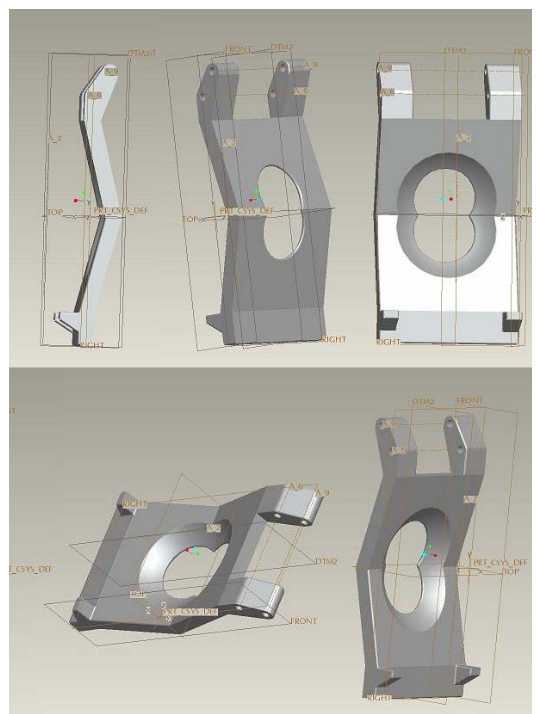

Figure 4. First paddle design

A rounded surface was later implemented in the place of the angled paddle surfaces as shown in figure 5, which would give the gripper a softer look as well as better function while grasping objects. A spherically channeled surface was decided to be placed in the center of the paddle surface with the intention to contour to spherical door knobs. Small protrusions were added to the end of each paddle at the tip of the gripper for grasping smaller objects allowing added dexterity and the operations of press buttons and toggle switches. The tips were specifically made narrow for precision operations and rounded off to prevent the marring of surfaces that they would come in contact with. Optional protrusions extending toward the center of the grip at the tip of one of the paddles was added to allow objects such as door handles and door knobs to be pulled open with more security, rather than relying on friction and the locking of the mechanisms grip alone. The other paddle would have a small opening for the protrusions to go through when closing the gripper is required as seen at the bottom of Figure 5.

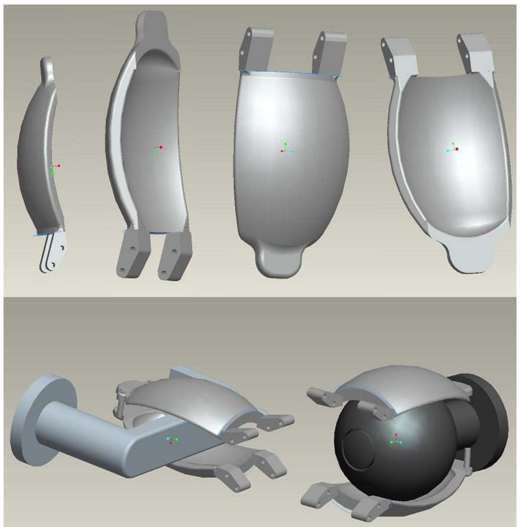

Figure 5. Modified paddle with application reference

We decided that an extra flat surface placed closer to the driver mechanism would be beneficial in grasping larger rectangular objects such as boxes or books. By relying on the finger tips of the gripper alone to grasp larger objects, a greater moment would be generated on the driving mechanism and higher stresses induced in the links to achieve the same amount of gripping force attainable from a location closer to the driving mechanism itself. Figure 6 shows these changes to the paddles.

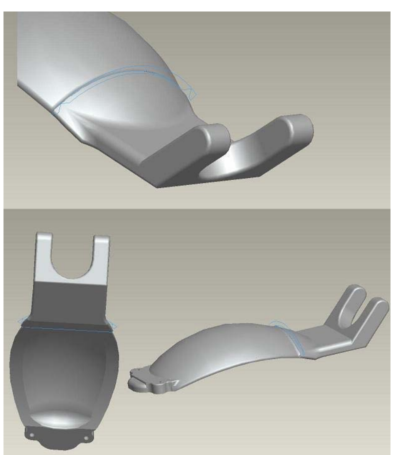

Figure 6. Extended interior surface added to the gripper

As a final modification to the paddles, a spring hinge was added to the back of the flat paddle surface, near the hinge location, to allow for a small amount of torsional rotation. The thought behind this modification was for an added degree of freedom in the paddles to allow for a better grasp on tapered objects such as cups and for self-adjustment. Four main contact surfaces were intended for this gripper: The spherical area at the center of the paddles for spherical objects, the two round surfaces on both sides of the paddle for handling cylindrical and tapered objects, the two flat surfaces at the bottom and top of the paddles for handling rectangular and large objects, and the paddles' tips for handling small objects, switches, knobs and sheets of paper.

3.2 Actuation Mechanism

The driving mechanism was the next step in creating the gripper. As noted previously, the design was going to utilize four bar linkages to allow the paddles to open and close in a parallel motion. The main reasons for this were increase the contact surfaces between the gripper and the handled object, and to prevent these objects from slipping out of the grasp of the paddles due to the angular change in the contact surfaces caused by simpler pin joint gripper designs. By keeping the paddles parallel, a more predictable surface contact angle could be controlled which would allow larger objects to be grasped safely without the risk of being dropped.

The first requirement for the gripper was for it to have a minimum gripping force of ten pounds and be capable of traveling from a full open position of four inches to a closed position within approximately four seconds. The gripper was also required to have an onboard motor for modularity reasons. The idea of utilizing an acme screw and a pull nut setup would be adequate for power transmission, and its compact size, relatively high variability in gear ratios, and its ability to lock the position without the use a mechanical brake mechanism made it a good choice for the purpose of this gripper. For this design a stainless steel 1/4-20 acme screw with a plastic nut was selected and thought to be the best design for space conservation and overall weight conservation as well. The selected motor carried relatively high torque to size ratio, and as a result, minimized the overall weight of the gripper dramatically. For the safety of the user, the handled object, and the mechanism, an adjustable slip-clutch was attached to the acme screw to build up the gripping force based on how delicate the object is, and to prevent the torque in the motor to rise above the designed limit of the mechanism. The selected components are as follows:

1) The Motor: A 24 volt DC coreless gearhead servo motor was selected since the wheelchair can supply that voltage from its batteries. The diameter of the selected motor was 0.67 inches having a length of 1.77 inches. This motor, made by Faulhaber, puts out a stall torque of 11.5 mNm with a maximum current of 190 mA and a maximum speed of 8000 rpm. This motor uses a 14-1 planetary gear ratio, and an optical encoder with 512 counts per revolution for the use of feedback control. Figure 7 shows the motor assembly with the gearhead and the encoder.

2) Acme Screw and Pull Nut: A Stainless Steel 20 thread-per-inch acme screw was selected with a diameter of 0.25 inches to transmit the motion from the motor to the linkages through a Delrin plastic pull nut. This helps in locking the mechanism when the motor is stopped, and it gives a proper conversion of the motor speed to the required torque for driving the system.

Figure 7. The selected coreless gearhead servo motor

3) Slip Clutch: An adjustable 0 to 50 oz-in slip clutch was selected to build up the grip force and slip in case the motor is still running while the required torque is reached. Figure 8 shows a drawing of the slip clutch

4) Spur Gears and Flange Ball Bearings: Two spur gears made out of anodized aluminum were selected with a pitch of 0.25 inch to transmit the motion from the motor shaft to the acme screw. A gear ration of 2:1 is used with 36 teeth, 9.5 mm diameter gear on the motor shaft and 72 teeth, 18.5 mm diameter gear on the acme screw.

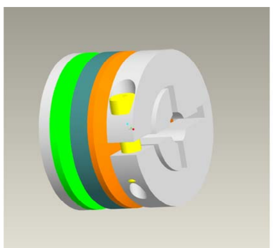

Figure 8. The selected slip clutch

Figure 9 shows the actual driving mechanism after assembly. Aluminum was the main component used in building the housing and shield of the mechanism and the links. When all the side panels are in place and the top cap of the housing seal the compartment of the spur gears, safety of the operator is ensured in terms of getting any external object caught in the driving mechanism. It also ensures proper protection of the motor and the small components driving the gripper from external dust and debris. Extensions on both sides of the gripper's base with extra holes were added for expandability in case other devices such as a camera and a laser range finder need to be mounted to the gripper's base plate.

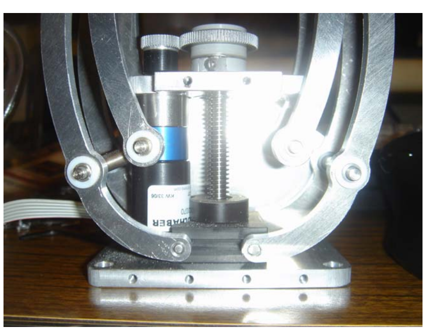

Figure 9. The assembled actuation mechanism

3.3 Control System

The controller hardware is chosen to be compatible with the Wheelchair-Mounted Robotic Arm (WMRA) system [7] that uses PIC-SERVO SC controllers that support the DC servo actuators and run its logic on 12 V DC power supply. At 5cm x 7.5cm, this unit has a microprocessor that drives the built-in amplifier with a PWM signal, handles PID position and velocity control, communicates with RS-485, and can be daisy-chained with up to 32 units. It also reads encoders, limit switches, an 8 bit analogue input, and supports coordinated motion control. Data for the entire arm and the gripper is interfaced to the main computer using a single serial link. The PIC-Servo SC controllers use RS-485, and a hardware converter interfaces this with the RS-232 or a USB port on the host PC. A timer has been utilized to cut the arm's power off after a preset time to minimize power consumption while not in use. An emergency stop button is placed to cut the power off the motors and leave the logic power on so that the system can be diagnosed without rebooting. Figure 10 shows the controller circuitry of the WMRA system [7], and the gripper controller board is another module added to the 7 modules shown in the diagram.

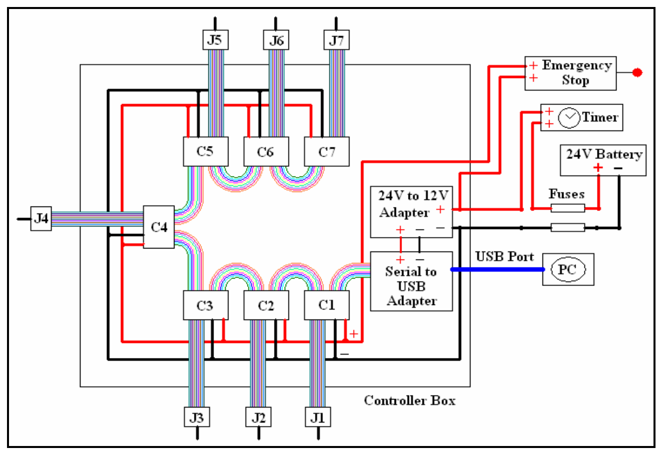

Figure 10: Control System Circuitry

The current host PC is an IBM laptop, running Windows XP. However, the communications protocol is simple and open, and could be adapted to virtually any hardware/software platform with an RS-232 or USB port. Figures 11 and 12 show the physical gripper and the final Pro/E drawing after assembly respectively.

Figure 11. The new gripper and the actuation mechanism

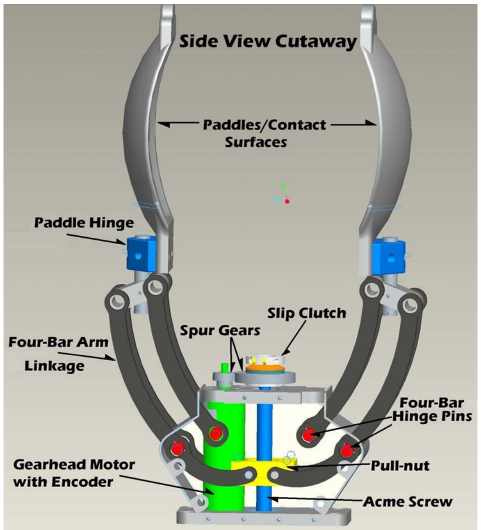

Figure 12. The gripper and the actuation mechanism drawing

4. ANALYSIS AND APPLICATION

Force analysis of the mechanism was accomplished by working from the paddles' contact surfaces through the mechanism linkages until reaching the electronic motor. The force considered in the design was 10 pounds of gripping force at the of the contact surfaces of the gripper. The force from the paddle surfaces was then translated through the parallel four-bar linkages to the pull-nut using static analysis. Teflon bushings were utilized in the hinges at this joint to reduce friction but accounted for while calculating the forces. The pull-nut static calculations were used to determine the required torque on the acme screw to generate the force needed at the pull-nut. This was accomplished relatively accurately by using the offered specifications by the manufacturer of the acme screw.

Input torque per output force measurements were utilized when calculating the torque required within the acme screw. Ball bearings were used to support the acme screw for maximum efficiency. After calculating the torque needed in the acme screw, forces were determined at the teeth of the spur gears used in the mechanism. The required torque and speed of the motor was calculated by assuming a required minimum opening and closing time of 4 seconds with the given force at the gripper. A safety factor of 2 was used in selecting a motor for the required torque.

Figure 13 shows a close-up view of the gripper, attached to the newly designed 9-DoF WMRA system [7] on a power wheelchair, holding a 2.5 inch diameter ball.

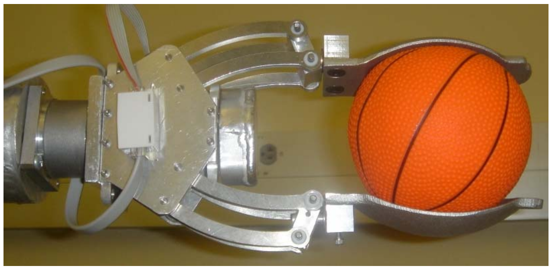

Figure 13. The new gripper when holding a spherical object

Several tests were conducted using the rapid prototype models and test objects to ensure proper application before the final design was reached. When the gripper machining was completed and the gripper was assembled, actual grasping tasks commonly used in ADL were conducted.

Another application tested show the adjustability of the paddles to the grasped object, as shown in figure 14. A standard cup was the test object to show adjustability of the paddles due to the added hinges that give them an extra degree of freedom for adjustment to the tapered object.

Figure 14. The new gripper when holding a tapered cup

One of the main objectives intended for this gripper is the ability to handle different door handles. Figures 15 and 16 show both kinds of handles, the lever handle and the knop handle, commonly used in doors. These handles were used in this test to ensure proper application.

Figure 15. The new gripper when opening a lever-handle door

Figure 16. The new gripper when opening a knob handle door

Another test for handling small objects and sheets of paper were conducted. Figure 17 shows the gripper holding a business card using the tips of the paddles without the need to fully close the other end of the gripper.

Figure 17. The new gripper when handling small objects

Handling large objects can be challenging based on the geometrical complexity of that object. Figure 18 shows the gripper holding the box of heavy tools while moving it from one place to another. The two side-curved surfaces and the middle spherical surfaces help in supporting odd objects in case complex shapes are handled.

Figure 18. The new gripper when handling large objects

5. CONCLUSIONS

This work presented the design and fabrication of a new custom designed gripper to help people with disabilities perform activities of daily living. The intended work environment of this gripper is to work with the newly developed Wheelchair-Mounted Robotic Arm (WMRA) attached to a power wheelchair [7]. Several design considerations were studied to ensure a proper design is selected for the intended use of the gripper. The paddles were designed with several contact surfaces with the handled objects to handle large objects, spherical objects, cylindrical or tapered objects, and delicate or small objects. The driving mechanism was designed to be efficient and independent of the arm attached to it for modularity and ease of use. Force propagation was conducted, and part selection was done based on the analysis. The control system was chosen to be compatible with the control of the WMRA system. Several tests were done on a prototype prior to the production of the final gripper to adjust the design, and these tests were conducted again with the actual gripper mounted on the WMRA system to ensure its functionality as designed.

As an improvement to the design, lower tolerances should be placed on the adjusting hinges of the paddles to reduce the undesirable flexion motion. A lighter and stronger material would be beneficial if used throughout the entire design. The use of carbon fiber composites would greatly decrease the weight of the device while stiffening the actuation output. Inner contact surfaces of the gripper can be covered in a rubber like substance often used for hand tool to ensure a better gripping capability.

6. REFERENCES

[1] US Census Bureau (1997), "Disabilities affect one-fifth of all americans," *Census Brief* , CENBR/97-5, December 1997, http://www.census.gov/prod/3/97pubs/cenbr975.pdf

[2] Reswick J.B., "The moon over dubrovnik - a tale of worldwide impact on persons with disabilities," *Advances in External Control of Human Extremities*, 1990.

[3] Holly A. Yanco., "Integrating robotic research: a survey of robotic wheelchair development," *AAAI Spring Symposium on Integrating Robotic Research*, Stanford, California, March 1998.

[4] Ramesh Kolluru, Kimon Valavanis, Stanfird Smith and Nikos Tsourveloudis, "Design and analysis of a reconfigurable robotic gripper for limp material handling." *Proceedings of the 2000 IEEE International Conference on Robotics and Automation (ICRA 2000)*, pp. 1988-1993, San Francisco, CA, April 2000.

[5] Benny Yeung and James Mills, "Design of a six DOF reconfigurable gripper for flexible fixtureless assembly," *IEEE Transactions on Systems, Man, and Cybernetics, Part C*, Vol. 34, No. 2, pp. 226-235, May 2004.

[6] GertWillem Römer, Harry Stuyt, Gijs Kramer, Malicum O'Callaghan and Jeroen Scheffe, "Alternative grippers for the assistive robotic manipulator (ARM)," *Proceedings of the 9th IEEE International Conference on Rehabilitation Robotics(ICORR 2005),* pp. 473-476, Chicago, IL, June 2005.

[7] Kevin Edwards, Redwan Alqasemi, Rajiv Dubey, "Design, construction and testing of a wheelchair-mounted robotic arm," *Proceedings of the 2006 IEEE International Conference on Robotics and Automation (ICRA 2006)*, pp. 3165-3170, Orlando, Florida, May 2006.